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Process Design: Maleic Anhydride Unit

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Abstract

Gamecock Chemical Company has proposed the construction of a maleic anhydride plant at its Houston refinery. The plant is to produce 40,000 metric tons per year of maleic anhydride from a mixture of excess butanes. This design team has been asked to produce a conceptual design, simulation, and profitability analysis for the proposed plant. The simulation software Aspen Plus by AspenTech was the primary software used to design the plant, and the CAPCOST program in Microsoft suite's Excel was utilized for the economic review of the process.

Maleic anhydride is produced by the thermal oxidation of n-butane at an elevated temperature and pressure, in this case 375°C and 20 bar. A catalyst, vanadium phosphorous oxide, assists in this reaction, adsorbing oxygen onto its surface to enable its reaction with n-butane. The process begins by feeding the mixed butane stream through two distillation columns to achieve pure n-butane. This pure stream is mixed with oxygen in air and fed to the reactor. Maleic anhydride and several byproducts are produced from this reaction. The desired solid maleic anhydride is purified using a series of cyclones.

It is recommended, based on the profitability analysis, that this process not be pursued further. Although the maleic anhydride product is more profitable than the feed stream, the high annual utility cost of $39,100,000 causes a negative net present value for this process. The main utility cost originates from the cost of compressing the large amount of air flowing through the system. Therefore, if this process is redesigned, it is recommended to design a process that requires less air flow or a lower pressure. Based on the current design, however, it is not recommended to move forward with this process.

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1 PROCESS DESCRIPTION

1.1 INTRODUCTION

As a result of its recent expansion, the Houston refinery has excess n-butane capacity. The management at the refinery is interested in utilizing the extra n-butane to produce up to 40,000 metric tons of maleic anhydride per year. The ECHE 466 Design Group 7-2 is tasked with producing a plant design and performing an economic analysis for the Houston refinery plant to produce 40,000 metric tons per year of 99.5% pure maleic anhydride (MAN) from excess n-butane. This design was produced using Aspen Plus, a modeling tool created by AspenTech to run simulations of the design. Chemsep was also utilized to assist in the design of distillation columns, and the CAPCOST program in Microsoft suit's Excel was used for the economic analysis.

There are many applications for which MAN is currently being used. About 50% of the world's production of MAN is used for the manufacturing of unsaturated polyester resins. If modified slightly, it can also be used in artificial sweeteners and flavor enhancements (Wiley Online Library, 2000). There are many current manufacturers of MAN, some of which are listed below:

Chevron
Neuchem
Huntsman
Wego Chemical & Mineral Corp.
Seidler Chemical Company
Almaida Chemicals
Mil-Spec Industries Corp.
U.S. Chemicals, LLC.

The maleic anhydride process as described in this report differs greatly from a traditional maleic anhydride process. While both processes utilize a packed-bed catalytic reactor, a traditional process, as referenced in Richard and Turton's Analysis, Synthesis, and Design of Chemical Processes (Turton, 2003), achieved cooling through the use of molten salt circulated concurrently through the reactor shell. Feed preparation was less intensive in the traditional process in terms of heat exchangers, pumps, and distillation columns, as the starting material was pure benzene rather than a mix of hydrocarbons. In the traditional process, a dibutyl phthalate make-up stream was fed to the recycle stream. In the process described in this report, no recycle streams were used, as they would have complicated the process with minimal benefit. To separate MAN from the rest of the components in the product stream, the stream's temperature was decreased to change the state of MAN to a solid, and a series of cyclones were used to separate out the solid. In the traditional process, liquid maleic anhydride was separated by the use of two distillation columns. This design represents a new technology and has the benefit of minimal separation of the product from feed stock.

1.2 DESIGN BASIS

1.2.1 Feedstock and Product Purity

The Houston refinery plant is providing a feedstock of mixed butanes. The composition of this feed stream is laid out in Table 1.2.1-1 below.

Table 1.2.1-1: Butanes feed stream analysis

Component	Mole Fraction
$<C_3$	0.005
iC_4	0.163
$2\text{-}Me\text{-}C_3$	0.005
$1\text{-}C_4$	0.002
nC_4	0.813
trans $2\text{-}C_4$	0.005
cis $2\text{-}C_4$	0.002
$2,2\text{-}diMe\text{-}C_3$	Trace
$3\text{-}Me\text{-}1\text{-}C_4$	Trace
$C_5>$	0.005
Total	1.000

The only reactants for the reaction are n-butane and oxygen. As can be seen from Table 1.2.1-1, the feed stream from Houston contains many additional butanes. These must be separated to produce a pure n-butane stream that is fed to the reactor. Two distillation columns are used for this separation, as described in Section 1.4.2 "Separations Section" of this report.

An air feed is used as the source of oxygen in this process instead of a pure oxygen feed. Mixtures of oxygen and butane are known to be explosive, so a relatively low concentration of oxygen is desired to decrease the likelihood of an explosion. The presence of inert nitrogen in air maintains a relatively safer oxygen concentration in the stream. Nitrogen, being an inert gas in this process, also does not produce any byproducts.

The product stream leaving the reactor contains MAN and unreacted butane. After separation, the MAN-lean effluent is not recycled back to the reactor. Although recycling this stream would increase the overall conversion of n-butane to MAN, and help to dilute the oxygen concentration to an even safer level, these effects would be minimal and a recycle stream would only add further complications to this process. Therefore, no butane recycle stream is included in this process.

The desired purity of the product is a minimum of 99.5% MAN. The color in the molten state is 15 APHA max and the color heat stability is 30 APHA max for 140°C for 2 hours. The melting point is 52.5°C minimum and the maximum Ash percentage is 0.003%. The maximum iron is 3 ppm. The free acidity is 0.2% max. The appearance of the solid product is a white solid briquette or as flakes, as seen in the Neuchem technical data sheet (Neuchem, 2019).

1.2.2 Process Concept Diagram

The process concept diagram, displaying the reactants and products of the desired reaction in this process, is shown in Figure 1.2.2-1 below. The desired product is maleic anhydride, and water is a byproduct of the reaction.

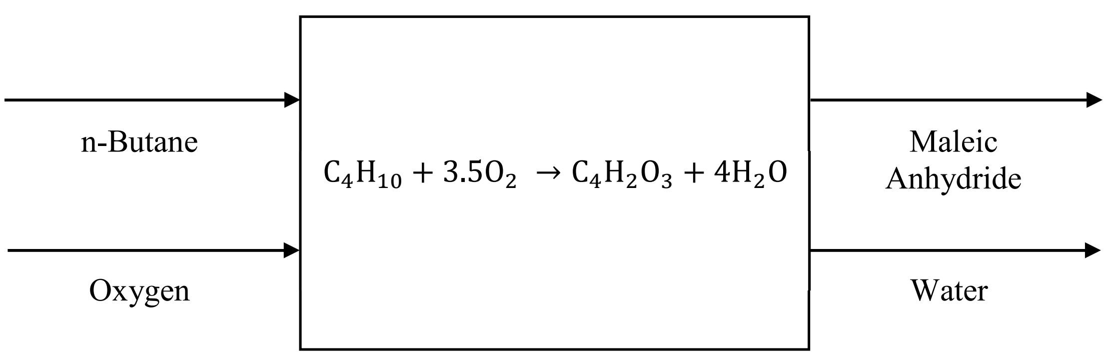

Figure 1.2.2-1: Process concept diagram

1.2.3 Overall Material Balance

The overall material balance, shown in Figure 1.2.3-1, is the summation of the results of the design of this process. It conveys the flowrate of the air and mixed butane feed streams entering the process, and most importantly the flowrate of MAN being produced annually.

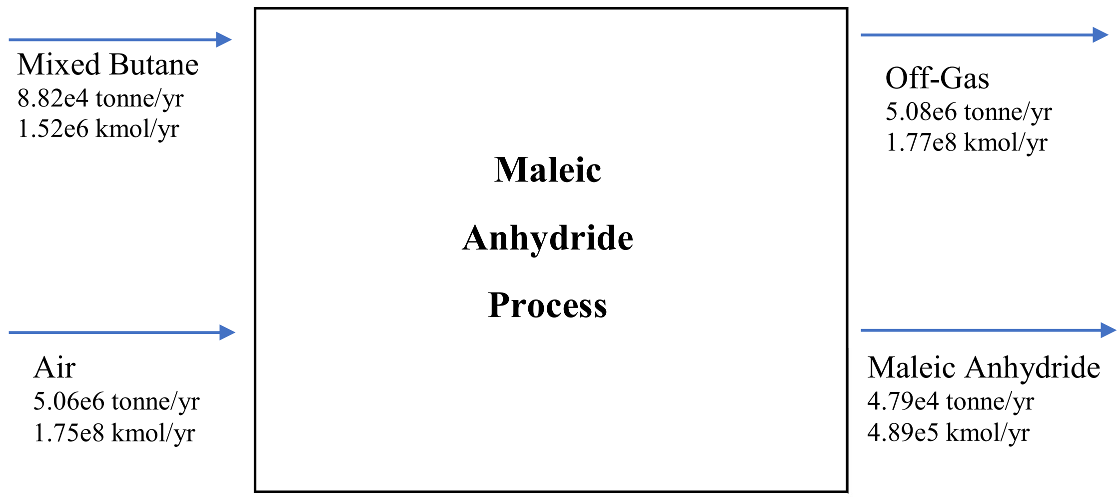

Figure 1.2.3-1: Overall material balance. This diagram displays the annual mass and molar flowrates of the feeds and products of this process.

From Figure 1.2.3-1, it can be seen that this process produces more than the required 40,000 tonnes of MAN per year with an n-butane conversion of about 73.6%.

1.2.4 Process Block Flow Diagram

The process block flow diagram is shown in Figure 1.2.4-1. The mixed butane stream must go through a separation process before it enters the reactor to separate the pure n-butane from the additional butanes listed in Table 1.2.1-1. These additional butanes are vented to the atmosphere. The pure n-butane is then mixed with air before entering the reactor. Once the reaction takes place, an expander and ejector are used to facilitate Joule-Thomson cooling in order to save energy while cooling the product stream to produce solid MAN. Cyclones are then used to separate the solid MAN from the rest of the product stream, which is vented to the atmosphere.

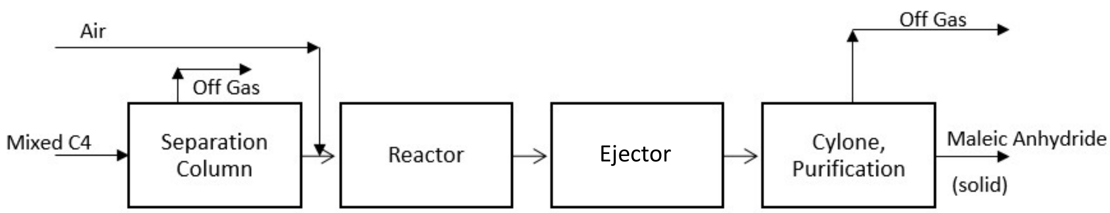

Figure 1.2.4-1: Process block flow diagram.

1.3 CHEMISTRY

1.3.1 Physical Properties

Table 1.3.1-1 displays important physical properties of the chemicals that are present during the reaction in this process. Oxygen and nitrogen are present from the air feed stream, and n-butane is present from the purified mixed butane feed stream. Carbon dioxide, carbon monoxide, water, and MAN are all products of the reaction.

Table 1.3.1-1: Physical properties of the chemicals present in this process's reaction.

Chemicals	Molecular Weight (g/mol)	Critical Temperature (°C)	Critical Pressure (atm)	Normal Boiling Point (°C)	Acentric Factor
Nitrogen	28.0135	-146.95	33.5554	-195.806	0.0377215
Carbon Dioxide	28.0104	-140.23	34.5324	-191.45	0.0481621
Oxygen	31.9988	-118.57	49.7705	-182.962	0.0221798
Carbon Monoxide	44.0098	31.06	72.8645	-78.45	0.223621
n-Butane	58.1234	151.97	37.4636	-0.5	0.200164
Water	18.0153	373.946	0.344861	100	0.344861
Maleic Anhydride	98.0581	447.85	71.848	202	0.54629

Aspen Plus was used to generate the values displayed in Table 1.3.1-1.

1.3.2 Thermodynamics

The chosen activity coefficient model for the maleic anhydride process is the Universal Quasi-Chemical Theory model (UNIQUAC). The UNIQUAC model can handle both binary and multicomponent systems, and is best for highly non-ideal chemical systems. It can also handle combinations of polar and non-polar compounds and very strong non-ideality. This model has received much more attention compared to other activity coefficient models, making it more accurate and up-to-date. For these reasons, UNIQUAC was used to model this process. Equation 1.3.2-1 shows the equation for the UNIQAC model.

$$\ln\gamma_i = \ln\frac{\Phi_i}{x_i} + \frac{z}{2}q_i\ln\frac{\theta_i}{\Phi_i} - q'_i\ln t'_i - q'_i\sum_j\frac{\theta'_j\tau_{ij}}{t'_j} + l_i + q'_i - \frac{\Phi_i}{x_i}\sum_j x_j l_j \quad (1.3.2\text{-}1)$$

The parameters for Equation 1.3.2-1 are defined as follows:

θ_i = $\frac{q_i x_i}{q_T}$; $q_T = \sum_k q_k x_k$

θ'_i = $\frac{q'_i x_i}{q'_T}$; $q'_T = \sum_k q'_k x_k$

Φ_i = $\frac{r_i x_i}{r_T}$; $r_T = \sum_k r_k x_k$

l_i = $\frac{z}{2}(r_i - q_i) + 1 - r_i$

t'_i = $\sum_k \theta'_k \tau_{ki}$

τ_{ij} = $\exp(a_{ij} + b_{ij}/T + C_{ij}\ln T + d_{ij}T + e_{ij}/T^2)$

z = 10

The binary parameter properties that affect the thermodynamics are displayed in Table 1.3.2-1. This table displays how each pair of chemicals interact in the process. These numbers were generated using Aspen Plus.

Table 1.3.2-1: Binary parameter properties of the interacting chemicals in this process.

Component i	**Component j**	b_{ij}	b_{ji}
Nitrogen	CO	-68.7194729	63.1800928
Nitrogen	O_2	32.5967014	-37.8890926
Nitrogen	CO_2	-69.0352687	3.25093311
Nitrogen	C_3	-30.1416862	56.4649826
Nitrogen	iC_4	-30.3589969	60.7930201
Nitrogen	2-Me-C_3	-13.504398	54.9065047
Nitrogen	1-C_4	-11.8054104	53.0332435
Nitrogen	n-Butane	-30.4974581	60.928586
Nitrogen	T 2-C_4	-11.0280666	51.9895207
Nitrogen	C 2-C_4	-11.0280666	51.9895207
Nitrogen	C_5	-30.777317	63.9332897
Nitrogen	Water	-379.807721	252.116278
CO	O_2	15.8087463	-21.6076213
CO	CO_2	-135.249829	55.2791077
CO	C_3	-41.1416922	90.2375082
CO	iC_4	-38.8556272	95.3265699
CO	2-Me-C_3	-33.1210953	99.1789668
CO	1-C_4	-28.5788479	93.0867171
CO	n-Butane	-39.0710354	95.5690921
CO	T 2-C_4	-28.0948696	92.4183374
CO	C 2-C_4	-28.0948696	92.4183374
CO	C_5	-37.8107209	99.2088629
CO	Water	-581.466719	339.527609
O_2	CO_2	-75.5177544	-14.1831311
O_2	C_3	-22.6489181	43.4829696
O_2	iC_4	-23.4616604	46.8375783
O_2	2-Me-C_3	-4.77806661	40.5654899
O_2	1-C_4	0.573930487	34.0779355
O_2	n-Butane	-23.7585354	47.1463697
O_2	T 2-C_4	1.40943339	32.9911175
O_2	C 2-C_4	1.40943339	32.9911175
O_2	C_5	-24.5163479	49.5992426
O_2	Water	-376.687898	255.000318
CO_2	C_3	-60.2447142	41.9281964
CO_2	iC_4	-40.8962922	33.9274162
CO_2	2-Me-C_3	-56.7294999	41.7197859
CO_2	1-C_4	17.9367771	-11.239696
CO_2	n-Butane	-43.9205784	36.1863907
CO_2	T 2-C_4	35.0305271	-30.3260499
CO_2	C 2-C_4	35.0305271	-30.3260499
CO_2	C_5	-99.578464	86.7772752
CO_2	Water	-61.3623147	-144.489519
C_3	iC_4	54.5326677	-60.2253411

C_3	2-Me-C_3	-5.91474285	-1.54944281
C_3	1-C4	-25.9578603	14.2532532
C_3	n-Butane	54.5293477	-60.2217701
C_3	T 2-C_4	1.65804135	-8.0634212
C_3	C 2-C_4	1.65804135	-8.0634212
C_3	C_5	54.5275234	-60.2197903
C_3	Water	-1317.99999	-300
iC_4	2-Me-C_3	-5.91152683	-1.55114933
iC_4	1-C_4	-25.9580202	14.2530406
iC_4	n-Butane	54.530771	-60.2232925
iC_4	T 2-C_4	1.46499414	-7.91175299
iC_4	C 2-C_4	1.46499414	-7.91175299
iC_4	C_5	54.5287298	-60.2211123
iC_4	Water	-1317.99439	-299.973829
2-Me-C_3	1-C_4	51.4870008	-56.9778804
2-Me-C_3	n-Butane	28.5295429	-37.683173
2-Me-C_3	T 2-C_4	54.8720999	-60.5949451
2-Me-C_3	C 2-C_4	54.8720999	-60.5949451
2-Me-C_3	C_5	28.5235402	-37.6774013
2-Me-C_3	Water	-551.659183	-362.09728
1-C_4	n-Butane	26.5013247	-39.2317163
1-C_4	T 2-C_4	50.041843	-55.5683062
1-C_4	C 2-C_4	50.041843	-55.5683062
1-C_4	C_5	26.5015026	-39.2318786
1-C_4	Water	-490.423601	-379.501274
n-Butane	T 2-C_4	1.47543476	-7.91969185
n-Butane	C 2-C_4	1.47543476	-7.91969185
n-Butane	C_5	54.5297141	-60.2221658
n-Butane	Water	-1318.00223	-300.01043
T 2-C_4	C 2-C_4	54.5301561	-60.2226393
T 2-C_4	C_5	30.1133236	-38.3760251
T 2-C_4	Water	-574.25646	-356.404351
C 2-C_4	C_5	30.1133236	-38.3760251
C 2-C_4	Water	-574.25646	-356.404351
C_5	Water	-1318.00405	-300.019768

The chosen equation of state used in this analysis was the Redlich-Kwang-Soave equation of state. Equation 1.3.2-2 shows the equation for the Redlich-Kwang-Soave equation of state.

$$p = \frac{RT}{V_m - b} - \frac{a}{V_m(V_m + b)} \qquad (1.3.2\text{-}2)$$

The parameters for Equation 1.3.2-2 are defined as follows:

$$a = a_0 + a_1$$

$$a_1 = \sum_{i=1}^{n} x_i \left(\sum_{j=1}^{n} x_j \left((a_i a_j)^{1/2} l_{j,i} \right)^{1/3} \right)^3$$

$$b = \sum_i x_i b_i$$

$$a_i = fcn(T, T_{ci}, p_{ci}, \omega_i)$$

$$b_i = fcn(T_{ci}, p_{ci})$$

$$k_{ij} = k_{ij}^{(1)} + k_{ij}^{(2)} T + \frac{k_{ij}^{(3)}}{T}$$

$k_{ij} = k_{ji}$

$$l_{ij} = l_{ij}^{(1)} + l_{ij}^{(2)} T + \frac{l_{ij}^{(3)}}{T}$$

In general, $l_{ij} \neq l_{ji}$, $l_{jw} = l_{wj} = 0$.

$$a_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} x_i x_j \sqrt{a_i a_j} \left(1 - k_{ij}\right)$$

1.3.3 Reaction Chemistry

As explained previously, the mixed butane feed consists of many compounds. However, after passing through two separation towers, the feed into the reactor contains only n-butane. Air is also added to the feed, which contains the oxygen needed to complete the reaction. Pure n-butane reacts with oxygen to produce MAN. To achieve this oxidation reaction, a catalyst, vanadium phosphorus oxide (VPO), must be used. The pure n-butane can only react with oxygen that is adsorbed onto the catalyst. The reaction mechanism is shown in Figure 1.3.1-1 below.

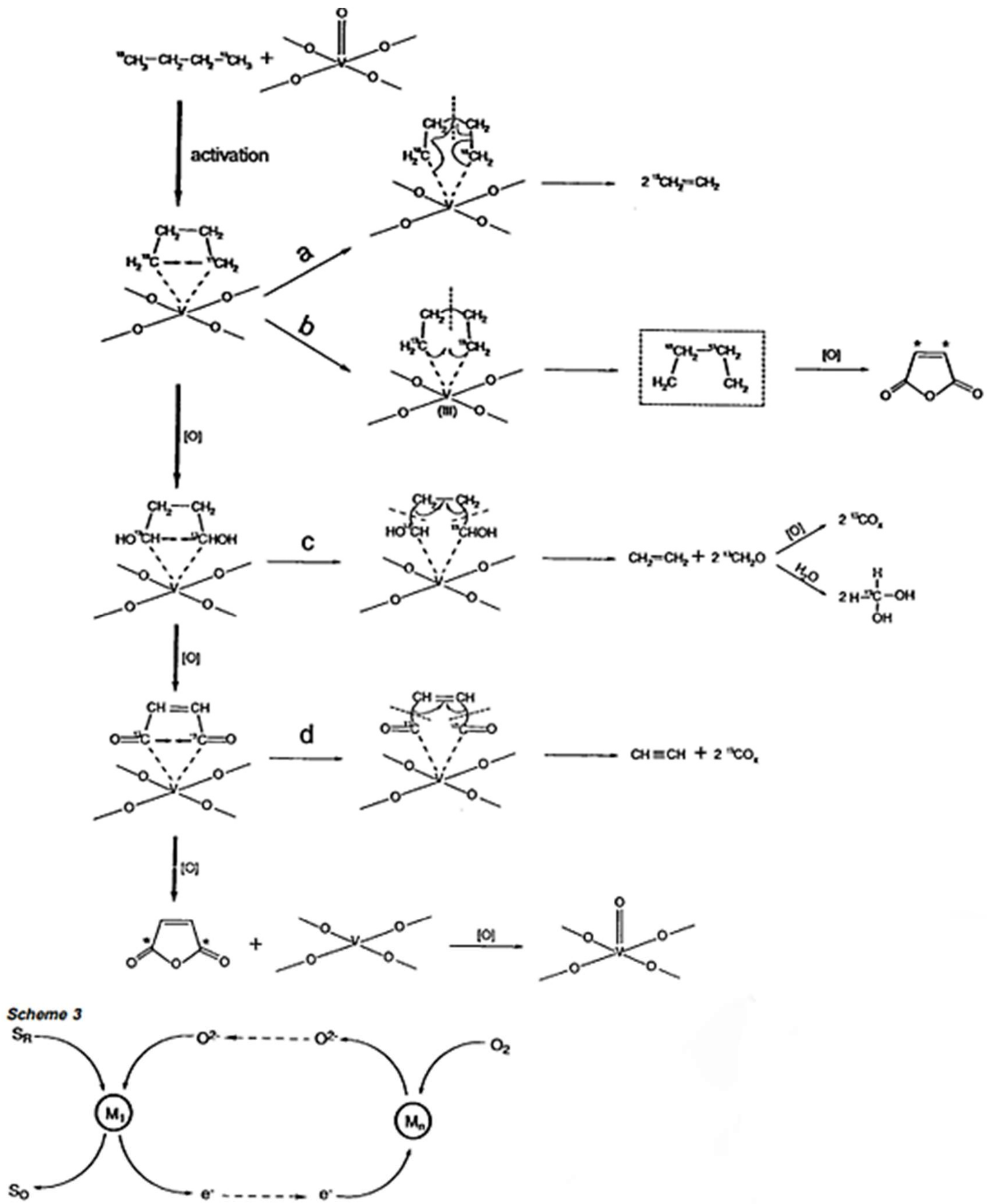

Figure 1.3.3-1: Mechanism of the catalyst during the reaction of n-butane with oxygen to produce MAN. Two additional byproducts are CO and CO_2.

Oxygen adsorbs onto the VPO active sites both in the form of O^- anions and in the form of O_2 molecules. The product that is produced depends on with which form of oxygen n-butane reacts. If the butane reacts with the adsorbed O^- anions, then it produces the desired MAN, as can be seen in path b of Figure 1.3.3-1. The undesired byproducts, CO and CO_2, are produced if n-butane reacts with the adsorbed O_2 molecules, as can be seen in paths c and d of Figure 1.3.3-1. This is an unselective process, so the more oxygen available to adsorb onto VPO, the more butane can react to form MAN. Because of this, a large amount of air flows through the system to increase the conversion of butane to MAN.

1.3.4 Reaction Kinetics

The information concerning the kinetics of the reaction in this process is obtained from Schneider, Emig, and Hofmann (Schneider, Emig, and Hofmann, 1987), who derived the kinetics using the Eley-Rideal model. The catalyst used in the reaction is vanadium phosphorus oxide (VPO), with the chemical formula $(VO)_2P_2O_7$. The VPO oxidation state is 4.10 due to the adsorbed oxygen in the active sites. In this process, the catalyst is crushed and packed into the plug flow reactor, so a continuous packed bed reactor model is adopted for this analysis.

The reactions to form MAN from n-butane are as follows:

$$\mathbf{C_4H_{10} + 3.5O_2 \rightarrow C_4H_2O_3 + 4H_2O} \qquad \textbf{(1)}$$

$-\Delta H_{R1} = 1.2606 \text{ X } 10^6$ kJ/kmol

$$\mathbf{C_4H_{10} + 4.5O_2 \rightarrow 4CO + 5H_2O} \qquad \textbf{(2)}$$

$-\Delta H_{R2} = 1.5262 \text{ X } 10^6$ kJ/kmol

$$\mathbf{C_4H_{10} + 6.5O_2 \rightarrow 4CO_2 + 5H_2O} \qquad \textbf{(3)}$$

$-\Delta H_{R3} = 2.6586 \text{ X } 10^6$ kJ/kmol

The desired reaction is reaction (1), which produces MAN ($C_4H_2O_3$). Reactions (2) and (3) produce the undesired products of CO and CO_2, which have to be separated from MAN after the reaction. All of these reactions are exothermic.

The overall reaction rate equations are modeled in Equations 1.3.4-(1-3) as follows:

$$r_1 = k_1 \frac{(K_{diss} p_{O2})^{1/2}}{1 + (K_{diss} p_{O2})^{1/2}} p_{But} \tag{1.3.4-1}$$

$$r_2 = k_2 \frac{K_{sorpt} p_{O2}}{1 + K_{sorpt} p_{O2}} p_{But} \tag{1.3.4-2}$$

$$r_3 = k_3 \frac{K_{sorpt} p_{O2}}{1 + K_{sorpt} p_{O2}} p_{But} \tag{1.3.4-3}$$

The estimated reaction kinetics parameters for the transient reaction are shown in Table 1.3.4-1 below.

Table 1.3.4-1: Estimated Reaction Kinetics Parameters Under Unsteady State

Parameter	Optimal Estimate
k_1	9.66×10^{-5} kmol/(kg cat.*s*Pa)
k_2	1.72×10^{-5} kmol/(kg cat.*s*Pa)
k_3	2.21×10^{-5} kmol/(kg cat.*s*Pa)
E_1/R	8677 K
E_2/R	8663 K
E_3/R	8940 K
K_{diss}	0.11×10^{-5} Pa^{-1}
K_{sorpt}	0.42×10^{-4} Pa^{-1}

The overall reaction rate equations do not reveal that the rate limiting step of this reaction is the adsorption of oxygen onto VPO. The remaining process steps are in equilibrium, so the unknown surface concentrations are replaced with the equilibrium constants, achieving Equations 1.3.4-(1-3). These overall reaction rate equations and the parameter values from Table 1.3.4-1 are used to model the reaction in Aspen Plus.

1.4 PROCESS FLOW

1.4.1 Reaction Section

Maleic anhydride is produced by the thermal oxidation of n-butane at elevated temperatures and relatively high pressures. Along with the main reaction, two side reactions also take place to produce carbon monoxide and carbon dioxide. The n-butane feed is slowly heated through a series of heaters and brought up to the reaction temperature of 375°C. Pumps and compressors are utilized throughout the process to bring the feed components from atmospheric pressure to the reaction pressure of 20 bar. The n-butane feed is fed through two distillation columns to produce pure n-butane, which is desired for the reaction. The pure n-butane is mixed with oxygen in air and fed to the reactor, which is a PBR packed with the catalyst, VPO. During the thermal oxidation process, the desired product, MAN, as well as the two side products, CO and CO_2 are produced from the reactor. This product stream is sent through an isentropic Joule-Thomson cooling process to decrease its temperature and pressure to solidify MAN. It is lastly purified with a series of cyclones to separate the solid MAN from the rest of the product stream.

1.4.2 Separation Section

A separation process is used to pretreat the reactants in the process. A pure n-butane stream is needed as the main reactant in the reactor. To obtain pure n-butane from the mixed butane feed stream, two distillation columns are utilized. The feed to the first distillation column consists of propane, isobutane, 1-butene, n-butane, trans 2-butene, cis 2-butene, and pentane. This column separates the chemicals with a lower boiling point, the low keys, from n-butane and the high keys. The first column includes 150 total stages with the feed stage being located at stage 87. The feed to the second distillation column consists of n-butane, trans 2-butene, cis 2-butene, 2-methyl-1-butene, and n-pentane. This column separates n-butane from the remaining high key butanes. The second column includes 250 total stages with the feed stage being located at stage 25. By utilizing these two distillation columns, effective separation of n-butane is achieved. ChemSep was used to design these distillation columns. The specifications and resulting flow rates from these columns are shown in the Detailed Calculations section of this report.

After the reaction, MAN is separated from the rest of the product stream consisting of oxygen and nitrogen from air, CO, CO_2, water, and any remaining n-butane. This separation is performed as a solids separation. The product stream temperature and pressure are decreased to 46°C and 1.4 bar, respectively, using an expander and ejector to induce isentropic Joule-Thomson cooling. This is used instead of a heat exchanger in order to save energy, and therefore decrease the total cost of utilities. At this temperature and pressure, MAN is a solid, while the remaining products are gases. A series of four cyclones is used for this separation. Four cyclones are necessary to accomplish about 99% recovery of MAN due to its small particle size, which averages around 10 microns in diameter. The particle size distribution of solid MAN is shown in Figure 1.4.2-1 below.

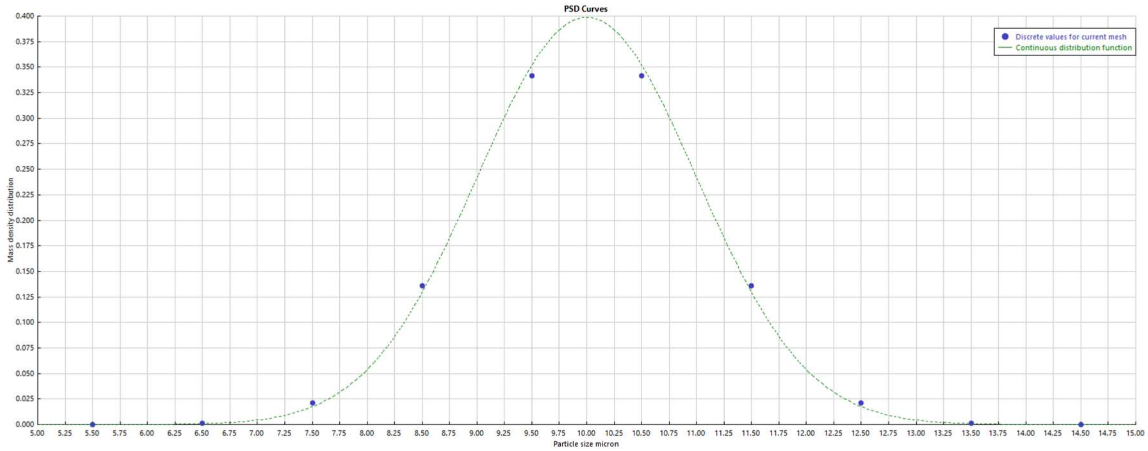

Figure 1.4.2-1: Particle size distribution of solid MAN.

1.4.3 Areas of Special Concern

Table 1.4.3-1: Process conditions matrix for the PFD of the maleic anhydride process

	Reactors and Separators					Other Equipment				
Equip.	High Temp	Low Temp	High Pres.	Low Pres.	Non-Stoich. Feed	Comp.	Exch.	Htr.	Valve	Mix
VAL-101										
T-100	X									
T-101										
E-100										
E-101										
E-102										
E-103										
E-104										
E-105							X			
E-106										
E-107										
C-100										
C-101										
C-102	X									
P-100										
P-101										
P-102										
P-103										
P-104										
S-100										
S-101										
S-102										
S-103										
R-100	X									

The reactor R-100 provides an area of special concern because R-100 operates at 375°C, which is greater than the safe temperature limit of 250°C. This temperature was needed to complete the reaction and increase conversion of butane to MAN. The reaction would have been extremely inefficient at a lower temperature.

The expander C-102 also provides an area of special concern because C-102 operates at 375°C, which is greater than the safe temperature limit of 250°C. The stream entering the expander is the same stream that exits the reactor. This high temperature is a result the reactor, R-100, so the same justification for the reactor temperature is applicable for the expander as well. The expander is used to cool the stream by utilizing the isentropic Joule-Thomson effect.

The heat exchanger E-105 provides an area of special concern, because the log mean temperature difference is over 100°C. The temperature of the feed stream was raised from 2.108°C to 375°C through the exchanger. This was necessary to raise the n-butane temperature to the reactor temperature. The distillation column, T-100, also provides an area of special concern, because T-100 operates at 298.15°C which is greater than the safe temperature limit of 250°C. This temperature was needed to achieve the separation of high key butanes from n-butane.

1.5 OPERATION

To be completed by operations personnel.

1.5.1 General

1.5.2 Startup

1.5.3 Shutdown

1.5.4 Emergencies

1.5.4.1 Power Failure

1.5.4.2 Utility Failures

1.5.4.2.1 Steam System Failure

1.5.4.2.2 Cooling System Failure

1.5.4.3 Upstream Unit Failure

1.5.4.4 Downstream Unit Failure

2 PROCESS FLOW DIAGRAM

The process flow diagram is displayed in Figure 2-1 below. The mixed butane feed stream from the Houston refinery, Stream 1, is heated slowly through the series of heat exchangers E-100 to E-103 to 298.15°C, and compressed with pump P-100 to 3.35 bar. These are the temperature and pressure conditions of distillation column T-100. After the high keys are separated from the feed stream, the bottom stream is cooled using cooling water in heat exchanger E-104 to 2°C before entering distillation column T-101. In this column, the low keys are separated from n-butane, which leaves the top of the column as a pure n-butane stream. The pressure and temperature of the pure n-butane is then increased using pumps P-103 and P-104 and heat exchanger E-105 to achieve the reaction pressure and temperature of 375°C and 20 bar. The air feed stream, Stream 18, is also compressed and heated to match the reaction conditions. Compressors C-100 and

C-101 are used to increase the pressure to 20 bar, and heat exchanger E-107 heats the air to 375°C.

The air and pure n-butane streams are mixed before entering the packed bed reactor, R-100. The outlet stream from this reactor contains MAN, byproducts CO and CO_2, and unreacted n-butane and air. A solids separation is used to separate MAN as a solid from the rest of the stream. To solidify MAN, expander C-102 and ejector VAL-101 are used to induce isentropic Joule-Thomson cooling to 46°C and 1.4 bar. At this point MAN is solid and can be separated from the rest of the gaseous stream by means of four cyclones in series, S-100 to S-103. About 99% of MAN is separated from the gaseous byproducts, and the MAN product streams 29, 31, 33, and 35 are 100% pure.

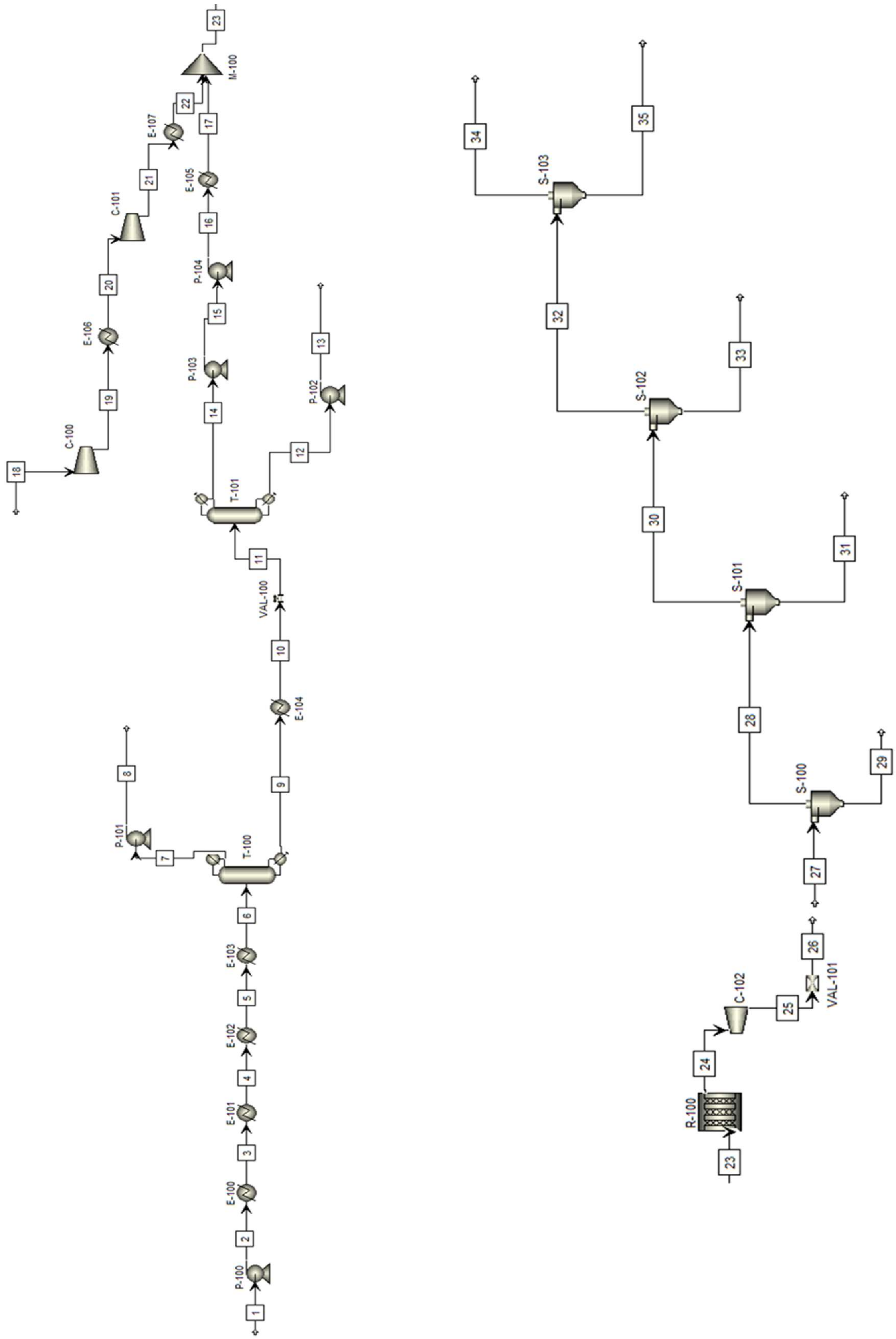

Figure 2-1: Process flow diagram.

3 STREAM SUMMARY TABLE

The conditions and flow rates of each stream in this process are displayed in Table 3-1 below.

Table 3-1: Stream summary table.

Stream Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Temperature (°C)	25	25.1	154	179	251	298.2	12.9
Pressure (bar)	2.63	3.4	3.38	3.37	3.36	3.35	2.5
Vapor fraction	0	0	1	1	1	1	0
Mass flowrate (tonne/h)	10.06	10.06	10.06	10.06	10.06	10.06	1.82
Molar flowrate (kmol/h)							
Nitrogen	-	-	-	-	-	-	-
Carbon-Monoxide	-	-	-	-	-	-	-
Oxygen	-	-	-	-	-	-	-
Carbon-Dioxide	-	-	-	-	-	-	-
Propane	0.87	0.87	0.87	0.87	0.87	0.87	0.87
Isobutane	28.23	28.23	28.23	28.23	28.23	28.23	28.23
Isobutylene	0.87	0.87	0.87	0.87	0.87	0.87	0.87
1-Butene	0.35	0.35	0.35	0.35	0.35	0.35	0.35
N-Butane	140.8	140.8	140.8	140.8	140.8	140.8	1.26
Trans-2-Butene	0.87	0.87	0.87	0.87	0.87	0.87	7.7e3
Cis-2-Butene	0.35	0.35	0.35	0.35	0.35	0.35	4.6e-6
N-Pentane	0.87	0.87	0.87	0.87	0.87	0.87	5.9e-47
Water	-	-	-	-	-	-	-
Maleic-Anhydride	-	-	-	-	-	-	-
Total mole flow (kmol/h)	173.2	173.2	173.2	173.2	173.2	173.2	173.2

Stream Number	8	9	10	11	12	13	14
Temperature (°C)	13.1	41.9	1.85	1.91	13.24	13.46	1.66
Pressure (bar)	5	3.98	3.97	2.1	1.29	5	1.1
Vapor fraction	0	1.1e-8	0	0	1.5e-7	0	0
Mass flowrate (tonne/h)	1.82	8.24	8.24	8.24	0.18	0.18	8.06
Molar flowrate (kmol/h)							
Nitrogen	-	-	-	-	-	-	-
Carbon-Monoxide	-	-	-	-	-	-	-
Oxygen	-	-	-	-	-	-	-
Carbon-Dioxide	-	-	-	-	-	-	-
Propane	0.87	7.9e-31	7.9e-31	7.9e-31	0	0	0
Isobutane	28.23	9.5e-7	9.5e-7	9.5e-7	1.2e-11	1.2e-11	9.5e-7
Isobutylene	0.87	5.4e-7	5.4e-7	5.4e-7	2.7e-11	2.7e-11	5.4e-7
1-Butene	0.35	3.8e-6	3.8e-6	3.8e-6	6.5e-10	6.5e-10	3.8e-6
N-Butane	1.26	139.5	139.5	139.5	2.04	2.04	137.5
Trans-2-Butene	7.7e-3	0.86	0.86	0.86	1.5e-2	1.5e-2	8.4e-2
Cis-2-Butene	4.6e-6	0.35	0.35	0.35	2.8e-2	2.8e-2	0.32
N-Pentane	5.91e-47	0.87	0.87	0.87	0.86	0.86	0.86
Water	-	-	-	-	-	-	-
Maleic-Anhydride	-	-	-	-	-	-	-
Total mole flow (kmol/h)	31.57	141.6	141.6	141.6	2.94	2.94	138.6

Stream Number	15	16	17	18	19	20	21
Temperature (°C)	2.11	2.99	375	25	251.20	40	240.36
Pressure (bar)	5	20	19.99	1.01	5	4.99	20
Vapor fraction	0	0	1	1	1	1	1
Mass flowrate (tonne/h)	8.06	8.06	8.06	577.01	577.01	577.01	577.01
Molar flowrate (kmol/h)							
Nitrogen	-	-	-	15800	15800	15800	15800
Carbon-Monoxide	-	-	-	-	-	-	-
Oxygen	-	-	-	4200	4200	4200	4200
Carbon-Dioxide	-	-	-	-	-	-	-
Propane	-	-	-	-	-	-	-
Isobutane	9.5e-7	9.5e-7	9.5e-7	-	-	-	-
Isobutylene	5.4e-7	5.4e-7	5.4e-7	-	-	-	-
1-Butene	3.8e-6	3.8e-6	3.8e-6	-	-	-	-
N-Butane	137.48	137.48	137.48	-	-	-	-
Trans-2-Butene	0.84	0.84	0.84	-	-	-	-
Cis-2-Butene	0.32	0.32	0.32	-	-	-	-
N-Pentane	1.12e-3	1.12e-3	1.12e-3	-	-	-	-
Water	-	-	-	-	-	-	-
Maleic-Anhydride	-	-	-	-	-	-	-
Total mole flow (kmol/h)	138.6	138.6	138.6	20000	20000	20000	20000

Stream Number	22	23	24	25	26	27	28
Temperature (°C)	375	374.86	375	95.03	46.22	46.22	46.22
Pressure (bar)	19.99	19.99	20	2.5	1.4	1.4	1.30
Vapor fraction	1	1	1	1	1	1	1
Mass flowrate (tonne/h)	577.00	585.06	585.06	585.06	585.06	585.06	583.2
Molar flowrate (kmol/h)							
Nitrogen	15800	15800	15800	15800	15800	15800	15800
Carbon-Monoxide	-	-	97.54	97.54	97.54	97	97.54
Oxygen	4200	4200	3759.99	3759.99	3759.99	3759.9	3759.98
Carbon-Dioxide	-	-	81.74	81.74	81.74	81.74	81.74
Propane	-	-	-	-	-	-	-
Isobutane	-	9.5e-7	9.5e-7	9.5e-7	9.5e-7	9.5e-7	9.5e-7
Isobutylene	-	5.4e-7	5.4e-7	5.4e-7	5.4e-7	5.4e-7	5.4e-7
1-Butene	-	3.8e-6	3.8e-6	3.8e-6	3.8e-6	3.8e-6	3.8e-6
N-Butane	-	137.48	36.25	36.25	36.25	36.25	36.25
Trans-2-Butene	-	0.84	0.84	0.84	0.84	0.84	0.84
Cis-2-Butene	-	0.32	0.32	0.32	0.32	0.32	0.32
N-Pentane	-	1.12e-3	1.12e-3	1.12e-3	1.12e-3	1.12e-3	1.12e-3
Water	-	-	449.75	449.75	449.75	449.75	449.75
Maleic-Anhydride	-	-	56.14	56.41	56.41	56.41	37.43
Total mole flow (kmol/h)	20000	20138.6	20282.8	20282.8	20282.8	20282.8	20263.4

Stream Number	29	30	31	32	33	34	35
Temperature (°C)	46.22	46.22	46.22	46.22	46.22	46.22	46.22
Pressure (bar)	1.40	1.20	1.30	1.10	1.20	1.00	1.10
Vapor fraction	0	1	0	1	0	1	0
Mass flowrate (tonne/h)	1.86	580.5	2.73	579.8	0.69	579.6	0.18
Molar flowrate (kmol/h)							
Nitrogen	-	15800	-	15800	-	15800	-
Carbon-Monoxide	-	97.54	-	97.54	-	97.54	-
Oxygen	-	3760	-	3760	-	3760	-
Carbon-Dioxide	-	81.74	-	81.74	-	81.74	-
Propane	-	-	-	-	-	0	-
Isobutane	-	9.54e-7	-	9.54e-7	-	9.54e-7	-
Isobutylene	-	5.44e-7	-	5.44e-7	-	5.44e-7	-
1-Butene	-	3.78e-6	-	3.78e-6	-	3.80e-6	-
N-Butane	-	36.25	-	36.25	-	36.25	-
Trans-2-Butene	-	0.84	-	0.84	-	0.84	-
Cis-2-Butene	-	0.32	-	0.32	-	0.32	-
N-Pentane	-	1.12e-3	-	1.12e-3	-	1.12e-3	-
Water	-	449.75	-	449.75	-	449.75	-
Maleic-Anhydride	18.99	9.54	27.89	2.53	7.01	0.68	1.85
Total mole flow (kmol/h)	18.99	20236	27.89	20229	7.01	20227.1	1.85

4 EQUIPMENT SPECIFICATIONS

4.1 Equipment list

VAL-101 Ejector

T-100 Distillation Column

T-101 Distillation Column

E-100 Heat Exchanger

E-101 Heat Exchanger

E-102 Heat Exchanger

E-103 Heat Exchanger

E-104 Heat Exchanger

E-105 Heat Exchanger

E-106 Heat Exchanger

E-107 Heat Exchanger

C-100 Compressor

C-101 Compressor

C-102 Compressor

P-100 Pump

P-101 Pump

P-102 Pump

P-103 Pump

P-104 Pump

S-100 Cyclone

S-101 Cyclone

S-102 Cyclone

S-103 Cyclone

R-100 Reactor

4.2 Ejector

Table 4.2-1: Ejector equipment summary table.

Ejector	VAL-101
Net Duty (kW)	-3.1716E+07
Pressure Drop (bar)	1.1

4.3 Columns

Table 4.3-1: Distillation column equipment summary table.

Columns	T-100	T-101
Temperature (°C)	298.15	1.9142
Pressure (bar)	2.5	2.1
Orientation	Vertical	Vertical
MOC	SS	SS
Size		
Height/Length (m)	90.2	11
Diameter (m)	3.66	7.68
Internals	148 sieve trays	18 sieve trays

4.4 *Heat Exchangers*

Table 4.4-1: Heat exchanger equipment summary table.

Heat Exchangers	E-100	E-101	E-102	E-103	E-104	E-105	E-106	E-107
Type	Fl.H.	Fl.H.	Fl.H.	Fl.H.	Fl.H.	Fl.H.	Fl.H.	Fl.H.
Area (m^2)	63.66	21.82	30.22	30.03	21.48	43.21	245.89	234.64
Duty (BTU/hr)	5840122	555385.1	1733570	1235528	-779600	9572436	-1.2E+08	78042955

4.5 *Compressor*

Table 4.5-1: Compressor equipment summary table.

Compressors	C-100	C-101	C-102
Flow (kg/h)	577008	577008	585064
Fluid Density (kg/m^3)	1.1798	5.53839	10.6537
Power (kW)	37090	32854.5	-48431.3
Type/Drive	Centrf./ Electric	Centrf./ Electric	Centrf./ Electric
Efficiency (Fluid Power/Shaft Power)	75%	75%	100%

4.6 *Pumps*

Table 4.6-1: Pump equipment summary table.

Pumps	P-100	P-101	P-102	P-103	P-104
Flow (kg/h)	10059.8	1820.47	183.203	8056.09	8056.09
Fluid Density (kg/m^3)	570.238	570.177	602.994	600.499	600.001
Power (kW)	.548853	.330197	.046385	3.13327	8.28815
Type/Drive	Centrf./ Electric	Centrf./ Electric	Centrf./ Electric	Centrf./ Electric	Centrf./ Electric
Efficiency (Fluid Power/Shaft Power)	75%	75%	75%	46%	75%

4.7 *Cyclones*

Table 4.7-1: Cyclone equipment summary table.

Cyclones	S-100	S-101	S-102	S-103
Length (m)	3.709	7.7421	7.9535	8.1583
Diameter (m)	2.4727	5.1614	5.3023	5.4389
Efficiency	34%	74%	73%	73%

4.8 Reactor

Table 4.8-1: Reactor equipment summary table.

Reactor	R-100
Temperature (°C)	37.86
Pressure (bar)	19.99
Orientation	Horizontal
MOC	Autoclave
Size	
Height/Length (m)	1.76
Diameter (m)	.02
Internals	Catalyst packed bed

5 HAZARDS AND OPERABILITY ANALYSIS

The assumptions considered in the safety analysis of the production of MAN from n-butane are as follows:

1. Process occurs outdoors.
2. Plant is over 25,000 ft^2, so did not have adequate access to safety equipment.
3. Area surrounding process unit is flat, so any spills would spread out.
4. Cooling takes at least 10 minutes.
5. All operating instructions/procedures have been covered to maintain and control the units.

The highest risk associated with this process operation is the accumulation of dust in the cyclone due to the small particle size (10 micrometers) of the solid MAN product. This dust is combustible when exposed to air and an ignition source. This is especially hazardous because a large amount of air also flows through the cyclones, feeding oxygen to the MAN and possibly fueling an explosion and resulting fire.

The reactor has the highest F&EI of 154.2, which indicates a heavy degree of hazard. The high temperature and pressure of the reactor contribute to this hazard. The presence of n-butane in oxygen in the reactor is also hazardous because n-butane becomes explosive in the presence of oxygen. Although the presence of inert nitrogen lowers the concentration of oxygen, this combination is still a safety hazard.

Neither of the distillation columns are highly hazardous. Both columns have an F&EI of below 60, which indicates a light degree of hazard.

Tables 5-(1-3) below summarize the safety analysis calculations for this process.

Table 5-1: Loss Control Credit Factor

T-100		
1. Process Control Credit Factor (C1)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. emergency power	0.98	0.98
b. cooling	0.97-0.99	0.99
c. explosion control	0.84-0.98	0.98
d. emergency shutdown	0.96-0.99	0.98
e. computer control	0.963-0.99	0.99
f. inert gas	0.94-0.96	0.94
g. operating instructions/procedures	0.91-0.99	0.91
h. reactive chemical review	0.91-0.98	0.98
i. other process hazards analysis	0.91-0.98	0.91
C1 Value		0.703696402
2. Material Isolation Credit Factor (C2)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. remote control valves	0.96-0.98	0.96
b. dump/blowdown	0.96-0.98	0.96
c. drainage	0.91-0.97	0.97
d. interlock	0.98	0.98
C2 Value		0.87607296
3. Fire Protection Credit Factor (C3)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. leak detection	0.94-0.98	0.98
b. structural steel	0.95-0.98	0.97
c. fire water supply	0.94-0.97	0.94
d. special systems	0.91	0.91
e. sprinkler systems	0.74-0.97	0.97
f. water curtains	0.97-0.98	0.97
g. foam	0.92-0.97	0.94
h. hand extinguisher/monitors	0.93-0.98	0.98
i. cable protection	0.94-0.98	0.94
C3 Value		0.662509801
Loss Control Credit Factor	**C1 x C2 x C3**	**0.408430263**

T-101		
1. Process Control Credit Factor (C1)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. emergency power	0.98	0.98
b. cooling	0.97-0.99	0.99
c. explosion control	0.84-0.98	0.98
d. emergency shutdown	0.96-0.99	0.98
e. computer control	0.963-0.99	0.99
f. inert gas	0.94-0.96	0.96
g. operating instructions/procedures	0.91-0.99	0.91
h. reactive chemical review	0.91-0.98	0.98
i. other process hazards analysis	0.91-0.98	0.98
C1 Value		0.77395087
2. Material Isolation Credit Factor (C2)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. remote control valves	0.96-0.98	0.96
b. dump/blowdown	0.96-0.98	0.98
c. drainage	0.91-0.97	0.97
d. interlock	0.98	0.98
C2 Value		0.89432448
3. Fire Protection Credit Factor (C3)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. leak detection	0.94-0.98	0.98
b. structural steel	0.95-0.98	0.97
c. fire water supply	0.94-0.97	0.94
d. special systems	0.91	0.91
e. sprinkler systems	0.74-0.97	0.97
f. water curtains	0.97-0.98	0.98
g. foam	0.92-0.97	0.94
h. hand extinguisher/monitors	0.93-0.98	0.98
i. cable protection	0.94-0.98	0.94
C3 Value		0.669339799
Loss Control Credit Factor	**C1 x C2 x C3**	**0.463292383**

R-100		
1. Process Control Credit Factor (C1)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. emergency power	0.98	0.98
b. cooling	0.97-0.99	0.99
c. explosion control	0.84-0.98	0.98
d. emergency shutdown	0.96-0.99	0.98
e. computer control	0.963-0.99	0.99
f. inert gas	0.94-0.96	0.94
g. operating instructions/procedures	0.91-0.99	0.91
h. reactive chemical review	0.91-0.98	0.98
i. other process hazards analysis	0.91-0.98	0.91
C1 Value		0.703696402
2. Material Isolation Credit Factor (C2)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. remote control valves	0.96-0.98	0.98
b. dump/blowdown	0.96-0.98	0.96
c. drainage	0.91-0.97	0.91
d. interlock	0.98	0.98
C2 Value		0.83900544
3. Fire Protection Credit Factor (C3)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. leak detection	0.94-0.98	0.98
b. structural steel	0.95-0.98	0.97
c. fire water supply	0.94-0.97	0.94
d. special systems	0.91	0.91
e. sprinkler systems	0.74-0.97	0.97
f. water curtains	0.97-0.98	0.97
g. foam	0.92-0.97	0.94
h. hand extinguisher/monitors	0.93-0.98	0.98
i. cable protection	0.94-0.98	0.94
C3 Value		0.662509801
Loss Control Credit Factor	**C1 x C2 x C3**	**0.391149171**

S-100		
1. Process Control Credit Factor (C1)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. emergency power	0.98	0.98
b. cooling	0.97-0.99	0.99
c. explosion control	0.84-0.98	0.98
d. emergency shutdown	0.96-0.99	0.98
e. computer control	0.963-0.99	0.99
f. inert gas	0.94-0.96	0.94
g. operating instructions/procedures	0.91-0.99	0.91
h. reactive chemical review	0.91-0.98	0.98
i. other process hazards analysis	0.91-0.98	0.91
C1 Value		0.703696402
2. Material Isolation Credit Factor (C2)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. remote control valves	0.96-0.98	0.96
b. dump/blowdown	0.96-0.98	0.98
c. drainage	0.91-0.97	0.97
d. interlock	0.98	0.98
C2 Value		0.89432448
3. Fire Protection Credit Factor (C3)		
Feature	**Credit Factor Ranger**	**Credit Factor Used**
a. leak detection	0.94-0.98	0.98
b. structural steel	0.95-0.98	0.97
c. fire water supply	0.94-0.97	0.94
d. special systems	0.91	0.91
e. sprinkler systems	0.74-0.97	0.97
f. water curtains	0.97-0.98	0.98
g. foam	0.92-0.97	0.94
h. hand extinguisher/monitors	0.93-0.98	0.98
i. cable protection	0.94-0.98	0.94
C3 Value		0.669339799
Loss Control Credit Factor	**C1 x C2 x C3**	**0.421237569**

Table 5-2: Process Unit Risk Analysis Summary

T-100		
1. fire & explosion index (F&EI)	59.26	
2. Radius of Exposure	49.7784	ft or m
3. Area of Exposure	7780.572	ft^2 or m^2
4. Value of Area of Exposure	165	$MM
5. Damage factor	0.59	
6. Base maximum Probable Property Damage-(Base MPPD) [4 x 5]	97.35	$MM
7. Loss Control Credit Factor	0.40843	
8. Actual Maximum Probable Damage - (Actual MPPD) [6 x 7]	39.76066	$MM
9. Maximum Probable Days Outage - (MPDO)	180.6206	days
10. Business Interruption - (BI)	-5.2681	$MM

T-101		
1. fire & explosion index (F&EI)	29.63	
2. Radius of Exposure	24.89004	ft
3. Area of Exposure	1945.274	ft^2
4. Value of Area of Exposure	165	$MM
5. Damage factor	0.42	
6. Base maximum Probable Property Damage-(Base MPPD) [4 x 5]	69.3	$MM
7. Loss Control Credit Factor	0.463292	
8. Actual Maximum Probable Damage - (Actual MPPD) [6 x 7]	32.10616	$MM
9. Maximum Probable Days Outage - (MPDO)	159.4689	days
10. Business Interruption - (BI)	-4.65118	$MM

R-100		
1. fire & explosion index (F&EI)	154.22	
2. Radius of Exposure	129.5482	ft or m
3. Area of Exposure	52697.76	ft^2 or m^2
4. Value of Area of Exposure	165	$MM
5. Damage factor	0.81	
6. Base maximum Probable Property Damage-(Base MPPD) [4 x 5]	133.65	$MM
7. Loss Control Credit Factor	0.39115	
8. Actual Maximum Probable Damage - (Actual MPPD) [6 x 7]	52.2772	$MM
9. Maximum Probable Days Outage - (MPDO)	211.8357	days
10. Business Interruption - (BI)	-6.178	$MM

S-100		
1. fire & explosion index (F&EI)	130.83	
2. Radius of Exposure	109.8972	ft or m
3. Area of Exposure	37923.02	ft^2 or m^2
4. Value of Area of Exposure	165	$MM
5. Damage factor	0.58	
6. Base maximum Probable Property Damage-(Base MPPD) [4 x 5]	95.7	$MM
7. Loss Control Credit Factor	0.421238	
8. Actual Maximum Probable Damage - (Actual MPPD) [6 x 7]	40.31244	$MM
9. Maximum Probable Days Outage - (MPDO)	182.0764	days
10. Business Interruption - (BI)	-5.31056	$MM

Table 5-3: Manufacturing Unit Risk Analysis

Area USA	**Division**	**Location** Houston
Site Houston Maleic Anhydride Plant	**Manufacturing Unit**	**Type of Operation** Maleic Anhydride Production
Prepared by Olivia Smithson	**Total MFG. Unit Replacement Value**	**Date** 4/28/2019
Process Unit/ Major Material	**Material Factor**	**F&EI**
T-100/ n-butane	21	59.26
T-101/ n-butane	21	29.631
R-100/ n-butane	21	154.224
S-100/Maleic Anhydride	14	130.83

Process Unit/ Major Material	**Value of Area of Exposure ($MM)**	**Base MPPD ($MM)**	**Actual MPPD ($MM)**	**Days Outage MPDO**	**BI Loss ($MM)**
T-100/ n-butane	165	97.35	39.76	180.62	54.6
T-101/ n-butane	165	69.3	32.11	159.47	48.205
R-100/ n-butane	165	133.65	52.27	211.83	64.03
S-100/ MAN	165	95.7	40.31	182.08	55.04
		69.3	32.10616217	159.4689186	48.20479626

6 ECONOMIC ANALYSIS

6.1 BASIS FOR EQUIPMENT COSTS

6.1.1 Methodology

Module costing is a technique to perform a preliminary estimate of the cost of a chemical plant based on the cost of purchasing the equipment in the plant. This gives a base estimate of the cost of the plant that may deviate slightly due to the specific type of equipment, the specific materials of construction, and the pressure of the system.

However, only a preliminary estimate of the plant is desired, so this technique will be used.

The bare module equipment cost C_{BM} provides an estimate based on the bare module cost factor F_{BM} and the purchased cost for base conditions $C^0{}_P$. The purchased cost for base conditions is the estimate of the cost of equipment based on the most common type of material used for that unit, and assuming the pressure of the system is close to ambient pressure. The bare module cost factor takes into account the specific materials of construction and the actual operating pressure. Equation 6.1.1-1 shows the relationship between these factors.

$$C_{BM} = C^0{}_P F_{BM} \tag{6.1.1-1}$$

To calculate C_{BM}, first use data or figures to obtain the value of $C^0{}_P$ for a piece of equipment. The type of equipment being analyzed will affect how F_{BM} is estimated. Once these two factors are found, C_{BM} is calculated using Equation 6.1.1-1.

The bare module cost, an important value in itself, can also be used to calculate the total module cost (C_{TM}). This takes into account the cost of making small to moderate alterations and expansions to each piece of equipment in the existing chemical plant. The total module cost is calculated using the value of the bare module cost, as seen in Equation 6.1.1-2. In this equation, “n” represents the total number of pieces of equipment.

$$C_{TM} = \sum_{i=1}^{n} C_{TM,i} = 1.18 \sum_{i=1}^{n} C_{BM,i} \tag{6.1.1-2}$$

6.1.2 Chemical Engineering Plant Cost Index

The bare module cost, calculated in the previous section, is dependent upon the year that the tables and figures used to calculate the factors were developed. The actual cost of the present year will be different due to inflation. This can be corrected using the Chemical Engineering Plant Cost Index (CEPCI). The equation to use CEPCI is as follows:

$$C_2 = C_1\left(\frac{I_2}{I_1}\right)$$

In this equation, "I" is the cost index, the subscript 1 refers to the base time when the cost is known, and subscript 2 refers to the time when the cost is desired. C_2 is the final bare module cost.

CAPCOST also uses the CEPCI to adjust the cost to the desired year of production. The CEPCI used for this analysis is 542.

6.2 BASIS FOR MANUFACTURING COSTS

6.2.1 Methodology

The calculation for the cost of manufacturing (COM) of a chemical plant takes three different factors into account. The first is the direct manufacturing cost (DMC), which includes the operating expenses that will change with production rate. This includes factors such as cost of raw materials (C_{RM}), cost of waste treatment (C_{WT}), maintenance costs, and cost of operating labor (C_{OL}). It also includes the fixed capital investment (FCI), which represents the cost to build the plant, as explained in the previous section. The second factor is the fixed manufacturing cost (FMC), which will not change with production rate. This includes factors such as taxes, insurance, and depreciation. The third is general expenses (GE) for a business to function, such as management sales, financing, and research functions. The manufacturing cost can be summarized by the following equations:

$$COM = DMC + FMC + GE \quad (6.2.1\text{-}1)$$

$$DMC = C_{RM} + C_{WT} + 1.33\,C_{OL} + 0.069FCI + 0.03COM \quad (6.2.1\text{-}2)$$

$$FMC = 0.708C_{OL} + 0.068FCI + depreciation \quad (6.2.1\text{-}3)$$

$$GE = 0.177C_{OL} + 0.009FCI + 0.16COM \quad (6.2.1\text{-}4)$$

The final equation for the total manufacturing cost is obtained by substituting Equations 6.2.1-(2-4) into Equation 6.2.1-1. This equation is shown as Equation 6.2.1-5 below:

$$COM = 0.280FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{WT} + C_{RM}) \quad (6.2.1\text{-}5)$$

Equation 6.2.1-5 represents the cost of manufacturing with a depreciation of 0.10FCI. The cost of manufacturing without depreciation (COM_d), is calculated using Equation 6.2.1-6 below:

$$COM_d = 0.180FCI + 2.73C_{OL} + 1.23(C_{UT} + C_{WT} + C_{RM}) \quad (6.2.1\text{-}5)$$

6.2.2 Chemical Costs

Only one chemical stream was purchased in this process: the mixed butane feed stream from the Houston refinery. The price of this stream, and its total purchasing cost, is listed in Table 6.2.2-1.

Table 6.2.2-1: List of chemical costs in the production of MAN process.

Chemical	Prices ($/kg)	Feed Flow (kg/yr)	Price ($/yr)
Mixed C4	0.50	10059.76	5029.88
Total			5029.88

6.2.3 Utility Costs

The utility costs are calculated using CAPCOST, which assumes that the cost to supply the utility is equal to the operating cost to generate the utility. The total annual utility cost of this process is $39,100,000. Most of this cost, $43,600,000, originates from the electricity to run the two compressors used to increase the pressure of air before entering the reactor. A relatively large amount of air is used in this process, so the compressors are large and expensive. Some utility cost is saved by utilizing the isentropic Joule-Thomson cooling effect during post-processing. An expander and ejector are used to decrease the temperature and pressure of the product stream in order to solidify MAN. The energy gained from Joule-Thomson cooling is recycled in the process to save money on the utility cost, approximately $2,020,000. The reactor, containing exothermic reactions, also releases energy, saving $7,536,404. The full list of utility costs, broken down for each piece of equipment, is shown in Table 6.2.3-1.

Table 6.2.3-1: Utility costs for each piece of equipment in the production of MAN process.

Name	Utility Used	Efficiency	Actual Usage	Annual Utility Cost
C-101	NA			
C-102	NA			
D-101	Electricity	0.9	36600 kW	$20,500,000
D-102	Electricity	0.9	41200 kW	$23,100,000
Dc-101	NA			
Dc-102	NA			
Dc-103	NA			
Dc-104	NA			
E-100	**Low-Pressure Steam**		6160 MJ/h	$104,100
E-101	**Medium-Pressure Steam**		587 MJ/h	$13,580
E-102	**High-Pressure Steam**		1830 MJ/h	$86,200
E-103	**Custom**		1300 MJ/h	$61,400
E-104	**Custom**		823 MJ/h	$58,120
E-105	**Custom**		10100 MJ/h	$475,700
E-106	**Cooling Water**		125000 MJ/h	$390,000
E-107	**Custom**		82300 MJ/h	$3,879,000
J-101	Electricity	0.9	3600 kW	$(2,020,000)
P-101	Electricity	0.86	0.345 kW	$194
P-102	Electricity	0.86	0.049 kW	$27
P-103	Electricity	0.86	3.64 kW	$2,040
P-104	Electricity	0.86	8.67 kW	$4,860
P-105	Electricity	0.86	0.574 kW	$322
R-101	NA		-160000.02 MJ/h	$(7,536,404)
T-101	NA			
T-102	NA			
Z-101	NA			
Totals				**$39,100,000**

6.2.4 Labor Costs

In order to calculate the labor costs, the number of operators needed to run the plant must first be calculated using Equation 6.2.4-1.

$$N_{OL} = \left(6.29 + 31.7P^2 + 0.23N_{np}\right)^{0.5} \qquad (6.2.4\text{-}1)$$

In this equation, N_{OL} is the number of operators per shift, P is the number of processing steps involved in handling the particulate solids such as transportation/distribution and particulate removal, and N_{np} is the number of nonparticulate processing steps such as compression, heating/cooling, mixing, and reaction.

This process includes a large number of pieces of equipment, and therefore a large number of processing steps. These are listed in Table 6.2.4-1.

Table 6.2.4-1: Results for the estimation of operating labor requirement N_{np}.

Equipment Type	Number of Equipment	N_{np}
Compressors/Expanders	3	3
Ejectors	1	1
Exchangers	8	8
Pumps	5	---
Reactors	1	1
Towers	2	2
Cyclones	4	4
	Total	19

A single operator is estimated to work an average of 49 weeks per year and five 8-hour shifts per week. Therefore, an operator works 245 shifts per year. Because chemical plants operate 24 hours per day, 3 shifts are required per day. Therefore, 1095 operating shifts are required per year, and approximately 4.5 operators are hired for each operator needed in the plant. Each operator is estimated to receive \$66,910 per year. Therefore, the labor cost is calculated as shown in Equation 6.2.4-2.

$$Labor\ Costs = N_{OL} * 4.5 * \$66{,}910 \qquad (6.2.4\text{-}2)$$

To remain consistent with the previous calculations, CAPCOST is again used to calculate the labor cost for this process instead of using these equations. The labor cost of this process was found to be \$1,271,290.

6.3 PROFITABILITY

6.3.1 Value Added Calculation

The overall material economic balance is displayed in Figure 6.3.1-1. This shows the cost of materials going into the process and the value of the materials being produced.

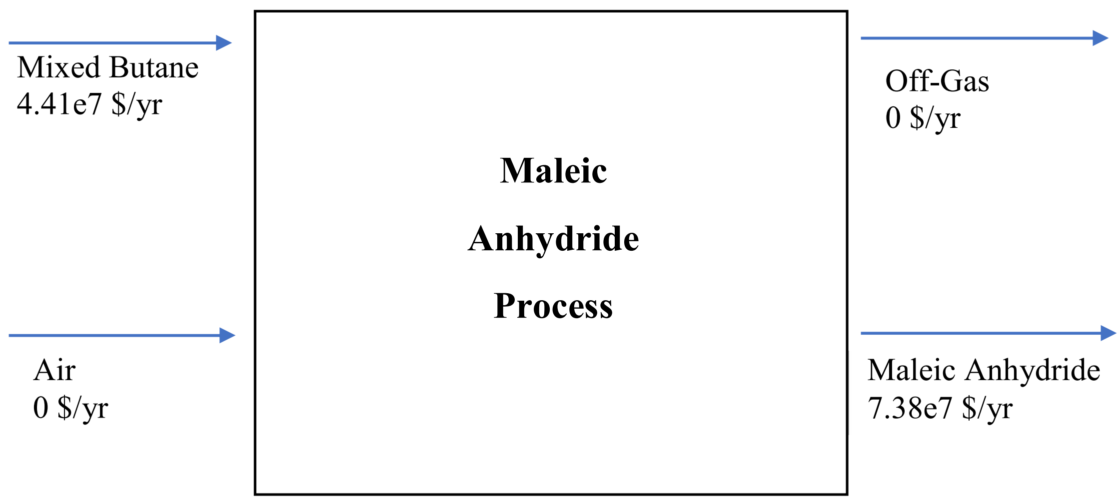

Figure 6.3.1-1: Value added calculation displayed as a material economic balance for the production of MAN process.

The value of the product MAN is higher than the cost of the feed of mixed butanes that was purchased from the Houston refinery. Taking into account only these material costs, a profit would be made of \$28,100,000/year. This value added calculation, including the price of the feed and product streams, is shown in Table 6.3.1-1 below.

Table 6.3.1-1: Value added calculation

	Chemical	Prices ($/kg)	Feed Flow (kg/yr)	Price ($/yr)
Product	**Maleic Anhydride**	1.54	4.79E7	7.00E7
Reactants	**Mixed C4**	0.50	8.82E7	(4.19E7)
Total				2.81E7

6.3.2 Cumulative Cash Flow Diagram

The cumulative cash flow diagram, shown in Figure 6.3.2-1, is a diagram of the project value with a discounted profitability, multiple investments, and a MACRS depreciation of 5 years. From this diagram, it is clear that the cost of running this chemical plant is greater than the revenue obtained from selling the produced MAN. The continually decreasing project value shown in Figure 6.3.2-1 reveals that money would be lost if invested in this process.

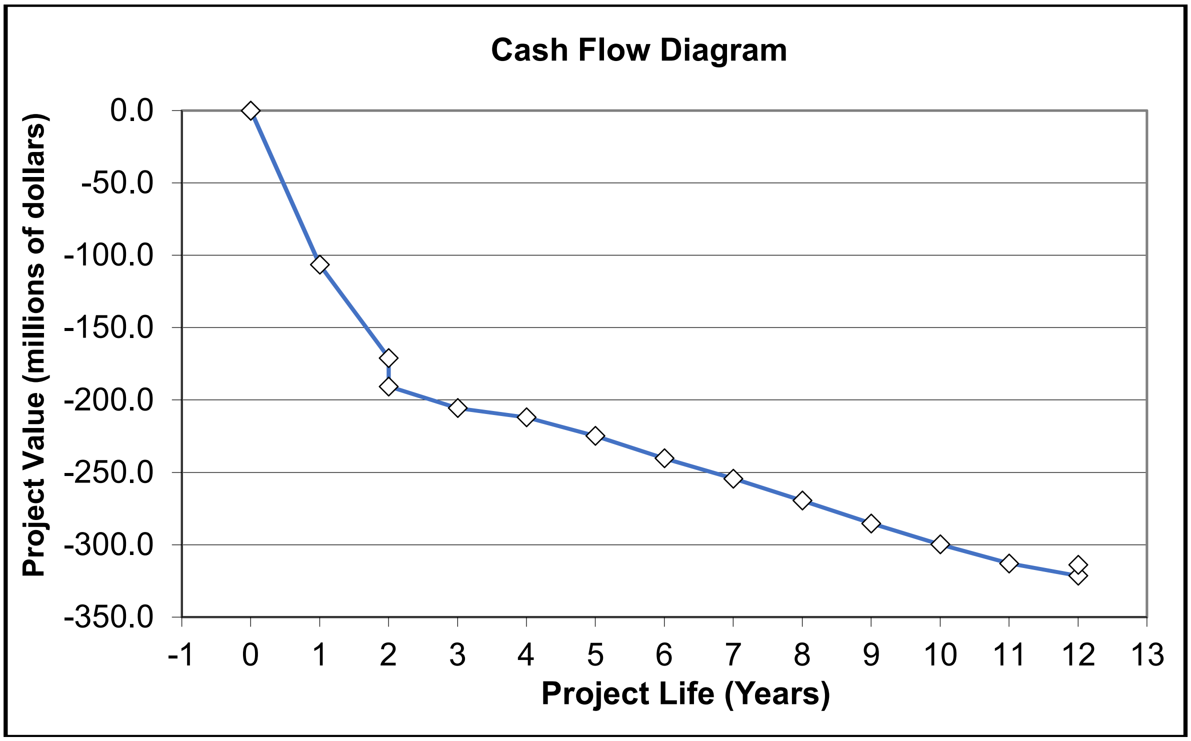

Figure 6.3.2-1: Cash flow diagram for the production of MAN process.

As can be seen from the value added calculation, this process would make a profit if the material costs alone were taken into consideration. However, the utility cost of this process is so large that it costs more to produce MAN than to sell it. As explained in the Utility Costs section, most of the utility cost is due to the two compressors used to compress the air stream before it enters the reactor. If less air was used in this process, this cost would decrease and the process could make a profit. As the process is, the value of MAN would have to be 2.6 times its current value in order to achieve a net present value of 0.

6.3.3 Capital Cost

When a chemical plant contains a large amount of equipment, the bare module technique becomes tedious to calculate. Instead, the computer program CAPCOST can be used to estimate the cost of the chemical plant. This program requires specific information for each piece of equipment, taking into account the specific materials of construction, the operating pressure, and the size of the equipment. Both the price of purchasing each piece of equipment and the bare module cost for each were determined from this program.

The compressors and the drivers used to power the compressors are the most expensive pieces of equipment. This process requires a large amount of air to be compressed, so the compressors are large and require a lot of power to drive them. The two distillation columns are also expensive to purchase. One column is 11 meters tall, and the other is about 90 meters tall. The large size of these columns is necessary to separate the n-butane from the other butanes in the mixed feed stream. It is assumed that almost all of the equipment is made out of stainless steel so that it would require less maintenance. The prices of all of the pieces of equipment can be found in Table V-1 in

Appendix V. The total module cost for the equipment in this process is calculated to be $195,100,000.

Because the feed stream was obtained from a Houston refinery, the chemical plant that would be built to produce MAN from this stream would share the same land as this refinery. Therefore, the cost of land is $0. The taxation rate is 45%, and the annual interest rate is 10%. The values of the factors used to analyze the economics of this process can be found in Tables V-4 and V-5 in Appendix V.

6.3.4 Manufacturing Cost

Due to the large amount of equipment in this process, CAPCOST is used to calculate the cost of manufacturing for this process. The calculated economic information is summarized in Table 6.3.4-1.

Table 6.3.4-1: Calculated Economic Information

Revenue from Sales	$70,035,708
C_{RM} (Raw Materials Costs)	$41,858,661
C_{UT} (Cost of Utilities)	$39,100,000
C_{WT} (Waste Treatment Costs)	$0
C_{OL} (Cost of Operating Labor)	$1,271,290

The only revenue in the process is the sale of the desired product, MAN, at $1.54/kg. The only raw material is the feed stream of mixed butane, which costs $0.50/kg. The utility costs from running the equipment are another large expense, and are explained fully in Section 6.2.3. This process has practically no waste except for venting some of the side products to the atmosphere. Therefore, there is no waste treatment cost for this process. The cost of operating labor includes the cost of building, running, and maintaining each piece of equipment, as explained in Section 6.2.4.

The total cost of manufacturing was calculated from this information. The multiplying factors and the total COM_d are shown in Table 6.3.4-2 below. The total cost of manufacturing was calculated to be $138,167,775.

Table 6.3.4-2: Factors Used in Calculation of Cost of Manufacturing (COM_d)

$COM_d = 0.18*FCIL + 2.73*C_{OL} + 1.23*(C_{UT} + C_{WT} + C_{RM})$

Multiplying factor for FCIL	0.18
Multiplying factor for C_{OL}	2.73
Factors for C_{UT}, C_{WT}, and C_{RM}	1.23
COM_d	**$138,167,775**

The remainder of the tables containing more specific information used to calculate COM_d and capital costs are displayed in Appendix V.

6.3.5 Return on Investment

As shown in Table 6.3.5-1, there is a negative return on investment for this MAN production process. This is because the cost of manufacturing MAN is greater than the revenue gained from selling it. Therefore, the rate of return on investment is -24.16%. An investment in this process would not be profitable.

Table 6.3.5-1: Non-Discounted Profitability Criteria

Cumulative Cash Position (millions)	(471.30)
Rate of Return on Investment	**-24.16%**
Payback Period (years)	Undefined

6.3.6 Payout Period

As shown in Table 6.3.6-(1-2), the payback period for this process is undefined. The production of MAN in this chemical plant will not ever make a profit, so the amount of money invested in the process will never be recovered. Therefore, the payout, or payback, period for this process cannot be defined.

Table 6.3.6-1: Discounted Profitability Criteria

Net Present Value (millions)	(313.77)
Discounted Cash Flow Rate of Return	NA
Discounted Payback Period (years)	**Undefined**

Table 6.3.6-2: Non-Discounted Profitability Criteria

Cumulative Cash Position (millions)	(471.30)
Rate of Return on Investment	-24.16%
Payback Period (years)	**Undefined**

6.3.7 Discounted Cash Flow Rate of Return

As shown in Table 6.3.7-1, the cash flow rate of return is not applicable. This is because there would be no return of investment for this process. The cost of manufacturing MAN is greater than the revenue gained from selling it, so no profit is made. Therefore, there is no cash flow rate of return.

Table 6.3.7-1: Discounted Profitability Criteria

Net Present Value (millions)	(313.77)
Discounted Cash Flow Rate of Return	**NA**
Discounted Payback Period (years)	Undefined

6.4 RECOMMENDATION

Based on economic analysis, it is not recommended to proceed with this project of building a chemical plant for this process. The cost of producing MAN is greater than the revenue gained from selling MAN, producing a negative profit. In order to obtain a net present value of 0 after 10 years, the product would have to be worth over twice as much for which it is currently being sold. More specifically, it would have to increase by a factor of 2.60 to a price of $4.01/kg.

If this process was redesigned, it is recommended to buy a pure butane stream instead of separating pure butane from a mixed stream. If this was done, the two distillation columns would not be needed, saving expenses on the price of the tower and the utilities to run it.

It is also recommended to design a process with a smaller amount of air. The main expense of this process is the cost of electricity to compress the air before it enters the reactor. A large amount of air is used to increase the amount of oxygen that reacts with butane. However, the large amount of air that needs to be compressed requires large and expensive compressors. If less air was used, the utility cost for driving the compressors would decrease, and the process would be more profitable.

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APPENDIX I. STEADY STATE SIMULATION REPORT

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28, 2019 
 VERSION: 36.0   Build 249                               SUNDAY 
 INSTALLATION:                                           8:51:48 
P.M.
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                              RUN CONTROL SECTION

 RUN CONTROL INFORMATION
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 THIS COPY OF ASPEN PLUS LICENSED TO UNIV OF SOUTH CAROLINA

 TYPE OF RUN: NEW

 INPUT FILE NAME: _3308utv.inm

 OUTPUT PROBLEM DATA FILE NAME: _3308utv
 LOCATED IN:


 PDF SIZE USED FOR INPUT TRANSLATION:
   NUMBER OF FILE RECORDS (PSIZE) =     0
   NUMBER OF IN-CORE RECORDS      =   256
 PSIZE NEEDED FOR SIMULATION    =   256

 CALLING PROGRAM NAME:          apmain
 LOCATED IN: C:\Program Files (x86)\AspenTech\Aspen Plus
V10.0\Engine\\xeq

 SIMULATION REQUESTED FOR ENTIRE FLOWSHEET
```

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FLOWSHEET SECTION

FLOWSHEET CONNECTIVITY BY STREAMS

STREAM	SOURCE	DEST	STREAM	SOURCE	DEST
18	----	C-100	1	----	P-100
27	----	S-100	24	R-100	C-102
23	M-100	R-100	19	C-100	E-106
15	P-103	P-104	16	P-104	E-105
17	E-105	M-100	20	E-106	C-101
21	C-101	E-107	22	E-107	M-100
13	P-102	----	8	P-101	----
11	VAL-100	T-101	3	E-100	E-101
2	P-100	E-100	7	T-100	P-101
9	T-100	E-104	14	T-101	P-103
12	T-101	P-102	4	E-101	E-102
5	E-102	E-103	6	E-103	T-100
10	E-104	VAL-100	26	VAL-101	----
25	C-102	VAL-101	28	S-100	S-101
29	S-100	----	30	S-101	S-102
31	S-101	----	32	S-102	S-103
33	S-102	----	34	S-103	----
35	S-103	----			

FLOWSHEET CONNECTIVITY BY BLOCKS

BLOCK	INLETS	OUTLETS
R-100	23	24
M-100	22 17	23

C-100	18	19
P-103	14	15
P-104	15	16
E-105	16	17
E-106	19	20
C-101	20	21
E-107	21	22
P-102	12	13
P-101	7	8
VAL-100	10	11
E-100	2	3
P-100	1	2
T-100	6	7 9
T-101	11	14 12
E-101	3	4
E-102	4	5
E-103	5	6
E-104	9	10
VAL-101	25	26
C-102	24	25
S-100	27	28 29
S-101	28	30 31
S-102	30	32 33
S-103	32	34 35

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                               FLOWSHEET SECTION

 CONVERGENCE STATUS SUMMARY
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   DESIGN-SPEC SUMMARY
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   DESIGN
CONV
   SPEC      ERROR        TOLERANCE    ERR/TOL      VARIABLE
STAT  BLOCK
   ------    -----        ---------    -------      --------   --
--  -----
   DS-1      0.53699E-03  0.10000E-01  0.53699E-01   46.218     #
$OLVER01

   #  = CONVERGED
   *  = NOT CONVERGED
   LB = AT LOWER BOUNDS
   UB = AT UPPER BOUNDS

 DESIGN-SPEC:  DS-1
 ------------------

   SAMPLED VARIABLES:
     S1       : MOLE ENTROPY IN STREAM 25 SUBSTREAM MIXED
     S2       : MOLE ENTROPY IN STREAM 26 SUBSTREAM MIXED

   SPECIFICATION:
     MAKE S1-S2 APPROACH 0.0
     WITHIN          0.0100000

   MANIPULATED VARIABLES:
     VARY     : SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK VAL-101
     LOWER LIMIT =         10.0000                  C
     UPPER LIMIT =        150.000                   C
     FINAL VALUE =         46.2184                  C

   VALUES OF ACCESSED FORTRAN VARIABLES:
     VARIABLE      VALUE AT START      FINAL VALUE     UNITS
                      OF LOOP
     --------      --------------      -----------     -----
     S1             0.638628           0.638628        CAL/MOL-K
     S2             0.721911           0.638091        CAL/MOL-K

 CONVERGENCE BLOCK:  $OLVER01
 ----------------------------
```

```
     SPECS: DS-1
     MAXIT=   30 STEP-SIZE=    50.000    % OF RANGE
                 MAX-STEP=       90.0    % OF RANGE
                 XTOL=       1.000000E-08
     THE NEW ALGORITHM WAS USED WITH BRACKETING=NO
     METHOD: SECANT        STATUS: CONVERGED
     TOTAL NUMBER OF ITERATIONS:     3

                           *** FINAL VALUES ***


VAR#  MANIPUL/TEAR-VAR VARIABLE DESCRIPTION
UNIT         VALUE       PREV VALUE       ERR/TOL
----  ---------------- -------------------------
----------- ------------   ------------   ------------
   1  BLOCK-VAR        VAL-101.PARAM.TEMP
C             46.2184       120.0000      5.3699-02

                           *** ITERATION HISTORY ***
```

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                              FLOWSHEET SECTION

 CONVERGENCE BLOCK:  $OLVER01 (CONTINUED)

     DESIGN-SPEC ID: DS-1
     ITERATED:  SENTENCE=PARAM VARIABLE=TEMP IN UOS BLOCK VAL-101

     ITERATION  VARIABLE         ERROR          ERR/TOL
     ---------  --------         -----          -------
          1      50.00         -0.8328E-01     -8.328
          2      120.0          -1.625         -162.5
          3      46.22          0.5370E-03     0.5370E-01

 COMPUTATIONAL SEQUENCE
 ----------------------

 SEQUENCE USED WAS:
    HPS MPS R134A-C LPS CW DOWA-H ELECT S-100 S-101 S-102 S-103
P-100 E-100
    E-101 E-102 E-103 T-100 P-101 E-104 VAL-100 T-101 P-103 P-104
P-102
    C-100 E-106 C-101 E-105 E-107 M-100 R-100 C-102
    $OLVER01 VAL-101
    (RETURN $OLVER01)
    AIR-C AIR-H

 OVERALL FLOWSHEET BALANCE
 -------------------------

                  ***  MASS AND ENERGY BALANCE  ***
                               IN              OUT
RELATIVE DIFF.
    CONVENTIONAL COMPONENTS (KMOL/HR )
       NITROGEN                 31600.0        31600.0
0.00000
       CO                       97.5374        195.075       -
0.500000
       O2                       7959.99        7519.98
0.552774E-01
       CO2                      81.7403        163.481       -
0.500000
       C3                      0.865800       0.865800
0.167375E-08
       IC4                      28.2251        28.2251
0.167374E-08
       2-ME-C3                 0.865801       0.865801
0.167371E-08
       1-C4                    0.346324       0.346324
0.167368E-08
```

```
       N-BUTANE                    177.027         75.7929
0.571856
       T2-C4                       1.70875         1.70875       -
0.179842E-09
       C2-C4                      0.664233        0.664233       -
0.194543E-09
       C5                         0.866922        0.866922       -
0.372867E-09
       WATER                       449.754         899.508       -
0.500000
       MA(L)                       0.00000        0.223821E-08    -
1.00000
       MA(S)                       56.4142         112.828       -
0.500000
    TOTAL BALANCE
       MOLE(KMOL/HR )              40456.0         40600.2       -
0.355183E-02
       MASS(KG/HR   )             0.117213E+07    0.117213E+07
0.731961E-09
       ENTHALPY(CAL/SEC )        -0.129870E+08   -0.229239E+08
0.433471
```

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                              FLOWSHEET SECTION

 OVERALL FLOWSHEET BALANCE (CONTINUED)

                     ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             3597.37      KG/HR
    PRODUCT STREAMS CO2E          7194.75      KG/HR
    NET STREAMS CO2E PRODUCTION   3597.37      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         3597.37      KG/HR
```

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                         PHYSICAL PROPERTIES SECTION

 COMPONENTS
 ----------

  ID        TYPE  ALIAS          NAME
   NITROGEN C     N2              NITROGEN
   CO       C     CO              CARBON-MONOXIDE
   O2       C     O2              OXYGEN
   CO2      C     CO2             CARBON-DIOXIDE
   C3       C     C3H8            PROPANE
   IC4      C     C4H10-2         ISOBUTANE
   2-ME-C3  C     C4H8-5          ISOBUTYLENE
   1-C4     C     C4H8-1          1-BUTENE
   N-BUTANE C     C4H10-1         N-BUTANE
   T2-C4    C     C4H8-3          TRANS-2-BUTENE
   C2-C4    C     C4H8-2          CIS-2-BUTENE
   C5       C     C5H12-1         N-PENTANE
   WATER    C     H2O             WATER
   MA(L)    C     C4H2O3          MALEIC-ANHYDRIDE
   MA(S)    C     C4H2O3          MALEIC-ANHYDRIDE
```

```
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                      PROPERTY CONSTANT ESTIMATION SECTION

 BINARY PARAMETERS
 -----------------


     ------------------------------------------------------------
---
     FOR COMPONENT PAIRS CONTAINING NITROGEN
     ------------------------------------------------------------
---

                               PARAMETER    ESTIMATED     METHOD
OF
     DESCRIPTION               NAME         VALUE
ESTIMATION
     -----------               -------      ---------     -------
---


     UNIQUAC PARAMETERS                                   UNIFAC
         NITROGEN   CO         UNIQ  /2    -68.72
         CO         NITROGEN   UNIQ  /2     63.18

         NITROGEN   O2         UNIQ  /2     32.60
         O2         NITROGEN   UNIQ  /2    -37.89

         NITROGEN   CO2        UNIQ  /2    -69.04
         CO2        NITROGEN   UNIQ  /2     3.251

         NITROGEN   C3         UNIQ  /2    -30.14
         C3         NITROGEN   UNIQ  /2     56.46

         NITROGEN   IC4        UNIQ  /2    -30.36
         IC4        NITROGEN   UNIQ  /2     60.79

         NITROGEN   2-ME-C3    UNIQ  /2    -13.50
         2-ME-C3    NITROGEN   UNIQ  /2     54.91

         NITROGEN   1-C4       UNIQ  /2    -11.81
         1-C4       NITROGEN   UNIQ  /2     53.03

         NITROGEN   N-BUTANE   UNIQ  /2    -30.50
         N-BUTANE   NITROGEN   UNIQ  /2     60.93
```

PROPERTY CONSTANT ESTIMATION SECTION

BINARY PARAMETERS (CONTINUED)

NITROGEN	T2-C4	UNIQ	/2	-11.03
T2-C4	NITROGEN	UNIQ	/2	51.99
NITROGEN	C2-C4	UNIQ	/2	-11.03
C2-C4	NITROGEN	UNIQ	/2	51.99
NITROGEN	C5	UNIQ	/2	-30.78
C5	NITROGEN	UNIQ	/2	63.93
NITROGEN	WATER	UNIQ	/2	-379.8
WATER	NITROGEN	UNIQ	/2	252.1

```
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                      PROPERTY CONSTANT ESTIMATION SECTION

 BINARY PARAMETERS (CONTINUED)


     ------------------------------------------------------------
---
     FOR COMPONENT PAIRS CONTAINING CO
     ------------------------------------------------------------
---

                                 PARAMETER    ESTIMATED     METHOD
OF
     DESCRIPTION                 NAME         VALUE
ESTIMATION
     -----------                 -------      ---------     -------
---


     UNIQUAC PARAMETERS                                     UNIFAC
         CO          O2          UNIQ  /2      15.81
         O2          CO          UNIQ  /2     -21.61

         CO          CO2         UNIQ  /2     -135.2
         CO2         CO          UNIQ  /2      55.28

         CO          C3          UNIQ  /2     -41.14
         C3          CO          UNIQ  /2      90.24

         CO          IC4         UNIQ  /2     -38.86
         IC4         CO          UNIQ  /2      95.33

         CO          2-ME-C3     UNIQ  /2     -33.12
         2-ME-C3     CO          UNIQ  /2      99.18

         CO          1-C4        UNIQ  /2     -28.58
         1-C4        CO          UNIQ  /2      93.09

         CO          N-BUTANE    UNIQ  /2     -39.07
         N-BUTANE    CO          UNIQ  /2      95.57

         CO          T2-C4       UNIQ  /2     -28.09
         T2-C4       CO          UNIQ  /2      92.42

         CO          C2-C4       UNIQ  /2     -28.09
         C2-C4       CO          UNIQ  /2      92.42
```

PROPERTY CONSTANT ESTIMATION SECTION

BINARY PARAMETERS (CONTINUED)

CO	C5	UNIQ	/2	-37.81
C5	CO	UNIQ	/2	99.21
CO	WATER	UNIQ	/2	-581.5
WATER	CO	UNIQ	/2	339.5

PROPERTY CONSTANT ESTIMATION SECTION

BINARY PARAMETERS (CONTINUED)

FOR COMPONENT PAIRS CONTAINING O2

DESCRIPTION		PARAMETER NAME	ESTIMATED VALUE	METHOD OF ESTIMATION
UNIQUAC PARAMETERS				UNIFAC
O2	CO2	UNIQ /2	-75.52	
CO2	O2	UNIQ /2	-14.18	
O2	C3	UNIQ /2	-22.65	
C3	O2	UNIQ /2	43.48	
O2	IC4	UNIQ /2	-23.46	
IC4	O2	UNIQ /2	46.84	
O2	2-ME-C3	UNIQ /2	-4.778	
2-ME-C3	O2	UNIQ /2	40.57	
O2	1-C4	UNIQ /2	0.5739	
1-C4	O2	UNIQ /2	34.08	
O2	N-BUTANE	UNIQ /2	-23.76	
N-BUTANE	O2	UNIQ /2	47.15	
O2	T2-C4	UNIQ /2	1.409	
T2-C4	O2	UNIQ /2	32.99	
O2	C2-C4	UNIQ /2	1.409	
C2-C4	O2	UNIQ /2	32.99	
O2	C5	UNIQ /2	-24.52	
C5	O2	UNIQ /2	49.60	

PROPERTY CONSTANT ESTIMATION SECTION

BINARY PARAMETERS (CONTINUED)

O2	WATER	UNIQ	/2	-376.7
WATER	O2	UNIQ	/2	255.0

PROPERTY CONSTANT ESTIMATION SECTION

BINARY PARAMETERS (CONTINUED)

FOR COMPONENT PAIRS CONTAINING CO2

DESCRIPTION		PARAMETER NAME	ESTIMATED VALUE	METHOD OF ESTIMATION
UNIQUAC PARAMETERS				UNIFAC
CO2	C3	UNIQ /2	-60.24	
C3	CO2	UNIQ /2	41.93	
CO2	IC4	UNIQ /2	-40.90	
IC4	CO2	UNIQ /2	33.93	
CO2	2-ME-C3	UNIQ /2	-56.73	
2-ME-C3	CO2	UNIQ /2	41.72	
CO2	1-C4	UNIQ /2	17.94	
1-C4	CO2	UNIQ /2	-11.24	
CO2	N-BUTANE	UNIQ /2	-43.92	
N-BUTANE	CO2	UNIQ /2	36.19	
CO2	T2-C4	UNIQ /2	35.03	
T2-C4	CO2	UNIQ /2	-30.33	
CO2	C2-C4	UNIQ /2	35.03	
C2-C4	CO2	UNIQ /2	-30.33	
CO2	C5	UNIQ /2	-99.58	
C5	CO2	UNIQ /2	86.78	
CO2	WATER	UNIQ /2	-61.36	
WATER	CO2	UNIQ /2	-144.5	

```
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                      PROPERTY CONSTANT ESTIMATION SECTION

 BINARY PARAMETERS (CONTINUED)


     ------------------------------------------------------------
---
     FOR COMPONENT PAIRS CONTAINING C3
     ------------------------------------------------------------
---

                          PARAMETER    ESTIMATED     METHOD
OF
     DESCRIPTION          NAME         VALUE
ESTIMATION
     -----------          -------      ---------     -------
---


     UNIQUAC PARAMETERS                              UNIFAC
         C3         IC4         UNIQ  /2     54.53
         IC4        C3          UNIQ  /2    -60.23

         C3         2-ME-C3     UNIQ  /2    -5.915
         2-ME-C3    C3          UNIQ  /2    -1.549

         C3         1-C4        UNIQ  /2    -25.96
         1-C4       C3          UNIQ  /2     14.25

         C3         N-BUTANE    UNIQ  /2     54.53
         N-BUTANE   C3          UNIQ  /2    -60.22

         C3         T2-C4       UNIQ  /2     1.658
         T2-C4      C3          UNIQ  /2    -8.063

         C3         C2-C4       UNIQ  /2     1.658
         C2-C4      C3          UNIQ  /2    -8.063

         C3         C5          UNIQ  /2     54.53
         C5         C3          UNIQ  /2    -60.22

         C3         WATER       UNIQ  /2    -1318.
         WATER      C3          UNIQ  /2    -300.0
```

PROPERTY CONSTANT ESTIMATION SECTION

BINARY PARAMETERS (CONTINUED)

```
    ------------------------------------------------------------
---
    FOR COMPONENT PAIRS CONTAINING IC4
    ------------------------------------------------------------
---

                              PARAMETER    ESTIMATED     METHOD
OF
    DESCRIPTION               NAME         VALUE
ESTIMATION
    -----------               -------      ---------     -------
---


    UNIQUAC PARAMETERS                                   UNIFAC
        IC4         2-ME-C3    UNIQ  /2    -5.912
        2-ME-C3     IC4        UNIQ  /2    -1.551

        IC4         1-C4       UNIQ  /2    -25.96
        1-C4        IC4        UNIQ  /2     14.25

        IC4         N-BUTANE   UNIQ  /2     54.53
        N-BUTANE    IC4        UNIQ  /2    -60.22

        IC4         T2-C4      UNIQ  /2     1.465
        T2-C4       IC4        UNIQ  /2    -7.912

        IC4         C2-C4      UNIQ  /2     1.465
        C2-C4       IC4        UNIQ  /2    -7.912

        IC4         C5         UNIQ  /2     54.53
        C5          IC4        UNIQ  /2    -60.22

        IC4         WATER      UNIQ  /2    -1318.
        WATER       IC4        UNIQ  /2    -300.0
```

```
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                      PROPERTY CONSTANT ESTIMATION SECTION

 BINARY PARAMETERS (CONTINUED)


     -------------------------------------------------------------
---
     FOR COMPONENT PAIRS CONTAINING 2-ME-C3
     -------------------------------------------------------------
---

                              PARAMETER    ESTIMATED     METHOD
OF
     DESCRIPTION              NAME         VALUE
ESTIMATION
     -----------              -------      ---------     -------
---


     UNIQUAC PARAMETERS                                  UNIFAC
         2-ME-C3    1-C4      UNIQ  /2      51.49
         1-C4       2-ME-C3   UNIQ  /2     -56.98

         2-ME-C3    N-BUTANE  UNIQ  /2      28.53
         N-BUTANE   2-ME-C3   UNIQ  /2     -37.68

         2-ME-C3    T2-C4     UNIQ  /2      54.87
         T2-C4      2-ME-C3   UNIQ  /2     -60.59

         2-ME-C3    C2-C4     UNIQ  /2      54.87
         C2-C4      2-ME-C3   UNIQ  /2     -60.59

         2-ME-C3    C5        UNIQ  /2      28.52
         C5         2-ME-C3   UNIQ  /2     -37.68

         2-ME-C3    WATER     UNIQ  /2     -551.7
         WATER      2-ME-C3   UNIQ  /2     -362.1
```

```
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                      PROPERTY CONSTANT ESTIMATION SECTION

 BINARY PARAMETERS (CONTINUED)


     ------------------------------------------------------------
---
     FOR COMPONENT PAIRS CONTAINING 1-C4
     ------------------------------------------------------------
---

                               PARAMETER    ESTIMATED     METHOD
OF
     DESCRIPTION               NAME         VALUE
ESTIMATION
     -----------               -------      ---------     -------
---


     UNIQUAC PARAMETERS                                   UNIFAC
         1-C4       N-BUTANE   UNIQ  /2      26.50
         N-BUTANE   1-C4       UNIQ  /2     -39.23

         1-C4       T2-C4      UNIQ  /2      50.04
         T2-C4      1-C4       UNIQ  /2     -55.57

         1-C4       C2-C4      UNIQ  /2      50.04
         C2-C4      1-C4       UNIQ  /2     -55.57

         1-C4       C5         UNIQ  /2      26.50
         C5         1-C4       UNIQ  /2     -39.23

         1-C4       WATER      UNIQ  /2     -490.4
         WATER      1-C4       UNIQ  /2     -379.5
```

PROPERTY CONSTANT ESTIMATION SECTION

BINARY PARAMETERS (CONTINUED)

FOR COMPONENT PAIRS CONTAINING N-BUTANE

DESCRIPTION		PARAMETER NAME	ESTIMATED VALUE	METHOD OF ESTIMATION
UNIQUAC PARAMETERS				UNIFAC
N-BUTANE	T2-C4	UNIQ /2	1.475	
T2-C4	N-BUTANE	UNIQ /2	-7.920	
N-BUTANE	C2-C4	UNIQ /2	1.475	
C2-C4	N-BUTANE	UNIQ /2	-7.920	
N-BUTANE	C5	UNIQ /2	54.53	
C5	N-BUTANE	UNIQ /2	-60.22	
N-BUTANE	WATER	UNIQ /2	-1318.	
WATER	N-BUTANE	UNIQ /2	-300.0	

PROPERTY CONSTANT ESTIMATION SECTION

BINARY PARAMETERS (CONTINUED)

FOR COMPONENT PAIRS CONTAINING T2-C4

DESCRIPTION		PARAMETER NAME	ESTIMATED VALUE	METHOD OF ESTIMATION
UNIQUAC PARAMETERS				UNIFAC
T2-C4	C2-C4	UNIQ /2	54.53	
C2-C4	T2-C4	UNIQ /2	-60.22	
T2-C4	C5	UNIQ /2	30.11	
C5	T2-C4	UNIQ /2	-38.38	
T2-C4	WATER	UNIQ /2	-574.3	
WATER	T2-C4	UNIQ /2	-356.4	

PROPERTY CONSTANT ESTIMATION SECTION

BINARY PARAMETERS (CONTINUED)

FOR COMPONENT PAIRS CONTAINING C2-C4

DESCRIPTION		PARAMETER NAME	ESTIMATED VALUE	METHOD OF ESTIMATION
UNIQUAC PARAMETERS				UNIFAC
C2-C4	C5	UNIQ /2	30.11	
C5	C2-C4	UNIQ /2	-38.38	
C2-C4	WATER	UNIQ /2	-574.3	
WATER	C2-C4	UNIQ /2	-356.4	

```
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                      PROPERTY CONSTANT ESTIMATION SECTION

 BINARY PARAMETERS (CONTINUED)


     ------------------------------------------------------------
---
     FOR COMPONENT PAIRS CONTAINING C5
     ------------------------------------------------------------
---

                               PARAMETER    ESTIMATED     METHOD
OF
     DESCRIPTION               NAME         VALUE
ESTIMATION
     -----------               -------      ---------     -------
---


     UNIQUAC PARAMETERS                                   UNIFAC
         C5         WATER      UNIQ  /2    -1318.
         WATER      C5         UNIQ  /2    -300.0
```

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                                REACTION SECTION

 REACTION:   R-1       TYPE: LHHW
 --------------------------------

      Unit operations referencing this reaction model:

      Reactor Name: R-100        Block Type: RPLUG
```

```
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                              U-O-S BLOCK SECTION

 BLOCK:  C-100    MODEL: COMPR
 -----------------------------
   INLET STREAM:          18
   OUTLET STREAM:         19
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            20000.0         20000.0
0.00000
       MASS(KG/HR   )            577008.         577008.
0.00000
       ENTHALPY(CAL/SEC )       -9038.85        0.884975E+07    -
1.00102

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                           ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR
5.00000
    ISENTROPIC EFFICIENCY
0.75000
    MECHANICAL EFFICIENCY
1.00000
```

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                              U-O-S BLOCK SECTION

 BLOCK:  C-100    MODEL: COMPR (CONTINUED)

                           ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                 37,090.0
    BRAKE      HORSEPOWER REQUIREMENT  KW                 37,090.0
    NET WORK REQUIRED                  KW                 37,090.0
    POWER LOSSES                       KW                      0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                 27,817.5
    CALCULATED OUTLET TEMP  C
251.204
    ISENTROPIC TEMPERATURE  C
195.465
    EFFICIENCY (POLYTR/ISENTR) USED
0.75000
    OUTLET VAPOR FRACTION
1.00000
    HEAD DEVELOPED,       M-KGF/KG                        17,697.7
    MECHANICAL EFFICIENCY USED
1.00000
    INLET HEAT CAPACITY RATIO
1.40081
    INLET VOLUMETRIC FLOW RATE , L/MIN                 8,151,200.
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                 2,909,740.
    INLET  COMPRESSIBILITY FACTOR
0.99953
    OUTLET COMPRESSIBILITY FACTOR
1.00114
    AV. ISENT. VOL. EXPONENT
1.39690
    AV. ISENT. TEMP EXPONENT
1.39524
    AV. ACTUAL VOL. EXPONENT
1.54963
    AV. ACTUAL TEMP EXPONENT
1.54722

                        ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                 ELECT
  RATE OF CONSUMPTION                    3.7090+04  KW
  COST                                   2499.8646  $/HR

 BLOCK:  C-101    MODEL: COMPR
 -----------------------------
   INLET STREAM:          20
   OUTLET STREAM:         21
```

```
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                   ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          20000.0         20000.0
0.00000
       MASS(KG/HR   )          577008.         577008.
0.00000
       ENTHALPY(CAL/SEC )      540896.        0.838806E+07   -
0.935516

                   ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR
```

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                             U-O-S BLOCK SECTION

 BLOCK:  C-101    MODEL: COMPR (CONTINUED)

                          ***  INPUT DATA  ***

   ISENTROPIC CENTRIFUGAL COMPRESSOR
    OUTLET PRESSURE  BAR
20.0000
    ISENTROPIC EFFICIENCY
0.75000
    MECHANICAL EFFICIENCY
1.00000

                          ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW                32,854.5
    BRAKE      HORSEPOWER REQUIREMENT  KW                32,854.5
    NET WORK REQUIRED                  KW                32,854.5
    POWER LOSSES                       KW                     0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW                24,640.9
    CALCULATED OUTLET TEMP  C
240.355
    ISENTROPIC TEMPERATURE  C
191.243
    EFFICIENCY (POLYTR/ISENTR) USED
0.75000
    OUTLET VAPOR FRACTION
1.00000
    HEAD DEVELOPED,       M-KGF/KG                       15,676.8
    MECHANICAL EFFICIENCY USED
1.00000
    INLET HEAT CAPACITY RATIO
1.40586
    INLET VOLUMETRIC FLOW RATE , L/MIN                 1,736,390.
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                   714,827.
    INLET  COMPRESSIBILITY FACTOR
0.99836
    OUTLET COMPRESSIBILITY FACTOR
1.00457
    AV. ISENT. VOL. EXPONENT
1.40388
    AV. ISENT. TEMP EXPONENT
1.39633
    AV. ACTUAL VOL. EXPONENT
1.56424
    AV. ACTUAL TEMP EXPONENT
1.55339
```

```
                    ***  ASSOCIATED  UTILITIES  ***

 UTILITY ID FOR ELECTRICITY                      ELECT
 RATE OF CONSUMPTION                         3.2854+04  KW
 COST                                        2214.3929  $/HR

BLOCK:  C-102    MODEL: COMPR
-----------------------------
  INLET STREAM:          24
  OUTLET STREAM:         25
  PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG
```

```
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                             U-O-S BLOCK SECTION

 BLOCK:  C-102    MODEL: COMPR (CONTINUED)

                       ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           20282.8         20282.8
0.00000
       MASS(KG/HR   )           585064.         585064.        -
0.198979E-15
       ENTHALPY(CAL/SEC )      0.249666E+07   -0.907095E+07
1.27524

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             3597.37      KG/HR
    PRODUCT STREAMS CO2E          3597.37      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                            ***  INPUT DATA  ***

   ISENTROPIC TURBINE
    OUTLET PRESSURE  BAR
2.50000
    ISENTROPIC EFFICIENCY
1.00000
    MECHANICAL EFFICIENCY
1.00000

                            ***  RESULTS  ***

    INDICATED  HORSEPOWER REQUIREMENT  KW             -48,431.3
    BRAKE      HORSEPOWER REQUIREMENT  KW             -48,431.3
    NET WORK REQUIRED                  KW             -48,431.3
    POWER LOSSES                       KW                   0.0
    ISENTROPIC HORSEPOWER REQUIREMENT  KW             -48,431.3
    CALCULATED OUTLET TEMP  C
95.0250
    ISENTROPIC TEMPERATURE  C
95.0250
    EFFICIENCY (POLYTR/ISENTR) USED
1.00000
    OUTLET VAPOR FRACTION
1.00000
    HEAD DEVELOPED,       M-KGF/KG                    -30,388.1
```

```
    MECHANICAL EFFICIENCY USED
1.00000
    INLET HEAT CAPACITY RATIO
1.36100
    INLET VOLUMETRIC FLOW RATE , L/MIN                  915,277.
    OUTLET VOLUMETRIC FLOW RATE, L/MIN                4,137,610.
    INLET  COMPRESSIBILITY FACTOR
1.00485
    OUTLET COMPRESSIBILITY FACTOR
0.99961
    AV. ISENT. VOL. EXPONENT
1.37835
    AV. ISENT. TEMP EXPONENT
1.37359
    AV. ACTUAL VOL. EXPONENT
1.37835
    AV. ACTUAL TEMP EXPONENT
1.37359
```

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                              U-O-S BLOCK SECTION

 BLOCK:  C-102    MODEL: COMPR (CONTINUED)

                       ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                ELECT
  RATE OF CONSUMPTION                   4.8431+04  KW
  COST                                  3264.2670  $/HR

 BLOCK:  E-100    MODEL: HEATER
 ------------------------------
   INLET STREAM:          2
   OUTLET STREAM:         3
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          173.160         173.160
0.00000
       MASS(KG/HR   )          10059.8         10059.8
0.00000
       ENTHALPY(CAL/SEC )    -0.168686E+07   -0.127803E+07   -
0.242361

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE                C
154.000
   PRESSURE DROP                        BAR
0.0100000
   MAXIMUM NO. ITERATIONS
30
   CONVERGENCE TOLERANCE
0.000100000
```

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U-O-S BLOCK SECTION

BLOCK: E-100 MODEL: HEATER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE C
154.00
OUTLET PRESSURE BAR
3.3800
HEAT DUTY CAL/SEC
0.40883E+06
OUTLET VAPOR FRACTION
1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
C3	0.50000E-02	0.33044E-02	0.50000E-02	9.6545
IC4	0.16300	0.15708	0.16300	6.6212
2-ME-C3	0.50000E-02	0.44248E-02	0.50000E-02	7.2100
1-C4	0.20000E-02	0.18510E-02	0.20000E-02	6.8940
N-BUTANE	0.81300	0.81950	0.81300	6.3299
T2-C4	0.50000E-02	0.45218E-02	0.50000E-02	7.0553
C2-C4	0.20000E-02	0.17885E-02	0.20000E-02	7.1351
C5	0.50000E-02	0.75335E-02	0.50000E-02	4.2348

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR STEAM	LPS	
RATE OF CONSUMPTION	2956.2920	KG/HR
COST	12.5090	$/HR

BLOCK: E-101 MODEL: HEATER

INLET STREAM: 3
OUTLET STREAM: 4
PROPERTY OPTION SET: UNIQ-RK UNIQUAC / REDLICH-KWONG

```
                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            173.160         173.160
0.00000
       MASS(KG/HR   )            10059.8         10059.8
0.00000
       ENTHALPY(CAL/SEC )      -0.127803E+07   -0.123915E+07   -
0.304210E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR
```

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U-O-S BLOCK SECTION

BLOCK: E-101 MODEL: HEATER (CONTINUED)

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE C
179.000
PRESSURE DROP BAR
0.0100000
MAXIMUM NO. ITERATIONS
30
CONVERGENCE TOLERANCE
0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C
179.00
OUTLET PRESSURE BAR
3.3700
HEAT DUTY CAL/SEC
38879.
OUTLET VAPOR FRACTION
1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
C3	0.50000E-02	0.32895E-02	0.50000E-02	11.077
IC4	0.16300	0.15411	0.16300	7.7084
2-ME-C3	0.50000E-02	0.43773E-02	0.50000E-02	8.3245
1-C4	0.20000E-02	0.18340E-02	0.20000E-02	7.9475
N-BUTANE	0.81300	0.82350	0.81300	7.1948
T2-C4	0.50000E-02	0.46036E-02	0.50000E-02	7.9153
C2-C4	0.20000E-02	0.18382E-02	0.20000E-02	7.9290
C5	0.50000E-02	0.64541E-02	0.50000E-02	5.6458

```
                    ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR STEAM                          MPS
  RATE OF CONSUMPTION                      293.2964  KG/HR
  COST                                    3.8910+08  $/HR

 BLOCK:  E-102    MODEL: HEATER
 ------------------------------
   INLET STREAM:          4
   OUTLET STREAM:         5
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           173.160         173.160
0.00000
       MASS(KG/HR   )           10059.8         10059.8
0.00000
       ENTHALPY(CAL/SEC )     -0.123915E+07   -0.111779E+07   -
0.979347E-01
```

U-O-S BLOCK SECTION

BLOCK: E-102 MODEL: HEATER (CONTINUED)

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	KG/HR
PRODUCT STREAMS CO2E	0.00000	KG/HR
NET STREAMS CO2E PRODUCTION	0.00000	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	0.00000	KG/HR

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE C
251.000
PRESSURE DROP BAR
0.0100000
MAXIMUM NO. ITERATIONS
30
CONVERGENCE TOLERANCE
0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C
251.00
OUTLET PRESSURE BAR
3.3600
HEAT DUTY CAL/SEC
0.12136E+06
OUTLET VAPOR FRACTION
1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
C3	0.50000E-02	0.36064E-02	0.50000E-02	14.461
IC4	0.16300	0.15887	0.16300	10.702
2-ME-C3	0.50000E-02	0.44619E-02	0.50000E-02	11.688
1-C4	0.20000E-02	0.18561E-02	0.20000E-02	11.239

```
     N-BUTANE         0.81300        0.81853        0.81300
10.360
     T2-C4            0.50000E-02    0.45703E-02    0.50000E-02
11.411
     C2-C4            0.20000E-02    0.18020E-02    0.20000E-02
11.577
     C5               0.50000E-02    0.63040E-02    0.50000E-02
8.2728

                       ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR STEAM                             HPS
  RATE OF CONSUMPTION                        1077.6498  KG/HR
  COST                                       2.4727+09  $/HR

 BLOCK:  E-103    MODEL: HEATER
 ------------------------------
   INLET STREAM:           5
   OUTLET STREAM:          6
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG
```

```
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                              U-O-S BLOCK SECTION

 BLOCK:  E-103    MODEL: HEATER (CONTINUED)

                      ***  MASS AND ENERGY BALANCE  ***
                                     IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           173.160         173.160
0.00000
       MASS(KG/HR   )           10059.8         10059.8
0.00000
       ENTHALPY(CAL/SEC )      -0.111779E+07   -0.103130E+07   -
0.773767E-01

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
    PRODUCT STREAMS CO2E           0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION    0.00000      KG/HR
    UTILITIES CO2E PRODUCTION      0.00000      KG/HR
    TOTAL CO2E PRODUCTION          0.00000      KG/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE                C
298.150
   PRESSURE DROP                        BAR
0.0100000
   MAXIMUM NO. ITERATIONS
30
   CONVERGENCE TOLERANCE
0.000100000



                           ***  RESULTS  ***
   OUTLET TEMPERATURE    C
298.15
   OUTLET PRESSURE       BAR
3.3500
   HEAT DUTY             CAL/SEC
86491.
   OUTLET VAPOR FRACTION
1.0000
   PRESSURE-DROP CORRELATION PARAMETER
555.86
```

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
C3	0.50000E-02	0.38430E-02	0.50000E-02	15.801
IC4	0.16300	0.16306	0.16300	12.140
2-ME-C3	0.50000E-02	0.45551E-02	0.50000E-02	13.330
1-C4	0.20000E-02	0.18809E-02	0.20000E-02	12.914
N-BUTANE	0.81300	0.81433	0.81300	12.124
T2-C4	0.50000E-02	0.45832E-02	0.50000E-02	13.249
C2-C4	0.20000E-02	0.17734E-02	0.20000E-02	13.696
C5	0.50000E-02	0.59664E-02	0.50000E-02	10.177

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR GENERAL	DOWA-H	
RATE OF CONSUMPTION	1.0289+05	KG/HR
COST	7.3786	$/HR

U-O-S BLOCK SECTION

```
 BLOCK:  E-104    MODEL: HEATER
 ------------------------------
   INLET STREAM:          9
   OUTLET STREAM:         10
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                   ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            141.588         141.588
0.00000
       MASS(KG/HR   )            8239.29         8239.29
0.00000
       ENTHALPY(CAL/SEC )      -0.135153E+07   -0.140611E+07
0.388126E-01

                   ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
    PRODUCT STREAMS CO2E           0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION    0.00000      KG/HR
    UTILITIES CO2E PRODUCTION      0.00000      KG/HR
    TOTAL CO2E PRODUCTION          0.00000      KG/HR

                       ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE              C
1.85000
   PRESSURE DROP                      BAR
0.0100000
   MAXIMUM NO. ITERATIONS
30
   CONVERGENCE TOLERANCE
0.000100000



                        ***  RESULTS  ***
   OUTLET TEMPERATURE    C
1.8500
   OUTLET PRESSURE       BAR
3.9700
   HEAT DUTY             CAL/SEC                                 -
54575.
   OUTLET VAPOR FRACTION
0.0000
```

U-O-S BLOCK SECTION

BLOCK: E-104 MODEL: HEATER (CONTINUED)

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
IC4	0.67347E-08	0.67347E-08	0.99398E-08	0.45515
2-ME-C3	0.38405E-08	0.38405E-08	0.52283E-08	0.41982
1-C4	0.26723E-07	0.26723E-07	0.33638E-07	0.38817
N-BUTANE	0.98538	0.98538	0.99026	0.30991
T2-C4	0.60603E-02	0.60603E-02	0.59727E-02	0.30393
C2-C4	0.24459E-02	0.24459E-02	0.22101E-02	0.27865
C5	0.61149E-02	0.61149E-02	0.15621E-02	0.78780E-01

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR REFRIGERANT	R134A-C	
RATE OF CONSUMPTION	3968.0463	KG/HR
COST	6.9837	$/HR

BLOCK: E-105 MODEL: HEATER

INLET STREAM: 16
OUTLET STREAM: 17
PROPERTY OPTION SET: UNIQ-RK UNIQUAC / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	138.643	138.643	0.00000
MASS(KG/HR)	8056.09	8056.09	0.00000
ENTHALPY(CAL/SEC)	-0.137326E+07	-703153.	-0.487967

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	KG/HR
PRODUCT STREAMS CO2E	0.00000	KG/HR

```
 NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
 UTILITIES CO2E PRODUCTION     0.00000      KG/HR
 TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   TWO    PHASE  TP  FLASH
   SPECIFIED TEMPERATURE               C
375.000
   PRESSURE DROP                       BAR
0.0100000
   MAXIMUM NO. ITERATIONS
30
   CONVERGENCE TOLERANCE
0.000100000
```

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U-O-S BLOCK SECTION

BLOCK: E-105   MODEL: HEATER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE	C	375.00
OUTLET PRESSURE	BAR	19.990
HEAT DUTY	CAL/SEC	0.67010E+06
OUTLET VAPOR FRACTION		1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
IC4	0.68777E-08	0.54825E-08	0.68777E-08	3.2440
2-ME-C3	0.39219E-08	0.30297E-08	0.39219E-08	3.3475
1-C4	0.27286E-07	0.24349E-07	0.27286E-07	2.8979
N-BUTANE	0.99162	0.99271	0.99162	2.5831
T2-C4	0.60800E-02	0.53152E-02	0.60800E-02	2.9580
C2-C4	0.22930E-02	0.19668E-02	0.22930E-02	3.0149
C5	0.80948E-05	0.81546E-05	0.80948E-05	2.5670

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR GENERAL	DOWA-H	
RATE OF CONSUMPTION	7.9717+05	KG/HR
COST	57.1667	$/HR

BLOCK: E-106   MODEL: HEATER

INLET STREAM: 19
OUTLET STREAM: 20
PROPERTY OPTION SET: UNIQ-RK   UNIQUAC / REDLICH-KWONG

*** MASS AND ENERGY BALANCE ***

```
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           20000.0         20000.0
0.00000
       MASS(KG/HR   )           577008.         577008.
0.00000
       ENTHALPY(CAL/SEC )     0.884975E+07     540896.
0.938880

                        ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
    PRODUCT STREAMS CO2E           0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION    0.00000      KG/HR
    UTILITIES CO2E PRODUCTION      0.00000      KG/HR
    TOTAL CO2E PRODUCTION          0.00000      KG/HR
```

U-O-S BLOCK SECTION

BLOCK: E-106 MODEL: HEATER (CONTINUED)

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE C
40.0000
PRESSURE DROP BAR
0.0100000
MAXIMUM NO. ITERATIONS
30
CONVERGENCE TOLERANCE
0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C
40.000
OUTLET PRESSURE BAR
4.9900
HEAT DUTY CAL/SEC -
0.83089E+07
OUTLET VAPOR FRACTION
1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
NITROGEN	0.79000	0.59601	0.79000	126.40
O2	0.21000	0.40399	0.21000	49.568

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR WATER	CW	
RATE OF CONSUMPTION	3.0024+06	KG/HR
COST	47.3388	$/HR

BLOCK: E-107 MODEL: HEATER

INLET STREAM: 21
OUTLET STREAM: 22
PROPERTY OPTION SET: UNIQ-RK UNIQUAC / REDLICH-KWONG

```
                      ***  MASS AND ENERGY BALANCE  ***
                                    IN             OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           20000.0        20000.0
0.00000
       MASS(KG/HR   )           577008.        577008.
0.00000
       ENTHALPY(CAL/SEC )      0.838806E+07   0.138513E+08   -
0.394423

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR
```

U-O-S BLOCK SECTION

BLOCK: E-107 MODEL: HEATER (CONTINUED)

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE C
375.000
PRESSURE DROP BAR
0.0100000
MAXIMUM NO. ITERATIONS
30
CONVERGENCE TOLERANCE
0.000100000

*** RESULTS ***

OUTLET TEMPERATURE C
375.00
OUTLET PRESSURE BAR
19.990
HEAT DUTY CAL/SEC
0.54633E+07
OUTLET VAPOR FRACTION
1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
NITROGEN	0.79000	0.71276	0.79000	571.03
O2	0.21000	0.28724	0.21000	376.66

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR GENERAL DOWA-H
RATE OF CONSUMPTION 6.4992+06 KG/HR
COST 466.0740 $/HR

BLOCK: M-100 MODEL: MIXER

INLET STREAMS: 22 17
OUTLET STREAM: 23
PROPERTY OPTION SET: UNIQ-RK UNIQUAC / REDLICH-KWONG

```
                    ***  MASS AND ENERGY BALANCE  ***
                                  IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           20138.6         20138.6
0.00000
       MASS(KG/HR   )           585064.         585064.
0.00000
       ENTHALPY(CAL/SEC )      0.131482E+08    0.131482E+08
0.929876E-07

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR
```

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                           U-O-S BLOCK SECTION

 BLOCK:  M-100    MODEL: MIXER (CONTINUED)

                       ***  INPUT DATA  ***
   TWO    PHASE      FLASH
   MAXIMUM NO. ITERATIONS                                  30
   CONVERGENCE TOLERANCE
0.000100000
   OUTLET PRESSURE:  MINIMUM OF INLET STREAM PRESSURES

 BLOCK:  P-100    MODEL: PUMP
 ----------------------------
   INLET STREAM:          1
   OUTLET STREAM:         2
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           173.160        173.160
0.00000
       MASS(KG/HR   )           10059.8        10059.8
0.00000
       ENTHALPY(CAL/SEC )      -0.168698E+07   -0.168686E+07   -
0.699370E-04

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                       ***  INPUT DATA  ***
    OUTLET PRESSURE  BAR
3.39000
    PUMP EFFICIENCY
0.75000
    DRIVER EFFICIENCY
0.90000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                           30
    TOLERANCE
0.000100000
```

```
                          ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  L/MIN                                   294.022
    PRESSURE CHANGE  BAR
0.75602
    NPSH AVAILABLE   M-KGF/KG                                       0.0
    FLUID POWER  KW
0.37048
    BRAKE POWER  KW
0.49397
    ELECTRICITY  KW
0.54885
    PUMP EFFICIENCY USED
0.75000
    NET WORK REQUIRED  KW
0.54885
    HEAD DEVELOPED M-KGF/KG
13.5193

                      ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                 ELECT
  RATE OF CONSUMPTION                       0.5489  KW
  COST                                  3.6993-02  $/HR
```

```
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                             U-O-S BLOCK SECTION

 BLOCK:  P-101    MODEL: PUMP
 ----------------------------
   INLET STREAM:           7
   OUTLET STREAM:          8
   PROPERTY OPTION SET:    UNIQ-RK   UNIQUAC / REDLICH-KWONG

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           31.5720         31.5720
0.00000
       MASS(KG/HR   )           1820.47         1820.47       -
0.249797E-15
       ENTHALPY(CAL/SEC )      -315173.        -315102.       -
0.225209E-03

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                          ***  INPUT DATA  ***
    OUTLET PRESSURE  BAR
5.00000
    PUMP EFFICIENCY
0.75000
    DRIVER EFFICIENCY
0.90000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                            30
    TOLERANCE
0.000100000

                           ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  L/MIN
53.4919
    PRESSURE CHANGE  BAR
2.50000
    NPSH AVAILABLE   M-KGF/KG                               0.0
    FLUID POWER  KW
0.22288
```

```
    BRAKE POWER  KW
0.29718
    ELECTRICITY  KW
0.33020
    PUMP EFFICIENCY USED
0.75000
    NET WORK REQUIRED  KW
0.33020
    HEAD DEVELOPED M-KGF/KG
44.9444

                       ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                      ELECT
  RATE OF CONSUMPTION                            0.3302  KW
  COST                                       2.2255-02  $/HR

 BLOCK:  P-102    MODEL: PUMP
 ----------------------------
   INLET STREAM:          12
   OUTLET STREAM:         13
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG
```

U-O-S BLOCK SECTION

BLOCK: P-102   MODEL: PUMP (CONTINUED)

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	2.94480	2.94480	0.00000
MASS(KG/HR)	183.203	183.203	0.00000
ENTHALPY(CAL/SEC)	-30334.7	-30324.8	-0.328697E-03

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	KG/HR
PRODUCT STREAMS CO2E	0.00000	KG/HR
NET STREAMS CO2E PRODUCTION	0.00000	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	0.00000	KG/HR

*** INPUT DATA ***

OUTLET PRESSURE BAR	5.00000
PUMP EFFICIENCY	0.75000
DRIVER EFFICIENCY	0.90000

FLASH SPECIFICATIONS:
LIQUID PHASE CALCULATION
NO FLASH PERFORMED

MAXIMUM NUMBER OF ITERATIONS	30
TOLERANCE	0.000100000

*** RESULTS ***

VOLUMETRIC FLOW RATE L/MIN	5.06357
PRESSURE CHANGE BAR	3.71000
NPSH AVAILABLE M-KGF/KG	0.0
FLUID POWER KW	0.031310
BRAKE POWER KW	0.041746
ELECTRICITY KW	0.046385

```
    PUMP EFFICIENCY USED
0.75000
    NET WORK REQUIRED  KW
0.046385
    HEAD DEVELOPED M-KGF/KG
62.7378

                       ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                 ELECT
  RATE OF CONSUMPTION                    4.6385-02  KW
  COST                                   3.1263-03  $/HR

 BLOCK:  P-103    MODEL: PUMP
 ----------------------------
   INLET STREAM:          14
   OUTLET STREAM:         15
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
```

U-O-S BLOCK SECTION

```
 BLOCK:  P-103    MODEL: PUMP (CONTINUED)
    TOTAL BALANCE
       MOLE(KMOL/HR )            138.643         138.643
0.00000
       MASS(KG/HR   )            8056.09         8056.09       -
0.112895E-15
       ENTHALPY(CAL/SEC )      -0.137579E+07   -0.137504E+07   -
0.543956E-03

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E              0.00000      KG/HR
    PRODUCT STREAMS CO2E           0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION    0.00000      KG/HR
    UTILITIES CO2E PRODUCTION      0.00000      KG/HR
    TOTAL CO2E PRODUCTION          0.00000      KG/HR

                        ***  INPUT DATA  ***
    OUTLET PRESSURE  BAR
5.00000
    DRIVER EFFICIENCY
1.00000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                             30
    TOLERANCE
0.000100000

                         ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  L/MIN                           223.594
    PRESSURE CHANGE  BAR
3.90000
    NPSH AVAILABLE   M-KGF/KG                                0.0
    FLUID POWER  KW
1.45336
    BRAKE POWER  KW
3.13327
    ELECTRICITY  KW
3.13327
    PUMP EFFICIENCY USED
0.46385
    NET WORK REQUIRED  KW
3.13327
    HEAD DEVELOPED M-KGF/KG
66.2265
```

```
                    ***  ASSOCIATED  UTILITIES  ***

 UTILITY ID FOR ELECTRICITY                    ELECT
 RATE OF CONSUMPTION                          3.1333  KW
 COST                                         0.2112  $/HR

BLOCK:  P-104    MODEL: PUMP
----------------------------
  INLET STREAM:          15
  OUTLET STREAM:         16
  PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                   ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )            138.643         138.643
0.00000
       MASS(KG/HR   )            8056.09         8056.09
0.00000
       ENTHALPY(CAL/SEC )      -0.137504E+07   -0.137326E+07   -
0.129569E-02
```

```
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                             U-O-S BLOCK SECTION

 BLOCK:  P-104    MODEL: PUMP (CONTINUED)

                       ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             0.00000      KG/HR
    PRODUCT STREAMS CO2E          0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
    OUTLET PRESSURE  BAR
20.0000
    PUMP EFFICIENCY
0.75000
    DRIVER EFFICIENCY
0.90000

    FLASH SPECIFICATIONS:
    LIQUID PHASE CALCULATION
    NO FLASH PERFORMED
    MAXIMUM NUMBER OF ITERATIONS                           30
    TOLERANCE
0.000100000

                           ***  RESULTS  ***
    VOLUMETRIC FLOW RATE  L/MIN                          223.780
    PRESSURE CHANGE  BAR
15.0000
    NPSH AVAILABLE   M-KGF/KG
65.9639
    FLUID POWER  KW
5.59450
    BRAKE POWER  KW
7.45933
    ELECTRICITY  KW
8.28815
    PUMP EFFICIENCY USED
0.75000
    NET WORK REQUIRED  KW
8.28815
    HEAD DEVELOPED M-KGF/KG                              254.929

                        ***  ASSOCIATED  UTILITIES  ***

  UTILITY ID FOR ELECTRICITY                ELECT
  RATE OF CONSUMPTION                      8.2881  KW
  COST                                     0.5586  $/HR
```

```
 BLOCK:  R-100    MODEL: RPLUG
 -----------------------------
   INLET STREAM:           23
   OUTLET STREAM:          24
   PROPERTY OPTION SET:    UNIQ-RK   UNIQUAC / REDLICH-KWONG

                      ***  MASS AND ENERGY BALANCE  ***
                              IN          OUT       GENERATION
RELATIVE DIFF.
   TOTAL BALANCE
   MOLE(KMOL/HR )         20138.6       20282.8       144.205
0.179362E-15
   MASS(KG/HR   )         585064.       585064.
0.238775E-14
   ENTHALPY(CAL/SEC )    0.131482E+08  0.249666E+07
0.810113

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E               0.00000      KG/HR
    PRODUCT STREAMS CO2E            3597.37      KG/HR
    NET STREAMS CO2E PRODUCTION     3597.37      KG/HR
    UTILITIES CO2E PRODUCTION       0.00000      KG/HR
    TOTAL CO2E PRODUCTION           3597.37      KG/HR
```

U-O-S BLOCK SECTION

BLOCK: R-100 MODEL: RPLUG (CONTINUED)

*** INPUT DATA ***

```
   REACTOR TYPE:
     SPECIFIED TEMPERATURE
     VAPOR FLUID PHASE
   REACTOR TUBE LENGTH                    METER
1.7600
   REACTOR DIAMETER                       METER
0.20000E-01
   REACTOR RISE                           METER
0.0000
   NUMBER OF REACTOR TUBES                                    50000
   REACTOR VOLUME                         L
27646.
   PRESSURE DROP OPTION:
SPECIFIED
   HOLDUP OPTION:                                                 NO-
SLIP
   ERROR TOLERANCE
0.10000E-03
   INTEGRATION METHOD                                             GEAR
   CORRECTOR METHOD
NEWTON
   INITIAL STEP SIZE FACTOR
0.10000E-01
   CORRECTOR TOLERANCE FACTOR
0.10000
   MAXIMUM NUMBER OF STEPS
1000

   TEMPERATURE PROFILES:

     RELATIVE LOCATION          TEMPERATURE
            0.0000              375.00       C


    REACTION PARAGRAPH            ID:  R-1            TYPE:  LHHW
    GLOBAL BASES:
    KBASIS
MOLE-GAMMA
    CBASIS
MOLARITY
    SBASIS
GLOBAL
```

```
    STOICHIOMETRY:

    REACTION NUMBER:          1
      SUBSTREAM:  MIXED
        O2          -3.5000      N-BUTANE   -1.0000      WATER
4.0000      MA(L)       1.0000

    REACTION NUMBER:          2
      SUBSTREAM:  MIXED
        CO           4.0000      O2         -4.5000      N-BUTANE
-1.0000      WATER       5.0000

    REACTION NUMBER:          3
      SUBSTREAM:  MIXED
        O2          -6.5000      CO2         4.0000      N-BUTANE
-1.0000      WATER       5.0000
```

U-O-S BLOCK SECTION

BLOCK: R-100 MODEL: RPLUG (CONTINUED)

REAC-DATA ENTRIES:

REACTION NO	TYPE	PHASE	DELT C	BASIS
1	KINETIC	V	0.0000	PARTIALPRES
2	KINETIC	V	0.0000	PARTIALPRES
3	KINETIC	V	0.0000	PARTIALPRES

REACTION NO	SOLID BASIS	LIQ. PHASE BASIS	SOL. PHASE BASIS
1	GLOBAL	L	S
2	GLOBAL	L	S
3	GLOBAL	L	S

RATE PARAMETERS:

REACTION NO	PREEXP. FACTOR	ACT. ENERGY CAL/MOL	TEMP. EXPONENT	REF. TEMP C
1	0.96600E-04	17230.	0.0000	
2	0.17200E-04	17203.	0.0000	
3	0.22100E-04	17753.	0.0000	

DRIVING FORCE 1 EXPONENTS:

REACTION NUMBER: 1
SUBSTREAM: MIXED
O2 0.50000 N-BUTANE 1.0000

REACTION NUMBER: 2
SUBSTREAM: MIXED
O2 1.0000 N-BUTANE 1.0000

REACTION NUMBER: 3
SUBSTREAM: MIXED
O2 1.0000 N-BUTANE 1.0000

DRIVING FORCE 2 EXPONENTS:

REACTION NUMBER: 1

REACTION NUMBER: 2

REACTION NUMBER: 3

DRIVING FORCE 1 EQUILIBRIUM VALUES:

REACTION NO	A	B	C	D
1	-6.8600	0.0000	0.0000	0.0000
2	-10.078	0.0000	0.0000	0.0000
3	-10.078	0.0000	0.0000	0.0000

U-O-S BLOCK SECTION

BLOCK: R-100   MODEL: RPLUG (CONTINUED)

DRIVING FORCE 2 EQUILIBRIUM VALUES:

REACTION NO	A	B	C	D
1	-0.10000E+35	0.0000	0.0000	0.0000
2	-0.10000E+35	0.0000	0.0000	0.0000
3	-0.10000E+35	0.0000	0.0000	0.0000

ADSORPTION EXPRESSION EXPONENTS:

REACTION NUMBER: 1
SUBSTREAM: MIXED
O2 0.0000
0.50000

REACTION NUMBER: 2
SUBSTREAM: MIXED
O2 0.0000
1.0000

REACTION NUMBER: 3
SUBSTREAM: MIXED
O2 0.0000
1.0000

ADSORPTION EQUILIBRIUM TERMS:
TERM   1

REACTION NO	A	B	C	D
1	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000

TERM   2

REACTION NO	A	B	C	D

```
          1        -6.8600         0.0000          0.0000
0.0000
          2        -10.078         0.0000          0.0000
0.0000
          3        -10.078         0.0000          0.0000
0.0000

    ADSORPTION EXPRESSION GLOBAL EXPONENTS:
      REACTION NO          EXPONENT

            1              1.0000
            2              1.0000
            3              1.0000
```

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U-O-S BLOCK SECTION

BLOCK: R-100 MODEL: RPLUG (CONTINUED)

*** RESULTS ***

REACTOR DUTY	CAL/SEC	-0.10652E+08
RESIDENCE TIME	HR	0.50473E-04
REACTOR MINIMUM TEMPERATURE	C	375.00
REACTOR MAXIMUM TEMPERATURE	C	375.00

*** RESULTS PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH METER	PRESSURE BAR	TEMPERATURE C	VAPOR FRAC	RES-TIME HR
0.0000	20.000	375.00	1.0000	0.0000
0.17600	20.000	375.00	1.0000	0.50649E-05
0.35200	20.000	375.00	1.0000	0.10124E-04
0.52800	20.000	375.00	1.0000	0.15179E-04
0.70400	20.000	375.00	1.0000	0.20230E-04
0.88000	20.000	375.00	1.0000	0.25277E-04
1.0560	20.000	375.00	1.0000	0.30321E-04
1.2320	20.000	375.00	1.0000	0.35362E-04
1.4080	20.000	375.00	1.0000	0.40401E-04
1.5840	20.000	375.00	1.0000	0.45438E-04
1.7600	20.000	375.00	1.0000	0.50473E-04

LENGTH METER	DUTY CAL/SEC	LIQUID HOLDUP
0.0000	0.0000	0.0000
0.17600	-0.18272E+07	0.0000

0.35200	-0.34246E+07	0.0000
0.52800	-0.48186E+07	0.0000
0.70400	-0.60325E+07	0.0000
0.88000	-0.70885E+07	0.0000
1.0560	-0.80083E+07	0.0000
1.2320	-0.88100E+07	0.0000
1.4080	-0.95105E+07	0.0000
1.5840	-0.10122E+08	0.0000
1.7600	-0.10657E+08	0.0000

*** TOTAL MOLE FRACTION PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH METER	NITROGEN	CO	O2	CO2
0.0000	0.78456	0.0000	0.20855	0.0000
0.17600	0.78360	0.82518E-03	0.20456	0.69154E-03
0.35200	0.78276	0.15462E-02	0.20107	0.12958E-02
0.52800	0.78203	0.21752E-02	0.19803	0.18229E-02
0.70400	0.78140	0.27228E-02	0.19539	0.22819E-02
0.88000	0.78085	0.31992E-02	0.19310	0.26810E-02
1.0560	0.78037	0.36141E-02	0.19111	0.30288E-02
1.2320	0.77995	0.39757E-02	0.18937	0.33318E-02
1.4080	0.77958	0.42916E-02	0.18786	0.35965E-02
1.5840	0.77926	0.45675E-02	0.18653	0.38277E-02
1.7600	0.77898	0.48089E-02	0.18538	0.40300E-02

U-O-S BLOCK SECTION

BLOCK: R-100 MODEL: RPLUG (CONTINUED)

*** TOTAL MOLE FRACTION PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH METER	IC4	2-ME-C3	1-C4	N-BUTANE
0.0000	0.47349E-10	0.27000E-10	0.18785E-09	0.68267E-02
0.17600	0.47291E-10	0.26967E-10	0.18762E-09	0.59563E-02
0.35200	0.47240E-10	0.26938E-10	0.18742E-09	0.51975E-02
0.52800	0.47196E-10	0.26913E-10	0.18725E-09	0.45369E-02
0.70400	0.47158E-10	0.26891E-10	0.18709E-09	0.39630E-02
0.88000	0.47125E-10	0.26872E-10	0.18696E-09	0.34647E-02
1.0560	0.47096E-10	0.26856E-10	0.18685E-09	0.30313E-02
1.2320	0.47070E-10	0.26841E-10	0.18675E-09	0.26542E-02
1.4080	0.47048E-10	0.26829E-10	0.18666E-09	0.23251E-02
1.5840	0.47029E-10	0.26818E-10	0.18658E-09	0.20380E-02
1.7600	0.47012E-10	0.26808E-10	0.18652E-09	0.17871E-02

LENGTH METER	T2-C4	C2-C4	C5	WATER
0.0000	0.41857E-04	0.15786E-04	0.55728E-07	0.0000
0.17600	0.41806E-04	0.15767E-04	0.55660E-07	0.38276E-02
0.35200	0.41761E-04	0.15750E-04	0.55600E-07	0.71649E-02
0.52800	0.41722E-04	0.15735E-04	0.55549E-07	0.10071E-01
0.70400	0.41689E-04	0.15723E-04	0.55503E-07	0.12596E-01

0.88000	0.41659E-04	0.15711E-04	0.55464E-07	0.14789E-01
1.0560	0.41633E-04	0.15702E-04	0.55430E-07	0.16696E-01
1.2320	0.41611E-04	0.15693E-04	0.55400E-07	0.18357E-01
1.4080	0.41592E-04	0.15686E-04	0.55374E-07	0.19805E-01
1.5840	0.41575E-04	0.15680E-04	0.55352E-07	0.21069E-01
1.7600	0.41560E-04	0.15674E-04	0.55332E-07	0.22174E-01

LENGTH METER	MA(L)
0.0000	0.0000
0.17600	0.48291E-03
0.35200	0.90311E-03
0.52800	0.12683E-02
0.70400	0.15851E-02
0.88000	0.18597E-02
1.0560	0.20982E-02
1.2320	0.23056E-02
1.4080	0.24863E-02
1.5840	0.26438E-02
1.7600	0.27814E-02

U-O-S BLOCK SECTION

BLOCK: R-100 MODEL: RPLUG (CONTINUED)

*** TOTAL MASS FRACTION PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH METER	NITROGEN	CO	O2	CO2
0.0000	0.75652	0.0000	0.22971	0.0000
0.17600	0.75652	0.79658E-03	0.22558	0.10489E-02
0.35200	0.75652	0.14942E-02	0.22198	0.19675E-02
0.52800	0.75652	0.21040E-02	0.21883	0.27704E-02
0.70400	0.75652	0.26359E-02	0.21609	0.34707E-02
0.88000	0.75652	0.30992E-02	0.21370	0.40808E-02
1.0560	0.75652	0.35033E-02	0.21163	0.46128E-02
1.2320	0.75652	0.38559E-02	0.20982	0.50771E-02
1.4080	0.75652	0.41642E-02	0.20823	0.54831E-02
1.5840	0.75652	0.44337E-02	0.20685	0.58380E-02
1.7600	0.75652	0.46697E-02	0.20564	0.61487E-02

LENGTH METER	IC4	2-ME-C3	1-C4	N-BUTANE
0.0000	0.94730E-10	0.52145E-10	0.36280E-09	0.13658E-01
0.17600	0.94730E-10	0.52145E-10	0.36280E-09	0.11931E-01
0.35200	0.94730E-10	0.52145E-10	0.36280E-09	0.10422E-01
0.52800	0.94730E-10	0.52145E-10	0.36280E-09	0.91063E-02
0.70400	0.94730E-10	0.52145E-10	0.36280E-09	0.79608E-02

0.88000	0.94730E-10	0.52145E-10	0.36280E-09	0.69647E-02
1.0560	0.94730E-10	0.52145E-10	0.36280E-09	0.60973E-02
1.2320	0.94730E-10	0.52145E-10	0.36280E-09	0.53415E-02
1.4080	0.94730E-10	0.52145E-10	0.36280E-09	0.46815E-02
1.5840	0.94730E-10	0.52145E-10	0.36280E-09	0.41052E-02
1.7600	0.94730E-10	0.52145E-10	0.36280E-09	0.36010E-02

LENGTH METER	T2-C4	C2-C4	C5	WATER
0.0000	0.80839E-04	0.30488E-04	0.13840E-06	0.0000
0.17600	0.80839E-04	0.30488E-04	0.13840E-06	0.23764E-02
0.35200	0.80839E-04	0.30488E-04	0.13840E-06	0.44532E-02
0.52800	0.80839E-04	0.30488E-04	0.13840E-06	0.62651E-02
0.70400	0.80839E-04	0.30488E-04	0.13840E-06	0.78426E-02
0.88000	0.80839E-04	0.30488E-04	0.13840E-06	0.92145E-02
1.0560	0.80839E-04	0.30488E-04	0.13840E-06	0.10409E-01
1.2320	0.80839E-04	0.30488E-04	0.13840E-06	0.11450E-01
1.4080	0.80839E-04	0.30488E-04	0.13840E-06	0.12360E-01
1.5840	0.80839E-04	0.30488E-04	0.13840E-06	0.13154E-01
1.7600	0.80839E-04	0.30488E-04	0.13840E-06	0.13849E-01

U-O-S BLOCK SECTION

BLOCK: R-100   MODEL: RPLUG (CONTINUED)

*** TOTAL MASS FRACTION PROFILE (PROCESS SUBSTREAM MIXED) ***

LENGTH METER	MA(L)
0.0000	0.0000
0.17600	0.16320E-02
0.35200	0.30552E-02
0.52800	0.42946E-02
0.70400	0.53717E-02
0.88000	0.63069E-02
1.0560	0.71202E-02
1.2320	0.78279E-02
1.4080	0.84455E-02
1.5840	0.89843E-02
1.7600	0.94552E-02

*** RESULTS PROFILE (PROCESS SUBSTREAM CIPSD) ***

LENGTH METER	PRESSURE BAR	TEMPERATURE C	RES-TIME HR
0.0000	20.000	375.00	0.0000
0.17600	20.000	375.00	0.50649E-05
0.35200	20.000	375.00	0.10124E-04
0.52800	20.000	375.00	0.15179E-04
0.70400	20.000	375.00	0.20230E-04
0.88000	20.000	375.00	0.25277E-04
1.0560	20.000	375.00	0.30321E-04
1.2320	20.000	375.00	0.35362E-04
1.4080	20.000	375.00	0.40401E-04
1.5840	20.000	375.00	0.45438E-04
1.7600	20.000	375.00	0.50473E-04

BLOCK: S-100   MODEL: CYCLONE

INLET STREAM: 27
OUTLET STREAMS: 28   29
PROPERTY OPTION SET: UNIQ-RK   UNIQUAC / REDLICH-KWONG

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                              U-O-S BLOCK SECTION

 BLOCK:  S-100    MODEL: CYCLONE (CONTINUED)

                      ***  MASS AND ENERGY BALANCE  ***
                                   IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          20282.8        20282.8
0.431391E-09
       MASS(KG/HR   )          585064.        585064.
0.146649E-08
       ENTHALPY(CAL/SEC )     -0.112910E+08   -0.112901E+08   -
0.798459E-04

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E             3597.37      KG/HR
    PRODUCT STREAMS CO2E          3597.37      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                          ***  INPUT DATA  ***
   CALCULATION METHOD                                      CYCLONE
MODEL
   DESIGN      MODE
   CYCLONE TYPE: STAIRMAND HIGH THROUGHPUT
   VOID FRACTION                                              0.0
   MAXIMUM NUMBER OF CYCLONES                               100
   PRESSURE DROP CONSTANT
16.0000
   REQUIRED EFFICIENCY
MISSING
   MAXIMUM ALLOWABLE PRESSURE DROP   BAR
0.015000
   MAXIMUM NO. OF FLASH ITERATIONS                           30
   FLASH TOLERANCE
0.000100000
   MAXIMUM NO. OF ITERATIONS                                 30
   CONVERGENCE TOLERANCE
0.000100000
   EFFICIENCY CALCULATED BY MUSCHELKNAUTZ METHOD

                           ***  RESULTS  ***

   TYPE OF CYCLONE (CALC)
STAIRMAND HIGH THROUGHPUT
   NUMBER OF CYCLONES (CALC)
1
```

```
   DIAMETER OF CYLINDER (CALC)   METER
2.47270
   EFFICIENCY OF CYCLONE
0.33657
   NATURAL LENGTH OF GAS VORTEX   METER
MISSING
   PRESSURE DROP                  BAR
0.10001
   LENGTH OF CYLINDER   METER
3.70900
   LENGTH OF CONE   METER
6.18170
   DIAMETER OF GAS OUTLET   METER
1.85450
   LENGTH OF GAS OUTLET   METER
2.16360
   WIDTH OF GAS INLET   METER
0.92730
   HEIGHT OF GAS INLET   METER
1.85450
   DIAMETER OF SOLID OUTLET   METER
0.92730
   NUMBER OF GAS TURNS
MISSING
   RATIO OF INLET TO SALTATION VELOCITY
MISSING
   AXIAL INLET VELOCITY           M/SEC
61.9300
   AXIAL OUTLET GAS VELOCITY      M/SEC
39.4280
   OUTER CIRCUMFERENTIAL VELOCITY M/SEC
37.0058
   INNER CIRCUMFERENTIAL VELOCITY M/SEC
43.3539

   SEPARATION EFFICIENCY FOR SUBSTREAM MIXED

   PARTICLE SIZE        INNER VORTEX EFF     EFFICIENCY
   METER
    0.55000E-05          0.49853E-03          0.20265
    0.65000E-05          0.18476E-01          0.21699
    0.75000E-05          0.53176E-01          0.24467
    0.85000E-05          0.96615E-01          0.27933
    0.95000E-05          0.14398              0.31711
    0.10500E-04          0.19245              0.35578
    0.11500E-04          0.24033              0.39398
    0.12500E-04          0.28666              0.43093
    0.13500E-04          0.33087              0.46620
    0.14500E-04          0.37271              0.49958
```

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                          U-O-S BLOCK SECTION

 BLOCK:  S-101    MODEL: CYCLONE
 -------------------------------
   INLET STREAM:          28
   OUTLET STREAMS:        30          31
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                   ***  MASS AND ENERGY BALANCE  ***
                                IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           20263.9         20263.9
0.00000
       MASS(KG/HR   )           583202.         583202.
0.00000
       ENTHALPY(CAL/SEC )      -0.107016E+08   -0.107007E+08   -
0.841450E-04

                   ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            3597.37      KG/HR
    PRODUCT STREAMS CO2E         3597.37      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                       ***  INPUT DATA  ***
   CALCULATION METHOD                                       CYCLONE
MODEL
   DESIGN      MODE
   CYCLONE TYPE: STAIRMAND HIGH EFFICIENCY
   VOID FRACTION                                              0.0
   MAXIMUM NUMBER OF CYCLONES                               100
   PRESSURE DROP CONSTANT
16.0000
   REQUIRED EFFICIENCY
MISSING
   MAXIMUM ALLOWABLE PRESSURE DROP   BAR
0.015000
   MAXIMUM NO. OF FLASH ITERATIONS                           30
   FLASH TOLERANCE
0.000100000
   MAXIMUM NO. OF ITERATIONS                                 30
   CONVERGENCE TOLERANCE
0.000100000
   EFFICIENCY CALCULATED BY MUSCHELKNAUTZ METHOD

                        ***  RESULTS  ***
```

```
   TYPE OF CYCLONE (CALC)
STAIRMAND HIGH EFFICIENCY
   NUMBER OF CYCLONES (CALC)
1
   DIAMETER OF CYLINDER (CALC)   METER
5.16140
   EFFICIENCY OF CYCLONE
0.74507
   NATURAL LENGTH OF GAS VORTEX   METER
MISSING
   PRESSURE DROP                  BAR
0.099902
   LENGTH OF CYLINDER   METER
7.74210
   LENGTH OF CONE   METER
12.9036
   DIAMETER OF GAS OUTLET   METER
2.58070
   LENGTH OF GAS OUTLET   METER
2.58070
   WIDTH OF GAS INLET   METER
1.03230
   HEIGHT OF GAS INLET   METER
2.58070
   DIAMETER OF SOLID OUTLET   METER
1.93550
   NUMBER OF GAS TURNS
MISSING
   RATIO OF INLET TO SALTATION VELOCITY
MISSING
   AXIAL INLET VELOCITY           M/SEC
43.0537
   AXIAL OUTLET GAS VELOCITY      M/SEC
21.9275
   OUTER CIRCUMFERENTIAL VELOCITY M/SEC
55.2135
   INNER CIRCUMFERENTIAL VELOCITY M/SEC
57.8504

   SEPARATION EFFICIENCY FOR SUBSTREAM MIXED

   PARTICLE SIZE        INNER VORTEX EFF     EFFICIENCY
   METER
    0.55000E-05          0.23317              0.50295
    0.65000E-05          0.33507              0.56900
    0.75000E-05          0.42820              0.62937
    0.85000E-05          0.51082              0.68292
    0.95000E-05          0.58306              0.72974
    0.10500E-04          0.64571              0.77036
    0.11500E-04          0.69981              0.80542
    0.12500E-04          0.74640              0.83562
    0.13500E-04          0.78644              0.86157
```

0.14500E-04	0.82081	0.88385

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                             U-O-S BLOCK SECTION

 BLOCK:  S-102    MODEL: CYCLONE
 -------------------------------
   INLET STREAM:          30
   OUTLET STREAMS:        32          33
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                  ***  MASS AND ENERGY BALANCE  ***
                                IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )          20236.0         20236.0
0.00000
       MASS(KG/HR   )          580468.         580468.       -
0.401109E-15
       ENTHALPY(CAL/SEC )     -0.983636E+07   -0.983545E+07   -
0.917070E-04

                  ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            3597.37      KG/HR
    PRODUCT STREAMS CO2E         3597.37      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                      ***  INPUT DATA  ***
   CALCULATION METHOD                                     CYCLONE
MODEL
   DESIGN      MODE
   CYCLONE TYPE: STAIRMAND HIGH EFFICIENCY
   VOID FRACTION                                            0.0
   MAXIMUM NUMBER OF CYCLONES                             100
   PRESSURE DROP CONSTANT
16.0000
   REQUIRED EFFICIENCY
MISSING
   MAXIMUM ALLOWABLE PRESSURE DROP   BAR
0.015000
   MAXIMUM NO. OF FLASH ITERATIONS                         30
   FLASH TOLERANCE
0.000100000
   MAXIMUM NO. OF ITERATIONS                               30
   CONVERGENCE TOLERANCE
0.000100000
   EFFICIENCY CALCULATED BY MUSCHELKNAUTZ METHOD

                       ***  RESULTS  ***
```

```
   TYPE OF CYCLONE (CALC)
STAIRMAND HIGH EFFICIENCY
   NUMBER OF CYCLONES (CALC)
1
   DIAMETER OF CYLINDER (CALC)   METER
5.30230
   EFFICIENCY OF CYCLONE
0.73464
   NATURAL LENGTH OF GAS VORTEX   METER
MISSING
   PRESSURE DROP                  BAR
0.10006
   LENGTH OF CYLINDER   METER
7.95350
   LENGTH OF CONE   METER
13.2558
   DIAMETER OF GAS OUTLET   METER
2.65120
   LENGTH OF GAS OUTLET   METER
2.65120
   WIDTH OF GAS INLET   METER
1.06050
   HEIGHT OF GAS INLET   METER
2.65120
   DIAMETER OF SOLID OUTLET   METER
1.98840
   NUMBER OF GAS TURNS
MISSING
   RATIO OF INLET TO SALTATION VELOCITY
MISSING
   AXIAL INLET VELOCITY           M/SEC
44.1923
   AXIAL OUTLET GAS VELOCITY      M/SEC
22.5074
   OUTER CIRCUMFERENTIAL VELOCITY M/SEC
56.8530
   INNER CIRCUMFERENTIAL VELOCITY M/SEC
61.4714

   SEPARATION EFFICIENCY FOR SUBSTREAM MIXED

   PARTICLE SIZE        INNER VORTEX EFF     EFFICIENCY
   METER
    0.55000E-05          0.25406              0.48075
    0.65000E-05          0.35819              0.55324
    0.75000E-05          0.45227              0.61872
    0.85000E-05          0.53499              0.67631
    0.95000E-05          0.60677              0.72627
    0.10500E-04          0.66860              0.76931
    0.11500E-04          0.72163              0.80623
    0.12500E-04          0.76700              0.83781
    0.13500E-04          0.80575              0.86478
```

0.14500E-04	0.83879	0.88778

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                         U-O-S BLOCK SECTION

 BLOCK:  S-103    MODEL: CYCLONE
 -------------------------------
   INLET STREAM:          32
   OUTLET STREAMS:        34          35
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                    ***  MASS AND ENERGY BALANCE  ***
                                 IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           20229.0         20229.0
0.00000
       MASS(KG/HR   )           579780.         579780.
0.00000
       ENTHALPY(CAL/SEC )      -0.961819E+07   -0.961729E+07   -
0.937623E-04

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            3597.37      KG/HR
    PRODUCT STREAMS CO2E         3597.37      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR

                        ***  INPUT DATA  ***
   CALCULATION METHOD                                         CYCLONE
MODEL
   DESIGN      MODE
   CYCLONE TYPE: STAIRMAND HIGH EFFICIENCY
   VOID FRACTION                                                0.0
   MAXIMUM NUMBER OF CYCLONES                                 100
   PRESSURE DROP CONSTANT
16.0000
   REQUIRED EFFICIENCY
MISSING
   MAXIMUM ALLOWABLE PRESSURE DROP   BAR
0.015000
   MAXIMUM NO. OF FLASH ITERATIONS                             30
   FLASH TOLERANCE
0.000100000
   MAXIMUM NO. OF ITERATIONS                                   30
   CONVERGENCE TOLERANCE
0.000100000
   EFFICIENCY CALCULATED BY MUSCHELKNAUTZ METHOD

                         ***  RESULTS  ***
```

```
   TYPE OF CYCLONE (CALC)
STAIRMAND HIGH EFFICIENCY
   NUMBER OF CYCLONES (CALC)
1
   DIAMETER OF CYLINDER (CALC)   METER
5.43890
   EFFICIENCY OF CYCLONE
0.72969
   NATURAL LENGTH OF GAS VORTEX   METER
MISSING
   PRESSURE DROP                  BAR
0.10001
   LENGTH OF CYLINDER   METER
8.15830
   LENGTH OF CONE   METER
13.5973
   DIAMETER OF GAS OUTLET   METER
2.71940
   LENGTH OF GAS OUTLET   METER
2.71940
   WIDTH OF GAS INLET   METER
1.08780
   HEIGHT OF GAS INLET   METER
2.71940
   DIAMETER OF SOLID OUTLET   METER
2.03960
   NUMBER OF GAS TURNS
MISSING
   RATIO OF INLET TO SALTATION VELOCITY
MISSING
   AXIAL INLET VELOCITY           M/SEC
45.8253
   AXIAL OUTLET GAS VELOCITY      M/SEC
23.3395
   OUTER CIRCUMFERENTIAL VELOCITY M/SEC
59.0010
   INNER CIRCUMFERENTIAL VELOCITY M/SEC
64.8457

   SEPARATION EFFICIENCY FOR SUBSTREAM MIXED

   PARTICLE SIZE        INNER VORTEX EFF     EFFICIENCY
   METER
    0.55000E-05          0.26835              0.47593
    0.65000E-05          0.37388              0.55152
    0.75000E-05          0.46852              0.61931
    0.85000E-05          0.55125              0.67857
    0.95000E-05          0.62267              0.72973
    0.10500E-04          0.68390              0.77358
    0.11500E-04          0.73618              0.81103
    0.12500E-04          0.78071              0.84293
    0.13500E-04          0.81856              0.87004
```

0.14500E-04	0.85068	0.89304

```
 ASPEN PLUS   PLAT: WINDOWS   VER: 36.0
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                              U-O-S BLOCK SECTION

 BLOCK:  T-100    MODEL: RADFRAC
 -------------------------------
    INLETS   - 6        STAGE  87
    OUTLETS  - 7        STAGE   1
               9        STAGE 150
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                      ***  MASS AND ENERGY BALANCE  ***
                                    IN              OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           173.160         173.160
0.164136E-15
       MASS(KG/HR   )           10059.8         10059.8       -
0.278967E-11
       ENTHALPY(CAL/SEC )      -0.103130E+07   -0.166671E+07
0.381233

                      ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION  0.00000      KG/HR
    UTILITIES CO2E PRODUCTION    0.00000      KG/HR
    TOTAL CO2E PRODUCTION        0.00000      KG/HR


                         **********************
                         ****  INPUT DATA  ****
                         **********************

   ****   INPUT PARAMETERS   ****

    NUMBER OF STAGES                                          150
    ALGORITHM OPTION
STANDARD
    ABSORBER OPTION                                          NO
    INITIALIZATION OPTION
STANDARD
    HYDRAULIC PARAMETER CALCULATIONS                         NO
    INSIDE LOOP CONVERGENCE METHOD                           BROYDEN
    DESIGN SPECIFICATION METHOD                              NESTED
    MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS                     25
    MAXIMUM NO. OF INSIDE LOOP ITERATIONS                      10
    MAXIMUM NUMBER OF FLASH ITERATIONS                         30
    FLASH TOLERANCE
0.000100000
```

```
    OUTSIDE LOOP CONVERGENCE TOLERANCE
0.000100000
```

U-O-S BLOCK SECTION

BLOCK: T-100   MODEL: RADFRAC (CONTINUED)

****   COL-SPECS   ****

MOLAR VAPOR DIST / TOTAL DIST 0.0
MOLAR REFLUX RATIO
80.0000
MOLAR BOTTOMS RATE KMOL/HR
141.588

****   PROFILES   ****

P-SPEC STAGE 1 PRES, BAR
2.50000

****
**** RESULTS ****
****

***   COMPONENT SPLIT FRACTIONS   ***

	OUTLET STREAMS	
	7	9
COMPONENT:		
C3	1.0000	0.0000
IC4	1.0000	.33784E-07
2-ME-C3	1.0000	.62806E-06
1-C4	.99999	.10925E-04
N-BUTANE	.89592E-02	.99104
T2-C4	.89312E-02	.99107
C2-C4	.13348E-04	.99999
C5	0.0000	1.0000

***   SUMMARY OF KEY RESULTS   ***

TOP STAGE TEMPERATURE	C	12.8929
BOTTOM STAGE TEMPERATURE	C	41.9147
TOP STAGE LIQUID FLOW	KMOL/HR	2,525.76
BOTTOM STAGE LIQUID FLOW	KMOL/HR	141.588
TOP STAGE VAPOR FLOW	KMOL/HR	0.0
BOILUP VAPOR FLOW	KMOL/HR	2,070.15

```
    MOLAR REFLUX RATIO
80.0000
    MOLAR BOILUP RATIO
14.6210
    CONDENSER DUTY (W/O SUBCOOL)   CAL/SEC          -3,383,530.
    REBOILER DUTY                  CAL/SEC           2,748,130.

   ****   MAXIMUM FINAL RELATIVE ERRORS   ****

    DEW POINT                        0.26458E-04  STAGE= 37
    BUBBLE POINT                     0.25345E-04  STAGE= 37
    COMPONENT MASS BALANCE           0.28117E-05  STAGE= 86
COMP=C3
    ENERGY BALANCE                   0.43378E-04  STAGE= 24
```

U-O-S BLOCK SECTION

BLOCK: T-100   MODEL: RADFRAC (CONTINUED)

****   PROFILES   ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

```
                                          ENTHALPY
 STAGE TEMPERATURE   PRESSURE             CAL/MOL             HEAT
DUTY
       C             BAR             LIQUID       VAPOR
CAL/SEC

   1   12.893        2.5000       -35938.      -31050.       -
.33835+07
   2   13.930        2.5000       -35916.      -31175.
   3   14.656        2.5100       -35826.      -31149.
  85   34.971        3.3300       -34551.      -29704.
  86   35.085        3.3400       -34550.      -29702.
  87   35.290        3.3500       -34535.      -29684.
 149   41.728        3.9700       -34344.      -29559.
 150   41.915        3.9800       -34364.      -29564.
.27481+07

 STAGE     FLOW RATE                  FEED RATE
PRODUCT RATE
            KMOL/HR                    KMOL/HR
KMOL/HR
       LIQUID     VAPOR       LIQUID    VAPOR    MIXED
LIQUID    VAPOR
   1  2557.      0.000
31.5720
   2  2524.      2557.
   3  2521.      2555.
  85  2471.      2502.
  86  2169.      2503.                 173.1600
  87  2170.      2028.
 149  2212.      2071.
 150  141.6      2070.
141.5880
```

**** MASS FLOW PROFILES ****

```
 STAGE     FLOW RATE                  FEED RATE
PRODUCT RATE
```

```
            KG/HR                          KG/HR
KG/HR
       LIQUID     VAPOR       LIQUID    VAPOR    MIXED
LIQUID    VAPOR
   1 0.1475E+06  0.000
1820.4684
   2 0.1461E+06 0.1475E+06
   3 0.1461E+06 0.1479E+06
  85 0.1436E+06 0.1454E+06
  86 0.1261E+06 0.1454E+06            .10060+05
  87 0.1261E+06 0.1178E+06
 149 0.1286E+06 0.1204E+06
 150  8239.     0.1204E+06
8239.2925
```

U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

**** MOLE-X-PROFILE ****

STAGE	C3	IC4	2-ME-C3	1-C4	N-BUTANE
1	0.27423E-01	0.89399	0.27423E-01	0.10969E-01	0.39949E-01
2	0.10925E-01	0.88978	0.29434E-01	0.11956E-01	0.57545E-01
3	0.43779E-02	0.87028	0.30998E-01	0.12882E-01	0.80955E-01
85	0.16982E-03	0.31102E-01	0.11512E-02	0.58661E-03	0.95709
86	0.16998E-03	0.31117E-01	0.11515E-02	0.58643E-03	0.95670
87	0.60095E-04	0.24617E-01	0.95436E-03	0.51063E-03	0.96344
149	0.15621E-31	0.89235E-08	0.48951E-08	0.32880E-07	0.98892
150	0.55978E-32	0.67347E-08	0.38405E-08	0.26723E-07	0.98538

**** MOLE-X-PROFILE ****

STAGE	T2-C4	C2-C4	C5
1	0.24492E-03	0.14642E-06	0.18726E-47
2	0.35601E-03	0.23372E-06	0.10093E-46
3	0.50895E-03	0.36662E-06	0.52999E-46
85	0.82532E-02	0.14518E-02	0.19325E-03
86	0.81690E-02	0.15258E-02	0.57930E-03
87	0.82929E-02	0.15472E-02	0.58072E-03
149	0.62288E-02	0.23908E-02	0.24584E-02
150	0.60603E-02	0.24459E-02	0.61149E-02

**** MOLE-Y-PROFILE ****

STAGE	C3	IC4	2-ME-C3	1-C4	N-BUTANE
1	0.67223E-01	0.87125	0.24749E-01	0.98048E-02	0.26807E-01
2	0.27423E-01	0.89399	0.27423E-01	0.10969E-01	0.39949E-01
3	0.11128E-01	0.88984	0.29409E-01	0.11944E-01	0.57328E-01
85	0.51353E-03	0.41972E-01	0.14824E-02	0.71765E-03	0.94565
86	0.51359E-03	0.41986E-01	0.14826E-02	0.71757E-03	0.94552

87	0.18184E-03	0.33290E-01	0.12319E-02	0.62737E-03	0.95470
149	0.45533E-31	0.12021E-07	0.63285E-08	0.40886E-07	0.99039
150	0.16307E-31	0.90732E-08	0.49672E-08	0.33301E-07	0.98916

**** MOLE-Y-PROFILE ****

STAGE	T2-C4	C2-C4	C5
1	0.16378E-03	0.89124E-07	0.33546E-48
2	0.24492E-03	0.14642E-06	0.18726E-47
3	0.35464E-03	0.23264E-06	0.99918E-47
85	0.82331E-02	0.13634E-02	0.63572E-04
86	0.81522E-02	0.14335E-02	0.19082E-03
87	0.83163E-02	0.14615E-02	0.19278E-03
149	0.63979E-02	0.23271E-02	0.88405E-03
150	0.62403E-02	0.23870E-02	0.22083E-02

**** K-VALUES ****

STAGE	C3	IC4	2-ME-C3	1-C4	N-BUTANE
1	2.4513	0.97457	0.90247	0.89385	0.67103
2	2.5102	1.0047	0.93168	0.91745	0.69422
3	2.5419	1.0225	0.94875	0.92719	0.70814
85	3.0239	1.3495	1.2877	1.2234	0.98805
86	3.0216	1.3493	1.2876	1.2236	0.98832
87	3.0259	1.3523	1.2908	1.2286	0.99093
149	2.9149	1.3471	1.2928	1.2435	1.0015
150	2.9131	1.3472	1.2934	1.2462	1.0038

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                              U-O-S BLOCK SECTION

 BLOCK:  T-100    MODEL: RADFRAC (CONTINUED)

                         ****   K-VALUES           ****
   STAGE     T2-C4         C2-C4         C5
      1    0.66873       0.60870       0.17914
      2    0.68795       0.62646       0.18553
      3    0.69681       0.63456       0.18853
     85    0.99756       0.93909       0.32896
     86    0.99794       0.93953       0.32939
     87     1.0028       0.94460       0.33196
    149     1.0272       0.97336       0.35960
    150     1.0297       0.97592       0.36114

                         ****   MASS-X-PROFILE     ****
   STAGE     C3            IC4           2-ME-C3       1-C4
N-BUTANE
      1    0.20972E-01   0.90116       0.26684E-01   0.10674E-01
0.40269E-01
      2    0.83221E-02   0.89343       0.28530E-01   0.11589E-01
0.57781E-01
      3    0.33300E-02   0.87254       0.30001E-01   0.12467E-01
0.81165E-01
     85    0.12889E-03   0.31114E-01   0.11117E-02   0.56649E-03
0.95747
     86    0.12899E-03   0.31127E-01   0.11119E-02   0.56626E-03
0.95699
     87    0.45604E-04   0.24624E-01   0.92150E-03   0.49305E-03
0.96369
    149    0.11848E-31   0.89209E-08   0.47239E-08   0.31731E-07
0.98863
    150    0.42419E-32   0.67268E-08   0.37030E-08   0.25766E-07
0.98422

                         ****   MASS-X-PROFILE     ****
   STAGE     T2-C4         C2-C4         C5
      1    0.23832E-03   0.14247E-06   0.23431E-47
      2    0.34507E-03   0.22654E-06   0.12581E-46
      3    0.49258E-03   0.35483E-06   0.65961E-46
     85    0.79700E-02   0.14020E-02   0.23999E-03
     86    0.78880E-02   0.14733E-02   0.71931E-03
     87    0.80075E-02   0.14940E-02   0.72106E-03
    149    0.60110E-02   0.23072E-02   0.30508E-02
    150    0.58432E-02   0.23583E-02   0.75817E-02

                         ****   MASS-Y-PROFILE     ****
   STAGE     C3            IC4           2-ME-C3       1-C4
N-BUTANE
```

1	0.51904E-01	0.88671	0.24314E-01	0.96326E-02	0.27282E-01
2	0.20972E-01	0.90116	0.26684E-01	0.10674E-01	0.40269E-01
3	0.84778E-02	0.89353	0.28507E-01	0.11577E-01	0.57565E-01
85	0.38980E-03	0.41994E-01	0.14317E-02	0.69312E-03	0.94614
86	0.38984E-03	0.42006E-01	0.14319E-02	0.69302E-03	0.94598
87	0.13801E-03	0.33303E-01	0.11896E-02	0.60586E-03	0.95508
149	0.34548E-31	0.12022E-07	0.61096E-08	0.39472E-07	0.99048
150	0.12368E-31	0.90711E-08	0.47938E-08	0.32139E-07	0.98893

**** MASS-Y-PROFILE ****

STAGE	T2-C4	C2-C4	C5
1	0.16091E-03	0.87559E-07	0.42380E-48
2	0.23832E-03	0.14247E-06	0.23431E-47
3	0.34376E-03	0.22551E-06	0.12455E-46
85	0.79516E-02	0.13168E-02	0.78955E-04
86	0.78732E-02	0.13845E-02	0.23698E-03
87	0.80310E-02	0.14114E-02	0.23940E-03
149	0.61766E-02	0.22466E-02	0.10975E-02
150	0.60225E-02	0.23037E-02	0.27406E-02

U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

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*******************************
***** HYDRAULIC PARAMETERS *****
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*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

	TEMPERATURE C	
STAGE	LIQUID FROM	VAPOR TO
1	12.893	13.930
2	13.930	14.656
3	14.656	15.260
85	34.971	35.085
86	35.085	61.386
87	35.290	35.471
149	41.728	41.915
150	41.915	41.915

	MASS FLOW KG/HR		VOLUME FLOW L/MIN		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	0.14746E+06	0.14746E+06	4332.8	0.38041E+06	57.661	57.661
2	0.14610E+06	0.14792E+06	4293.2	0.37945E+06	57.886	57.883

3	0.14615E+06	0.14797E+06	4294.8	0.37824E+06	57.973	57.969
85	0.14359E+06	0.14541E+06	4265.1	0.29503E+06	58.101	58.095
86	0.12606E+06	0.12788E+06	3745.0	0.28668E+06	58.106	58.100
87	0.12608E+06	0.11784E+06	3746.4	0.23785E+06	58.108	58.102
149	0.12859E+06	0.12035E+06	3872.0	0.20686E+06	58.141	58.137
150	8239.3	0.0000	248.10	0.0000	58.192	

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U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

	DENSITY GM/CC		VISCOSITY CP		SURFACE TENSION DYNE/CM
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM
1	0.56721	0.64604E-02	0.18741	0.74442E-02	11.368
2	0.56715	0.64970E-02	0.18722	0.74532E-02	11.338
3	0.56716	0.65200E-02	0.18641	0.74654E-02	11.326
85	0.56111	0.82146E-02	0.14544	0.79694E-02	10.741
86	0.56099	0.74343E-02	0.14531	0.85782E-02	10.730
87	0.56089	0.82574E-02	0.14496	0.79790E-02	10.721
149	0.55351	0.96968E-02	0.13681	0.81657E-02	10.058
150	0.55349		0.13677		10.050

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR L/MIN	REDUCED F-FACTOR (GM-L)**.5/MIN
1		0.10672	40832.	0.96691E+06
2	-.29880E-01	0.10571	40847.	0.96718E+06
3	-.11946E-01	0.10590	40790.	0.96582E+06
85	-.11598E-01	0.11948	35961.	0.84558E+06
86	-.11375E-01	0.11348	33223.	0.78166E+06
87	-.92150E-02	0.12982	29074.	0.68348E+06
149	-.92814E-02	0.14142	27623.	0.64415E+06
150	-.74897E-02		0.0000	0.0000

```
                 ************************************
                 ***** TRAY SIZING CALCULATIONS *****
                 ************************************


    *******************
    *** SECTION   1 ***
    *******************

    STARTING STAGE NUMBER
2
    ENDING STAGE NUMBER
86
    FLOODING CALCULATION METHOD
GLITSCH6

    DESIGN PARAMETERS
    -----------------
    PEAK CAPACITY FACTOR
1.00000
    SYSTEM FOAMING FACTOR
1.00000
    FLOODING FACTOR
0.80000
    MINIMUM COLUMN DIAMETER         METER
0.30480
    MINIMUM DC AREA/COLUMN AREA
0.100000
    HOLE AREA/ACTIVE AREA
0.100000
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                             U-O-S BLOCK SECTION

 BLOCK:  T-100    MODEL: RADFRAC (CONTINUED)

    TRAY SPECIFICATIONS
    -------------------
    TRAY TYPE
SIEVE
    NUMBER OF PASSES
1
    TRAY SPACING                      METER
0.60960


            ***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER
*****

    STAGE WITH MAXIMUM DIAMETER
2
    COLUMN DIAMETER                   METER
3.65640
    DC AREA/COLUMN AREA
0.100000
    DOWNCOMER VELOCITY                M/SEC
0.068146
    FLOW PATH LENGTH                  METER
2.51212
    SIDE DOWNCOMER WIDTH              METER
0.57214
    SIDE WEIR LENGTH                  METER
2.65678
    CENTER DOWNCOMER WIDTH            METER                        0.0
    CENTER WEIR LENGTH                METER
MISSING
    OFF-CENTER DOWNCOMER WIDTH        METER                        0.0
    OFF-CENTER SHORT WEIR LENGTH      METER
MISSING
    OFF-CENTER LONG WEIR LENGTH       METER
MISSING
    TRAY CENTER TO OCDC CENTER        METER                        0.0


                          **** SIZING PROFILES ****

       STAGE    DIAMETER      TOTAL AREA   ACTIVE AREA   SIDE DC
AREA
                 METER          SQM          SQM            SQM
          2      3.6564        10.500       8.4001        1.0500
          3      3.6564        10.500       8.4001        1.0500
```

4	3.6564	10.500	8.4001	1.0500
5	3.6564	10.500	8.4001	1.0500
6	3.6564	10.500	8.4001	1.0500
7	3.6564	10.500	8.4001	1.0500
8	3.6564	10.500	8.4001	1.0500
9	3.6564	10.500	8.4001	1.0500
10	3.6564	10.500	8.4001	1.0500
11	3.6564	10.500	8.4001	1.0500
12	3.6564	10.500	8.4001	1.0500
13	3.6564	10.500	8.4001	1.0500
14	3.6564	10.500	8.4001	1.0500
15	3.6564	10.500	8.4001	1.0500
16	3.6564	10.500	8.4001	1.0500
17	3.6564	10.500	8.4001	1.0500
18	3.6564	10.500	8.4001	1.0500
19	3.6564	10.500	8.4001	1.0500
20	3.6564	10.500	8.4001	1.0500
21	3.6564	10.500	8.4001	1.0500
22	3.6564	10.500	8.4001	1.0500
23	3.6564	10.500	8.4001	1.0500
24	3.6564	10.500	8.4001	1.0500
25	3.6564	10.500	8.4001	1.0500
26	3.6564	10.500	8.4001	1.0500
27	3.6564	10.500	8.4001	1.0500
28	3.6564	10.500	8.4001	1.0500
29	3.6564	10.500	8.4001	1.0500
30	3.6564	10.500	8.4001	1.0500
31	3.6564	10.500	8.4001	1.0500
32	3.6564	10.500	8.4001	1.0500
33	3.6564	10.500	8.4001	1.0500
34	3.6564	10.500	8.4001	1.0500

U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	METER	SQM	SQM	SQM
35	3.6564	10.500	8.4001	1.0500
36	3.6564	10.500	8.4001	1.0500
37	3.6564	10.500	8.4001	1.0500
38	3.6564	10.500	8.4001	1.0500
39	3.6564	10.500	8.4001	1.0500
40	3.6564	10.500	8.4001	1.0500
41	3.6564	10.500	8.4001	1.0500
42	3.6564	10.500	8.4001	1.0500
43	3.6564	10.500	8.4001	1.0500
44	3.6564	10.500	8.4001	1.0500
45	3.6564	10.500	8.4001	1.0500
46	3.6564	10.500	8.4001	1.0500
47	3.6564	10.500	8.4001	1.0500
48	3.6564	10.500	8.4001	1.0500
49	3.6564	10.500	8.4001	1.0500
50	3.6564	10.500	8.4001	1.0500
51	3.6564	10.500	8.4001	1.0500
52	3.6564	10.500	8.4001	1.0500
53	3.6564	10.500	8.4001	1.0500
54	3.6564	10.500	8.4001	1.0500
55	3.6564	10.500	8.4001	1.0500
56	3.6564	10.500	8.4001	1.0500
57	3.6564	10.500	8.4001	1.0500
58	3.6564	10.500	8.4001	1.0500
59	3.6564	10.500	8.4001	1.0500
60	3.6564	10.500	8.4001	1.0500
61	3.6564	10.500	8.4001	1.0500
62	3.6564	10.500	8.4001	1.0500
63	3.6564	10.500	8.4001	1.0500
64	3.6564	10.500	8.4001	1.0500
65	3.6564	10.500	8.4001	1.0500
66	3.6564	10.500	8.4001	1.0500
67	3.6564	10.500	8.4001	1.0500
68	3.6564	10.500	8.4001	1.0500
69	3.6564	10.500	8.4001	1.0500
70	3.6564	10.500	8.4001	1.0500
71	3.6564	10.500	8.4001	1.0500
72	3.6564	10.500	8.4001	1.0500
73	3.6564	10.500	8.4001	1.0500
74	3.6564	10.500	8.4001	1.0500
75	3.6564	10.500	8.4001	1.0500
76	3.6564	10.500	8.4001	1.0500

77	3.6564	10.500	8.4001	1.0500
78	3.6564	10.500	8.4001	1.0500
79	3.6564	10.500	8.4001	1.0500
80	3.6564	10.500	8.4001	1.0500
81	3.6564	10.500	8.4001	1.0500
82	3.6564	10.500	8.4001	1.0500
83	3.6564	10.500	8.4001	1.0500
84	3.6564	10.500	8.4001	1.0500
85	3.6564	10.500	8.4001	1.0500

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U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	METER	SQM	SQM	SQM
86	3.6564	10.500	8.4001	1.0500

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP	DC BACKUP	DC BACKUP/ (TSPC+WHT)
		BAR	METER	
2	80.00	0.6392E-02	0.3968	60.08
3	79.93	0.6386E-02	0.3967	60.07
4	79.73	0.6372E-02	0.3958	59.93
5	79.45	0.6353E-02	0.3943	59.71
6	79.12	0.6330E-02	0.3924	59.42
7	78.75	0.6306E-02	0.3903	59.10
8	78.36	0.6280E-02	0.3880	58.75
9	77.98	0.6255E-02	0.3857	58.41
10	77.62	0.6232E-02	0.3836	58.09
11	77.29	0.6211E-02	0.3817	57.80
12	77.01	0.6193E-02	0.3802	57.57
13	76.78	0.6178E-02	0.3790	57.39
14	76.59	0.6165E-02	0.3781	57.25
15	76.44	0.6154E-02	0.3774	57.15
16	76.31	0.6145E-02	0.3769	57.08
17	76.21	0.6137E-02	0.3766	57.03
18	76.12	0.6129E-02	0.3764	57.00
19	76.04	0.6123E-02	0.3763	56.98
20	75.97	0.6116E-02	0.3763	56.98
21	75.90	0.6110E-02	0.3763	56.98
22	75.84	0.6104E-02	0.3763	56.98
23	75.78	0.6099E-02	0.3763	56.99
24	75.71	0.6092E-02	0.3764	56.99
25	75.66	0.6087E-02	0.3764	57.00
26	75.60	0.6082E-02	0.3765	57.02
27	75.55	0.6077E-02	0.3766	57.03
28	75.50	0.6072E-02	0.3767	57.05
29	75.45	0.6067E-02	0.3768	57.06
30	75.40	0.6062E-02	0.3769	57.08
31	75.35	0.6057E-02	0.3770	57.09
32	75.30	0.6052E-02	0.3772	57.11
33	75.25	0.6047E-02	0.3773	57.13
34	75.20	0.6042E-02	0.3774	57.14
35	75.15	0.6037E-02	0.3775	57.16

36	75.10	0.6033E-02	0.3776	57.18
37	75.05	0.6028E-02	0.3777	57.20
38	75.01	0.6024E-02	0.3778	57.21
39	74.96	0.6019E-02	0.3780	57.23
40	74.91	0.6015E-02	0.3781	57.25
41	74.86	0.6010E-02	0.3782	57.27
42	74.82	0.6006E-02	0.3783	57.29
43	74.77	0.6001E-02	0.3784	57.30

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U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

STAGE	FLOODING FACTOR	PRES. DROP BAR	DC BACKUP METER	DC BACKUP/ (TSPC+WHT)
44	74.73	0.5997E-02	0.3786	57.32
45	74.68	0.5993E-02	0.3787	57.34
46	74.64	0.5988E-02	0.3788	57.36
47	74.59	0.5984E-02	0.3789	57.38
48	74.55	0.5980E-02	0.3790	57.40
49	74.50	0.5976E-02	0.3792	57.41
50	74.46	0.5972E-02	0.3793	57.43
51	74.41	0.5968E-02	0.3794	57.45
52	74.37	0.5964E-02	0.3795	57.47
53	74.33	0.5960E-02	0.3797	57.49
54	74.29	0.5956E-02	0.3798	57.51
55	74.24	0.5952E-02	0.3799	57.53
56	74.20	0.5948E-02	0.3801	57.55
57	74.16	0.5944E-02	0.3802	57.57
58	74.12	0.5940E-02	0.3803	57.59
59	74.07	0.5936E-02	0.3804	57.61
60	74.03	0.5933E-02	0.3806	57.63
61	73.99	0.5929E-02	0.3807	57.65
62	73.95	0.5925E-02	0.3808	57.67
63	73.91	0.5922E-02	0.3810	57.69
64	73.87	0.5918E-02	0.3811	57.71
65	73.83	0.5914E-02	0.3812	57.73
66	73.79	0.5911E-02	0.3814	57.75
67	73.75	0.5907E-02	0.3815	57.77
68	73.71	0.5904E-02	0.3817	57.79
69	73.67	0.5900E-02	0.3818	57.81
70	73.63	0.5897E-02	0.3819	57.83
71	73.59	0.5893E-02	0.3821	57.85
72	73.56	0.5890E-02	0.3822	57.88
73	73.52	0.5887E-02	0.3823	57.90
74	73.48	0.5883E-02	0.3825	57.92
75	73.44	0.5880E-02	0.3826	57.94
76	73.40	0.5877E-02	0.3828	57.96
77	73.37	0.5874E-02	0.3829	57.98
78	73.33	0.5870E-02	0.3830	58.00
79	73.29	0.5867E-02	0.3832	58.02
80	73.26	0.5864E-02	0.3833	58.04
81	73.22	0.5861E-02	0.3835	58.06
82	73.18	0.5858E-02	0.3836	58.08
83	73.15	0.5855E-02	0.3837	58.11
84	73.11	0.5852E-02	0.3839	58.13
85	73.07	0.5848E-02	0.3840	58.14

86	66.44	0.5398E-02	0.3390	51.33

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U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

STAGE	HEIGHT OVER WEIR METER	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.1870	0.5902	0.2165	46.55
3	0.1869	0.5902	0.2167	46.50
4	0.1864	0.5902	0.2171	46.37
5	0.1856	0.5903	0.2176	46.19
6	0.1846	0.5903	0.2182	45.97
7	0.1835	0.5904	0.2188	45.73
8	0.1823	0.5905	0.2195	45.48
9	0.1812	0.5906	0.2202	45.23
10	0.1801	0.5907	0.2208	45.00
11	0.1791	0.5908	0.2214	44.79
12	0.1783	0.5908	0.2219	44.61
13	0.1776	0.5909	0.2223	44.46
14	0.1771	0.5909	0.2227	44.33
15	0.1767	0.5909	0.2231	44.23
16	0.1764	0.5909	0.2234	44.14
17	0.1762	0.5909	0.2237	44.07
18	0.1760	0.5909	0.2239	44.01
19	0.1759	0.5908	0.2242	43.95
20	0.1758	0.5908	0.2244	43.90
21	0.1757	0.5908	0.2246	43.86
22	0.1756	0.5907	0.2249	43.81
23	0.1755	0.5907	0.2251	43.77
24	0.1754	0.5907	0.2253	43.72
25	0.1754	0.5906	0.2255	43.68
26	0.1753	0.5906	0.2258	43.64
27	0.1753	0.5905	0.2260	43.61
28	0.1752	0.5905	0.2262	43.57
29	0.1752	0.5905	0.2264	43.53
30	0.1751	0.5904	0.2266	43.50
31	0.1751	0.5904	0.2268	43.46
32	0.1750	0.5904	0.2270	43.42
33	0.1750	0.5903	0.2272	43.39
34	0.1749	0.5903	0.2275	43.35
35	0.1749	0.5902	0.2277	43.32
36	0.1748	0.5902	0.2279	43.28
37	0.1748	0.5902	0.2281	43.25
38	0.1748	0.5901	0.2283	43.21
39	0.1747	0.5901	0.2285	43.18
40	0.1747	0.5900	0.2287	43.14
41	0.1746	0.5900	0.2289	43.11
42	0.1746	0.5900	0.2291	43.08
43	0.1746	0.5899	0.2293	43.04

44	0.1745	0.5899	0.2295	43.01
45	0.1745	0.5898	0.2297	42.98
46	0.1744	0.5898	0.2299	42.94
47	0.1744	0.5898	0.2301	42.91
48	0.1744	0.5897	0.2303	42.88
49	0.1743	0.5897	0.2305	42.85
50	0.1743	0.5897	0.2307	42.81

U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

STAGE	HEIGHT OVER WEIR METER	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
51	0.1742	0.5896	0.2309	42.78
52	0.1742	0.5896	0.2311	42.75
53	0.1742	0.5895	0.2313	42.72
54	0.1741	0.5895	0.2315	42.69
55	0.1741	0.5895	0.2317	42.65
56	0.1740	0.5894	0.2319	42.62
57	0.1740	0.5894	0.2321	42.59
58	0.1740	0.5893	0.2323	42.56
59	0.1739	0.5893	0.2325	42.53
60	0.1739	0.5893	0.2327	42.50
61	0.1739	0.5892	0.2329	42.47
62	0.1738	0.5892	0.2331	42.44
63	0.1738	0.5892	0.2333	42.41
64	0.1738	0.5891	0.2335	42.38
65	0.1737	0.5891	0.2337	42.35
66	0.1737	0.5890	0.2339	42.32
67	0.1736	0.5890	0.2341	42.29
68	0.1736	0.5890	0.2343	42.26
69	0.1736	0.5889	0.2345	42.23
70	0.1735	0.5889	0.2347	42.21
71	0.1735	0.5888	0.2349	42.18
72	0.1735	0.5888	0.2351	42.15
73	0.1734	0.5888	0.2353	42.12
74	0.1734	0.5887	0.2355	42.09
75	0.1734	0.5887	0.2356	42.06
76	0.1733	0.5887	0.2358	42.04
77	0.1733	0.5886	0.2360	42.01
78	0.1733	0.5886	0.2362	41.98
79	0.1732	0.5885	0.2364	41.95
80	0.1732	0.5885	0.2366	41.92
81	0.1732	0.5885	0.2368	41.90
82	0.1731	0.5884	0.2370	41.87
83	0.1731	0.5884	0.2372	41.84
84	0.1731	0.5883	0.2374	41.82
85	0.1730	0.5883	0.2376	41.79
86	0.1501	0.5885	0.2514	38.44

U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

****
*** SECTION 2 ***
****

STARTING STAGE NUMBER
87
ENDING STAGE NUMBER
149
FLOODING CALCULATION METHOD
GLITSCH6

DESIGN PARAMETERS

PEAK CAPACITY FACTOR
1.00000
SYSTEM FOAMING FACTOR
1.00000
FLOODING FACTOR
0.80000
MINIMUM COLUMN DIAMETER METER
0.30480
MINIMUM DC AREA/COLUMN AREA
0.100000
HOLE AREA/ACTIVE AREA
0.100000

TRAY SPECIFICATIONS

TRAY TYPE
SIEVE
NUMBER OF PASSES
1
TRAY SPACING METER
0.60960

***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER
*****

STAGE WITH MAXIMUM DIAMETER
87
COLUMN DIAMETER METER
3.10723

DC AREA/COLUMN AREA
0.100000
DOWNCOMER VELOCITY M/SEC
0.082343
FLOW PATH LENGTH METER
2.13482
SIDE DOWNCOMER WIDTH METER
0.48621
SIDE WEIR LENGTH METER
2.25775
CENTER DOWNCOMER WIDTH METER 0.0
CENTER WEIR LENGTH METER
MISSING
OFF-CENTER DOWNCOMER WIDTH METER 0.0
OFF-CENTER SHORT WEIR LENGTH METER
MISSING
OFF-CENTER LONG WEIR LENGTH METER
MISSING
TRAY CENTER TO OCDC CENTER METER 0.0

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	METER	SQM	SQM	SQM
87	3.1072	7.5829	6.0663	0.75829
88	3.1072	7.5829	6.0663	0.75829
89	3.1072	7.5829	6.0663	0.75829
90	3.1072	7.5829	6.0663	0.75829
91	3.1072	7.5829	6.0663	0.75829
92	3.1072	7.5829	6.0663	0.75829
93	3.1072	7.5829	6.0663	0.75829
94	3.1072	7.5829	6.0663	0.75829
95	3.1072	7.5829	6.0663	0.75829
96	3.1072	7.5829	6.0663	0.75829
97	3.1072	7.5829	6.0663	0.75829
98	3.1072	7.5829	6.0663	0.75829
99	3.1072	7.5829	6.0663	0.75829
100	3.1072	7.5829	6.0663	0.75829

U-O-S BLOCK SECTION

BLOCK: T-100   MODEL: RADFRAC (CONTINUED)

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA	SIDE DC AREA
	METER	SQM	SQM	SQM
101	3.1072	7.5829	6.0663	0.75829
102	3.1072	7.5829	6.0663	0.75829
103	3.1072	7.5829	6.0663	0.75829
104	3.1072	7.5829	6.0663	0.75829
105	3.1072	7.5829	6.0663	0.75829
106	3.1072	7.5829	6.0663	0.75829
107	3.1072	7.5829	6.0663	0.75829
108	3.1072	7.5829	6.0663	0.75829
109	3.1072	7.5829	6.0663	0.75829
110	3.1072	7.5829	6.0663	0.75829
111	3.1072	7.5829	6.0663	0.75829
112	3.1072	7.5829	6.0663	0.75829
113	3.1072	7.5829	6.0663	0.75829
114	3.1072	7.5829	6.0663	0.75829
115	3.1072	7.5829	6.0663	0.75829
116	3.1072	7.5829	6.0663	0.75829
117	3.1072	7.5829	6.0663	0.75829
118	3.1072	7.5829	6.0663	0.75829
119	3.1072	7.5829	6.0663	0.75829
120	3.1072	7.5829	6.0663	0.75829
121	3.1072	7.5829	6.0663	0.75829
122	3.1072	7.5829	6.0663	0.75829
123	3.1072	7.5829	6.0663	0.75829
124	3.1072	7.5829	6.0663	0.75829
125	3.1072	7.5829	6.0663	0.75829
126	3.1072	7.5829	6.0663	0.75829
127	3.1072	7.5829	6.0663	0.75829
128	3.1072	7.5829	6.0663	0.75829
129	3.1072	7.5829	6.0663	0.75829
130	3.1072	7.5829	6.0663	0.75829
131	3.1072	7.5829	6.0663	0.75829
132	3.1072	7.5829	6.0663	0.75829
133	3.1072	7.5829	6.0663	0.75829
134	3.1072	7.5829	6.0663	0.75829
135	3.1072	7.5829	6.0663	0.75829
136	3.1072	7.5829	6.0663	0.75829
137	3.1072	7.5829	6.0663	0.75829
138	3.1072	7.5829	6.0663	0.75829
139	3.1072	7.5829	6.0663	0.75829
140	3.1072	7.5829	6.0663	0.75829
141	3.1072	7.5829	6.0663	0.75829
142	3.1072	7.5829	6.0663	0.75829

143	3.1072	7.5829	6.0663	0.75829
144	3.1072	7.5829	6.0663	0.75829
145	3.1072	7.5829	6.0663	0.75829
146	3.1072	7.5829	6.0663	0.75829
147	3.1072	7.5829	6.0663	0.75829
148	3.1072	7.5829	6.0663	0.75829
149	3.1072	7.5829	6.0663	0.75829

U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP BAR	DC BACKUP METER	DC BACKUP/ (TSPC+WHT)
87	80.00	0.6370E-02	0.4054	61.39
88	79.96	0.6366E-02	0.4055	61.40
89	79.91	0.6361E-02	0.4055	61.41
90	79.87	0.6357E-02	0.4056	61.42
91	79.83	0.6353E-02	0.4057	61.44
92	79.79	0.6349E-02	0.4058	61.45
93	79.75	0.6345E-02	0.4059	61.47
94	79.72	0.6341E-02	0.4061	61.49
95	79.68	0.6337E-02	0.4062	61.50
96	79.64	0.6333E-02	0.4063	61.52
97	79.61	0.6330E-02	0.4064	61.54
98	79.57	0.6326E-02	0.4066	61.56
99	79.54	0.6322E-02	0.4067	61.58
100	79.50	0.6318E-02	0.4068	61.60
101	79.47	0.6315E-02	0.4070	61.62
102	79.44	0.6311E-02	0.4071	61.65
103	79.40	0.6307E-02	0.4073	61.67
104	79.37	0.6304E-02	0.4074	61.69
105	79.34	0.6300E-02	0.4075	61.71
106	79.30	0.6297E-02	0.4077	61.73
107	79.27	0.6293E-02	0.4078	61.75
108	79.24	0.6290E-02	0.4080	61.78
109	79.21	0.6287E-02	0.4081	61.80
110	79.18	0.6283E-02	0.4083	61.82
111	79.15	0.6280E-02	0.4084	61.84
112	79.11	0.6276E-02	0.4086	61.86
113	79.08	0.6273E-02	0.4087	61.89
114	79.05	0.6270E-02	0.4089	61.91
115	79.02	0.6267E-02	0.4090	61.93
116	78.99	0.6263E-02	0.4092	61.96
117	78.96	0.6260E-02	0.4093	61.98
118	78.93	0.6257E-02	0.4095	62.00
119	78.90	0.6254E-02	0.4096	62.02
120	78.87	0.6251E-02	0.4098	62.05
121	78.84	0.6248E-02	0.4099	62.07
122	78.81	0.6244E-02	0.4101	62.09
123	78.78	0.6241E-02	0.4102	62.12
124	78.75	0.6238E-02	0.4104	62.14
125	78.73	0.6235E-02	0.4105	62.16

126	78.70	0.6232E-02	0.4107	62.19
127	78.67	0.6229E-02	0.4108	62.21
128	78.64	0.6226E-02	0.4110	62.24
129	78.61	0.6224E-02	0.4112	62.26
130	78.59	0.6221E-02	0.4113	62.28
131	78.56	0.6218E-02	0.4115	62.31
132	78.53	0.6215E-02	0.4116	62.33
133	78.50	0.6212E-02	0.4118	62.36

U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

STAGE	FLOODING FACTOR	PRES. DROP BAR	DC BACKUP METER	DC BACKUP/ (TSPC+WHT)
134	78.48	0.6209E-02	0.4120	62.38
135	78.45	0.6207E-02	0.4121	62.40
136	78.42	0.6204E-02	0.4123	62.43
137	78.40	0.6201E-02	0.4124	62.45
138	78.37	0.6198E-02	0.4126	62.48
139	78.34	0.6196E-02	0.4128	62.50
140	78.32	0.6193E-02	0.4129	62.53
141	78.29	0.6190E-02	0.4131	62.55
142	78.27	0.6188E-02	0.4133	62.58
143	78.24	0.6185E-02	0.4134	62.60
144	78.22	0.6182E-02	0.4136	62.63
145	78.19	0.6180E-02	0.4138	62.65
146	78.16	0.6177E-02	0.4139	62.68
147	78.14	0.6175E-02	0.4141	62.70
148	78.10	0.6171E-02	0.4142	62.72
149	78.05	0.6167E-02	0.4142	62.71

STAGE	HEIGHT OVER WEIR METER	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
87	0.1961	0.5882	0.2197	46.88
88	0.1960	0.5882	0.2199	46.85
89	0.1960	0.5882	0.2200	46.82
90	0.1959	0.5881	0.2202	46.78
91	0.1959	0.5881	0.2203	46.76
92	0.1959	0.5881	0.2205	46.73
93	0.1958	0.5880	0.2206	46.70
94	0.1958	0.5880	0.2208	46.67
95	0.1958	0.5880	0.2209	46.64
96	0.1957	0.5879	0.2211	46.62
97	0.1957	0.5879	0.2213	46.59
98	0.1957	0.5878	0.2214	46.57
99	0.1957	0.5878	0.2216	46.54
100	0.1957	0.5878	0.2217	46.52
101	0.1956	0.5877	0.2219	46.49
102	0.1956	0.5877	0.2220	46.47
103	0.1956	0.5877	0.2222	46.44
104	0.1956	0.5876	0.2223	46.42
105	0.1956	0.5876	0.2225	46.39
106	0.1955	0.5875	0.2226	46.37
107	0.1955	0.5875	0.2228	46.34
108	0.1955	0.5875	0.2229	46.32

109	0.1955	0.5874	0.2230	46.30
110	0.1955	0.5874	0.2232	46.27
111	0.1955	0.5874	0.2233	46.25
112	0.1954	0.5873	0.2235	46.23
113	0.1954	0.5873	0.2236	46.20
114	0.1954	0.5872	0.2238	46.18
115	0.1954	0.5872	0.2239	46.16

U-O-S BLOCK SECTION

BLOCK: T-100 MODEL: RADFRAC (CONTINUED)

STAGE	HEIGHT OVER WEIR METER	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
116	0.1954	0.5872	0.2241	46.14
117	0.1954	0.5871	0.2242	46.11
118	0.1953	0.5871	0.2244	46.09
119	0.1953	0.5870	0.2245	46.07
120	0.1953	0.5870	0.2246	46.05
121	0.1953	0.5870	0.2248	46.02
122	0.1953	0.5869	0.2249	46.00
123	0.1953	0.5869	0.2251	45.98
124	0.1953	0.5868	0.2252	45.96
125	0.1952	0.5868	0.2254	45.94
126	0.1952	0.5868	0.2255	45.92
127	0.1952	0.5867	0.2257	45.89
128	0.1952	0.5867	0.2258	45.87
129	0.1952	0.5867	0.2259	45.85
130	0.1952	0.5866	0.2261	45.83
131	0.1952	0.5866	0.2262	45.81
132	0.1952	0.5865	0.2264	45.79
133	0.1951	0.5865	0.2265	45.77
134	0.1951	0.5865	0.2266	45.75
135	0.1951	0.5864	0.2268	45.73
136	0.1951	0.5864	0.2269	45.71
137	0.1951	0.5863	0.2271	45.69
138	0.1951	0.5863	0.2272	45.67
139	0.1951	0.5863	0.2273	45.65
140	0.1951	0.5862	0.2275	45.63
141	0.1951	0.5862	0.2276	45.61
142	0.1950	0.5861	0.2277	45.59
143	0.1950	0.5861	0.2279	45.57
144	0.1950	0.5861	0.2280	45.55
145	0.1950	0.5860	0.2282	45.53
146	0.1950	0.5860	0.2283	45.51
147	0.1950	0.5859	0.2284	45.49
148	0.1949	0.5859	0.2286	45.46
149	0.1948	0.5859	0.2288	45.43

*** ASSOCIATED UTILITIES ***

UTILITY USAGE: R134A-C (REFRIGERANT)

CONDENSER 2.4601+05
432.9750

```
                        -------------                        -------
------
 TOTAL:                     2.4601+05  KG/HR
432.9750  $/HR
                        =============
 UTILITY USAGE:  LPS        (STEAM)
 ------------------------------
 REBOILER                   1.9872+04
84.0849
                        -------------                        -------
------
 TOTAL:                     1.9872+04  KG/HR
84.0849  $/HR
                        =============

 BLOCK:  T-101    MODEL: RADFRAC
 -------------------------------
    INLETS   - 11       STAGE   3
    OUTLETS  - 14       STAGE   1
               12       STAGE  20
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG
```

U-O-S BLOCK SECTION

BLOCK: T-101   MODEL: RADFRAC (CONTINUED)

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	141.588	141.588	0.00000
MASS(KG/HR)	8239.29	8239.29	0.00000
ENTHALPY(CAL/SEC)	-0.140611E+07	-0.140612E+07	0.958313E-05

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	0.00000	KG/HR
PRODUCT STREAMS CO2E	0.00000	KG/HR
NET STREAMS CO2E PRODUCTION	0.00000	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	0.00000	KG/HR

****
**** INPUT DATA ****
****

**** INPUT PARAMETERS ****

NUMBER OF STAGES	20
ALGORITHM OPTION	STANDARD
ABSORBER OPTION	NO
INITIALIZATION OPTION	STANDARD
HYDRAULIC PARAMETER CALCULATIONS	NO
INSIDE LOOP CONVERGENCE METHOD	BROYDEN
DESIGN SPECIFICATION METHOD	NESTED
MAXIMUM NO. OF OUTSIDE LOOP ITERATIONS	25
MAXIMUM NO. OF INSIDE LOOP ITERATIONS	10
MAXIMUM NUMBER OF FLASH ITERATIONS	30
FLASH TOLERANCE	0.000100000
OUTSIDE LOOP CONVERGENCE TOLERANCE	0.000100000

**** COL-SPECS ****

```
    MOLAR VAPOR DIST / TOTAL DIST                                0.0
    MOLAR REFLUX RATIO
60.0000
    MOLAR BOTTOMS RATE               KMOL/HR
2.94480
```

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U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

**** PROFILES ****

P-SPEC STAGE 1 PRES, BAR
1.10000

****
**** RESULTS ****
****

*** COMPONENT SPLIT FRACTIONS ***

	OUTLET STREAMS	
	14	12
COMPONENT:		
IC4	.99999	.12391E-04
2-ME-C3	.99995	.48886E-04
1-C4	.99983	.17263E-03
N-BUTANE	.98540	.14597E-01
T2-C4	.98238	.17619E-01
C2-C4	.91798	.82017E-01
C5	.12962E-02	.99870

*** SUMMARY OF KEY RESULTS ***

TOP STAGE TEMPERATURE C
1.65660
BOTTOM STAGE TEMPERATURE C
13.2425
TOP STAGE LIQUID FLOW KMOL/HR 8,318.59
BOTTOM STAGE LIQUID FLOW KMOL/HR
2.94480
TOP STAGE VAPOR FLOW KMOL/HR 0.0
BOILUP VAPOR FLOW KMOL/HR 8,143.38
MOLAR REFLUX RATIO
60.0000
MOLAR BOILUP RATIO 2,765.34
CONDENSER DUTY (W/O SUBCOOL) CAL/SEC -
0.125243+08
REBOILER DUTY CAL/SEC
0.125243+08

**** MAXIMUM FINAL RELATIVE ERRORS ****

```
    DEW POINT                        0.23717E-05  STAGE= 19
    BUBBLE POINT                     0.12859E-05  STAGE= 19
    COMPONENT MASS BALANCE           0.38554E-07  STAGE=  3
COMP=C5
    ENERGY BALANCE                   0.25498E-04  STAGE= 20
```

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U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

**** PROFILES ****

NOTE REPORTED VALUES FOR STAGE LIQUID AND VAPOR RATES ARE THE FLOWS
FROM THE STAGE INCLUDING ANY SIDE PRODUCT.

STAGE	TEMPERATURE	PRESSURE	ENTHALPY CAL/MOL		HEAT DUTY
	C	BAR	LIQUID	VAPOR	CAL/SEC
1	1.6566	1.1000	-35724.	-30406.	-.12524+08
2	1.9004	1.1100	-35707.	-30392.	
3	2.1442	1.1200	-35690.	-30378.	
4	2.3842	1.1300	-35671.	-30364.	
14	4.7065	1.2300	-35433.	-30164.	
15	4.9395	1.2400	-35404.	-30137.	
16	5.1962	1.2500	-35380.	-30109.	
17	5.5494	1.2600	-35384.	-30084.	
19	8.2319	1.2800	-35950.	-30128.	
20	13.243	1.2900	-37084.	-30413.	.12524+08

STAGE	FLOW RATE KMOL/HR		FEED RATE KMOL/HR			PRODUCT RATE KMOL/HR	
	LIQUID	VAPOR	LIQUID	VAPOR	MIXED	LIQUID	VAPOR
1	8457.	0.000				138.6432	
2	8323.	8457.					
3	8469.	8462.	141.5880				
4	8474.	8466.					
14	8518.	8511.					
15	8520.	8515.					
16	8517.	8517.					
17	8494.	8514.					
19	8146.	8401.					
20	2.945	8143.				2.9448	

**** MASS FLOW PROFILES ****

STAGE	FLOW RATE KG/HR LIQUID	FLOW RATE KG/HR VAPOR	FEED RATE KG/HR LIQUID	FEED RATE KG/HR VAPOR	FEED RATE KG/HR MIXED	PRODUCT RATE KG/HR LIQUID	PRODUCT RATE KG/HR VAPOR
1	0.4914E+06	0.000				8056.0897	
2	0.4836E+06	0.4914E+06					
3	0.4921E+06	0.4917E+06	8239.2925				
4	0.4924E+06	0.4919E+06					
14	0.4948E+06	0.4944E+06					
15	0.4950E+06	0.4947E+06					
16	0.4950E+06	0.4948E+06					
17	0.4944E+06	0.4948E+06					
19	0.4854E+06	0.4916E+06					
20	183.2	0.4852E+06				183.2027	

U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

**** MOLE-X-PROFILE ****

STAGE	IC4	2-ME-C3	1-C4	N-BUTANE	T2-C4
1	0.68777E-08	0.39219E-08	0.27286E-07	0.99162	0.60800E-02
2	0.46360E-08	0.28558E-08	0.21570E-07	0.99127	0.61608E-02
3	0.31522E-08	0.20931E-08	0.17124E-07	0.99082	0.62391E-02
4	0.21288E-08	0.15259E-08	0.13540E-07	0.99045	0.63184E-02
14	0.43890E-10	0.66354E-10	0.12935E-08	0.98453	0.70642E-02
15	0.29906E-10	0.48614E-10	0.10223E-08	0.98327	0.71305E-02
16	0.20391E-10	0.35621E-10	0.80693E-09	0.98080	0.71863E-02
17	0.13903E-10	0.26077E-10	0.63389E-09	0.97385	0.72039E-02
19	0.63388E-11	0.13567E-10	0.35527E-09	0.87537	0.65295E-02
20	0.40124E-11	0.90271E-11	0.22180E-09	0.69159	0.51338E-02

**** MOLE-X-PROFILE ****

STAGE	C2-C4	C5
1	0.22930E-02	0.80948E-05
2	0.25377E-02	0.33325E-04
3	0.28022E-02	0.13510E-03
4	0.30948E-02	0.13514E-03
14	0.81426E-02	0.26777E-03
15	0.89417E-02	0.66058E-03
16	0.98008E-02	0.22115E-02
17	0.10680E-01	0.82628E-02
19	0.11387E-01	0.10671
20	0.96453E-02	0.29363

**** MOLE-Y-PROFILE ****

STAGE	IC4	2-ME-C3	1-C4	N-BUTANE	T2-C4
1	0.10211E-07	0.53885E-08	0.34517E-07	0.99193	0.59984E-02
2	0.68777E-08	0.39219E-08	0.27286E-07	0.99162	0.60800E-02

3	0.46728E-08	0.28733E-08	0.21663E-07	0.99127	0.61595E-02
4	0.31533E-08	0.20938E-08	0.17129E-07	0.99093	0.62395E-02
14	0.64486E-10	0.90632E-10	0.16365E-08	0.98553	0.69951E-02
15	0.43904E-10	0.66374E-10	0.12938E-08	0.98463	0.70648E-02
16	0.29915E-10	0.48627E-10	0.10226E-08	0.98337	0.71312E-02
17	0.20397E-10	0.35630E-10	0.80713E-09	0.98090	0.71870E-02
19	0.94555E-11	0.19001E-10	0.48916E-09	0.95061	0.70832E-02
20	0.63396E-11	0.13569E-10	0.35532E-09	0.87544	0.65300E-02

**** MOLE-Y-PROFILE ****

STAGE	C2-C4	C5
1	0.20707E-02	0.19607E-05
2	0.22930E-02	0.80948E-05
3	0.25337E-02	0.32912E-04
4	0.27998E-02	0.33014E-04
14	0.74080E-02	0.67203E-04
15	0.81421E-02	0.16631E-03
16	0.89414E-02	0.55929E-03
17	0.98008E-02	0.21107E-02
19	0.11404E-01	0.30907E-01
20	0.11388E-01	0.10665

```
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                                U-O-S BLOCK SECTION

 BLOCK:  T-101    MODEL: RADFRAC (CONTINUED)

                           ****   K-VALUES            ****
   STAGE     IC4           2-ME-C3       1-C4          N-BUTANE
T2-C4
      1     1.4846        1.3739        1.2650        1.0003
0.98657
      2     1.4835        1.3733        1.2650        1.0004
0.98688
      3     1.4824        1.3727        1.2651        1.0005
0.98724
      4     1.4813        1.3721        1.2651        1.0005
0.98752
     14     1.4693        1.3659        1.2652        1.0010
0.99022
     15     1.4680        1.3653        1.2656        1.0014
0.99079
     16     1.4670        1.3651        1.2672        1.0026
0.99233
     17     1.4670        1.3663        1.2733        1.0072
0.99766
     19     1.4918        1.4006        1.3769        1.0859
1.0848
     20     1.5800        1.5031        1.6020        1.2658
1.2720

                           ****   K-VALUES            ****
   STAGE     C2-C4         C5
      1    0.90305       0.24221
      2    0.90359       0.24290
      3    0.90418       0.24361
      4    0.90469       0.24429
     14    0.90977       0.25098
     15    0.91058       0.25176
     16    0.91232       0.25290
     17    0.91767       0.25546
     19     1.0015       0.28963
     20     1.1807       0.36320

                           ****   MASS-X-PROFILE      ****
   STAGE     IC4           2-ME-C3       1-C4          N-BUTANE
T2-C4
      1    0.68796E-08   0.37870E-08   0.26348E-07   0.99190
0.58708E-02
      2    0.46374E-08   0.27576E-08   0.20828E-07   0.99156
0.59489E-02
```

3	0.31530E-08	0.20210E-08	0.16534E-07	0.99110	0.60244E-02
4	0.21294E-08	0.14735E-08	0.13074E-07	0.99074	0.61010E-02
14	0.43910E-10	0.64083E-10	0.12492E-08	0.98498	0.68223E-02
15	0.29918E-10	0.46946E-10	0.98721E-09	0.98366	0.68859E-02
16	0.20393E-10	0.34387E-10	0.77899E-09	0.98086	0.69374E-02
17	0.13884E-10	0.25138E-10	0.61107E-09	0.97252	0.69445E-02
19	0.61834E-11	0.12775E-10	0.33454E-09	0.85391	0.61485E-02
20	0.37487E-11	0.81413E-11	0.20004E-09	0.64614	0.46300E-02

**** MASS-X-PROFILE ****

STAGE	C2-C4	C5
1	0.22141E-02	0.10051E-04
2	0.24504E-02	0.41380E-04
3	0.27058E-02	0.16775E-03
4	0.29883E-02	0.16781E-03
14	0.78639E-02	0.33254E-03
15	0.86350E-02	0.82033E-03
16	0.94614E-02	0.27454E-02
17	0.10296E-01	0.10243E-01
19	0.10723E-01	0.12922
20	0.86989E-02	0.34053

U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

**** MASS-Y-PROFILE ****

STAGE	IC4	2-ME-C3	1-C4	N-BUTANE	T2-C4
1	0.10214E-07	0.52030E-08	0.33330E-07	0.99221	0.57919E-02
2	0.68796E-08	0.37870E-08	0.26348E-07	0.99190	0.58708E-02
3	0.46741E-08	0.27744E-08	0.20918E-07	0.99156	0.59476E-02
4	0.31542E-08	0.20218E-08	0.16540E-07	0.99123	0.60249E-02
14	0.64517E-10	0.87531E-10	0.15805E-08	0.98601	0.67557E-02
15	0.43925E-10	0.64103E-10	0.12496E-08	0.98511	0.68231E-02
16	0.29928E-10	0.46961E-10	0.98751E-09	0.98378	0.68867E-02
17	0.20399E-10	0.34397E-10	0.77920E-09	0.98098	0.69383E-02
19	0.93915E-11	0.18218E-10	0.46900E-09	0.94417	0.67913E-02
20	0.61843E-11	0.12777E-10	0.33460E-09	0.85399	0.61491E-02

**** MASS-Y-PROFILE ****

STAGE	C2-C4	C5
1	0.19995E-02	0.24345E-05
2	0.22141E-02	0.10051E-04
3	0.24465E-02	0.40866E-04
4	0.27035E-02	0.40994E-04
14	0.71545E-02	0.83461E-04
15	0.78636E-02	0.20654E-03
16	0.86350E-02	0.69455E-03
17	0.94617E-02	0.26203E-02
19	0.10934E-01	0.38106E-01
20	0.10724E-01	0.12914

U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

****
***** HYDRAULIC PARAMETERS *****
****

*** DEFINITIONS ***

MARANGONI INDEX = SIGMA - SIGMATO
FLOW PARAM = (ML/MV)*SQRT(RHOV/RHOL)
QR = QV*SQRT(RHOV/(RHOL-RHOV))
F FACTOR = QV*SQRT(RHOV)
WHERE:
SIGMA IS THE SURFACE TENSION OF LIQUID FROM THE STAGE
SIGMATO IS THE SURFACE TENSION OF LIQUID TO THE STAGE
ML IS THE MASS FLOW OF LIQUID FROM THE STAGE
MV IS THE MASS FLOW OF VAPOR TO THE STAGE
RHOL IS THE MASS DENSITY OF LIQUID FROM THE STAGE
RHOV IS THE MASS DENSITY OF VAPOR TO THE STAGE
QV IS THE VOLUMETRIC FLOW RATE OF VAPOR TO THE STAGE

	TEMPERATURE C	
STAGE	LIQUID FROM	VAPOR TO
1	1.6566	1.9004
2	1.9004	2.1442
3	2.1442	2.3842
4	2.3842	2.6227
14	4.7065	4.9395
15	4.9395	5.1962
16	5.1962	5.5494
17	5.5494	6.2701
19	8.2319	13.243
20	13.243	13.243

	MASS FLOW KG/HR		VOLUME FLOW L/MIN		MOLECULAR WEIGHT	
STAGE	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO	LIQUID FROM	VAPOR TO
1	0.49142E+06	0.49142E+06	13639.	0.28047E+07	58.107	58.107

2	0.48362E+06	0.49167E+06	13428.	0.27829E+07	58.106	58.106
3	0.49213E+06	0.49195E+06	13670.	0.27615E+07	58.107	58.106
4	0.49239E+06	0.49221E+06	13683.	0.27405E+07	58.106	58.105
14	0.49484E+06	0.49466E+06	13805.	0.25477E+07	58.097	58.095
15	0.49501E+06	0.49482E+06	13815.	0.25298E+07	58.100	58.099
16	0.49501E+06	0.49482E+06	13819.	0.25115E+07	58.120	58.119
17	0.49438E+06	0.49420E+06	13802.	0.24911E+07	58.203	58.202
19	0.48539E+06	0.48521E+06	13502.	0.24116E+07	59.584	59.583
20	183.20	0.0000	5.0636	0.0000	62.212	

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U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

STAGE	DENSITY GM/CC LIQUID FROM	DENSITY GM/CC VAPOR TO	VISCOSITY CP LIQUID FROM	VISCOSITY CP VAPOR TO	SURFACE TENSION DYNE/CM LIQUID FROM
1	0.60050	0.29203E-02	0.19556	0.70496E-02	14.658
2	0.60024	0.29447E-02	0.19511	0.70561E-02	14.629
3	0.59999	0.29690E-02	0.19466	0.70625E-02	14.601
4	0.59974	0.29934E-02	0.19422	0.70688E-02	14.574
14	0.59740	0.32360E-02	0.19004	0.71312E-02	14.311
15	0.59720	0.32600E-02	0.18965	0.71379E-02	14.287
16	0.59703	0.32837E-02	0.18930	0.71462E-02	14.263
17	0.59699	0.33065E-02	0.18907	0.71604E-02	14.244
19	0.59917	0.33533E-02	0.19066	0.72670E-02	14.267
20	0.60301		0.19408		14.327

STAGE	MARANGONI INDEX DYNE/CM	FLOW PARAM	QR L/MIN	REDUCED F-FACTOR (GM-L)**.5/MIN
1		0.69736E-01	0.19606E+06	0.47928E+07
2	-.28221E-01	0.68894E-01	0.19540E+06	0.47754E+07
3	-.28194E-01	0.70371E-01	0.19474E+06	0.47584E+07
4	-.27738E-01	0.70674E-01	0.19410E+06	0.47415E+07
14	-.24950E-01	0.73626E-01	0.18802E+06	0.45830E+07
15	-.24405E-01	0.73912E-01	0.18742E+06	0.45676E+07

```
   16   -.23133E-01      0.74190E-01      0.18677E+06
0.45511E+07
   17   -.19125E-01      0.74449E-01      0.18591E+06
0.45297E+07
   19   0.28860E-01      0.74838E-01      0.18092E+06
0.44161E+07
   20   0.59978E-01                        0.0000
0.0000
```

U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

```
                 ************************************
                 ***** TRAY SIZING CALCULATIONS *****
                 ************************************


    *******************
    *** SECTION   1 ***
    *******************

    STARTING STAGE NUMBER
2
    ENDING STAGE NUMBER
3
    FLOODING CALCULATION METHOD
GLITSCH6

    DESIGN PARAMETERS
    -----------------
    PEAK CAPACITY FACTOR
1.00000
    SYSTEM FOAMING FACTOR
1.00000
    FLOODING FACTOR
0.80000
    MINIMUM COLUMN DIAMETER          METER
0.30480
    MINIMUM DC AREA/COLUMN AREA
0.100000
    HOLE AREA/ACTIVE AREA
0.100000

    TRAY SPECIFICATIONS
    -------------------
    TRAY TYPE
SIEVE
    NUMBER OF PASSES
2
    TRAY SPACING                     METER
0.60960


            ***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER
*****
```

```
    STAGE WITH MAXIMUM DIAMETER
3
    COLUMN DIAMETER                 METER
7.68001
    DC AREA/COLUMN AREA
0.087500
    SIDE DOWNCOMER VELOCITY         M/SEC
0.056209
    FLOW PATH LENGTH                METER
2.79077
    SIDE DOWNCOMER WIDTH            METER
0.74733
    SIDE WEIR LENGTH                METER
4.55236
    CENTER DOWNCOMER WIDTH          METER
0.60381
    CENTER WEIR LENGTH              METER
7.65624
    OFF-CENTER DOWNCOMER WIDTH      METER                        0.0
    OFF-CENTER SHORT WEIR LENGTH    METER
MISSING
    OFF-CENTER LONG WEIR LENGTH     METER
MISSING
    TRAY CENTER TO OCDC CENTER      METER                        0.0
```

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA PER PANEL	SIDE DC AREA PER PANEL
	METER	SQM	SQM	SQM
2	7.6800	46.325	18.530	2.0267
3	7.6800	46.325	18.530	2.0267

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U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP BAR	DC BACKUP METER	DC BACKUP/ (TSPC+WHT)
2	79.91	0.6704E-02	0.3083	46.69
3	80.00	0.6694E-02	0.3110	47.10

STAGE	HEIGHT OVER WEIR METER	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
2	0.1361	0.5971	0.2016	46.80
3	0.1375	0.5970	0.2021	46.68

****
*** SECTION 2 ***
****

STARTING STAGE NUMBER
4
ENDING STAGE NUMBER
19
FLOODING CALCULATION METHOD
GLITSCH6

DESIGN PARAMETERS

PEAK CAPACITY FACTOR
1.00000
SYSTEM FOAMING FACTOR
1.00000
FLOODING FACTOR
0.80000
MINIMUM COLUMN DIAMETER METER
0.30480
MINIMUM DC AREA/COLUMN AREA
0.100000
HOLE AREA/ACTIVE AREA
0.100000

TRAY SPECIFICATIONS

```
    TRAY TYPE
SIEVE
    NUMBER OF PASSES
2
    TRAY SPACING                    METER
0.60960


            ***** SIZING RESULTS @ STAGE WITH MAXIMUM DIAMETER
*****

    STAGE WITH MAXIMUM DIAMETER
4
    COLUMN DIAMETER                 METER
7.66984
    DC AREA/COLUMN AREA
0.087500
    SIDE DOWNCOMER VELOCITY         M/SEC
0.056412
    FLOW PATH LENGTH                METER
2.78708
    SIDE DOWNCOMER WIDTH            METER
0.74634
    SIDE WEIR LENGTH                METER
4.54633
    CENTER DOWNCOMER WIDTH          METER
0.60301
    CENTER WEIR LENGTH              METER
7.64610
    OFF-CENTER DOWNCOMER WIDTH      METER                        0.0
    OFF-CENTER SHORT WEIR LENGTH    METER
MISSING
    OFF-CENTER LONG WEIR LENGTH     METER
MISSING
    TRAY CENTER TO OCDC CENTER      METER                        0.0
```

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U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

**** SIZING PROFILES ****

STAGE	DIAMETER	TOTAL AREA	ACTIVE AREA PER PANEL	SIDE DC AREA PER PANEL
	METER	SQM	SQM	SQM
4	7.6698	46.202	18.481	2.0213
5	7.6698	46.202	18.481	2.0213
6	7.6698	46.202	18.481	2.0213
7	7.6698	46.202	18.481	2.0213
8	7.6698	46.202	18.481	2.0213
9	7.6698	46.202	18.481	2.0213
10	7.6698	46.202	18.481	2.0213
11	7.6698	46.202	18.481	2.0213
12	7.6698	46.202	18.481	2.0213
13	7.6698	46.202	18.481	2.0213
14	7.6698	46.202	18.481	2.0213
15	7.6698	46.202	18.481	2.0213
16	7.6698	46.202	18.481	2.0213
17	7.6698	46.202	18.481	2.0213
18	7.6698	46.202	18.481	2.0213
19	7.6698	46.202	18.481	2.0213

**** ADDITIONAL SIZING PROFILES ****

STAGE	FLOODING FACTOR	PRES. DROP	DC BACKUP	DC BACKUP/ (TSPC+WHT)
		BAR	METER	
4	80.00	0.6690E-02	0.3114	47.15
5	79.81	0.6666E-02	0.3110	47.10
6	79.63	0.6643E-02	0.3107	47.05
7	79.44	0.6621E-02	0.3104	47.00
8	79.26	0.6598E-02	0.3101	46.96
9	79.08	0.6576E-02	0.3098	46.91
10	78.91	0.6555E-02	0.3095	46.87
11	78.73	0.6534E-02	0.3092	46.83
12	78.56	0.6513E-02	0.3090	46.79
13	78.38	0.6492E-02	0.3087	46.74
14	78.21	0.6472E-02	0.3084	46.70
15	78.03	0.6451E-02	0.3081	46.65
16	77.83	0.6429E-02	0.3077	46.59
17	77.53	0.6399E-02	0.3068	46.46

18	76.91	0.6346E-02	0.3045	46.11
19	75.54	0.6241E-02	0.2991	45.29

U-O-S BLOCK SECTION

BLOCK: T-101 MODEL: RADFRAC (CONTINUED)

STAGE	HEIGHT OVER WEIR METER	DC REL FROTH DENS	TR LIQ REL FROTH DENS	FRA APPR TO SYS LIMIT
4	0.1377	0.5970	0.2022	46.68
5	0.1376	0.5969	0.2026	46.55
6	0.1375	0.5969	0.2030	46.42
7	0.1374	0.5968	0.2035	46.30
8	0.1373	0.5968	0.2039	46.18
9	0.1372	0.5968	0.2043	46.06
10	0.1371	0.5967	0.2047	45.94
11	0.1369	0.5967	0.2052	45.82
12	0.1368	0.5967	0.2056	45.70
13	0.1367	0.5966	0.2060	45.58
14	0.1366	0.5966	0.2064	45.46
15	0.1365	0.5965	0.2069	45.34
16	0.1363	0.5965	0.2073	45.21
17	0.1359	0.5965	0.2080	45.02
18	0.1349	0.5966	0.2091	44.65
19	0.1324	0.5968	0.2113	43.84

*** ASSOCIATED UTILITIES ***

```
UTILITY USAGE:  R134A-C   (REFRIGERANT)
------------------------------
CONDENSER                  9.1062+05
1602.6787
                       -------------                  -------
------
TOTAL:                     9.1062+05  KG/HR
1602.6787  $/HR
                       =============
UTILITY USAGE:  LPS       (STEAM)
------------------------------
REBOILER                   9.0565+04
383.2078
                       -------------                  -------
------
TOTAL:                     9.0565+04  KG/HR
383.2078  $/HR
                       =============
```

BLOCK: VAL-100 MODEL: VALVE

```
-----------------------------
  INLET STREAM:          10
  OUTLET STREAM:         11
```

```
   PROPERTY OPTION SET:   UNIQ-RK   UNIQUAC / REDLICH-KWONG

                    ***  MASS AND ENERGY BALANCE  ***
                                     IN               OUT
RELATIVE DIFF.
    TOTAL BALANCE
       MOLE(KMOL/HR )           141.588         141.588
0.00000
       MASS(KG/HR   )           8239.29         8239.29
0.00000
       ENTHALPY(CAL/SEC )      -0.140611E+07   -0.140611E+07   -
0.908897E-12

                    ***  CO2 EQUIVALENT SUMMARY ***
    FEED STREAMS CO2E            0.00000      KG/HR
    PRODUCT STREAMS CO2E         0.00000      KG/HR
    NET STREAMS CO2E PRODUCTION   0.00000      KG/HR
    UTILITIES CO2E PRODUCTION     0.00000      KG/HR
    TOTAL CO2E PRODUCTION         0.00000      KG/HR

                        ***  INPUT DATA  ***

    VALVE OUTLET PRESSURE     BAR
2.10000
    VALVE FLOW COEF CALC.                                NO
```

U-O-S BLOCK SECTION

BLOCK: VAL-100 MODEL: VALVE (CONTINUED)

FLASH SPECIFICATIONS:

NPHASE 2
MAX NUMBER OF ITERATIONS 30
CONVERGENCE TOLERANCE
0.000100000

*** RESULTS ***

VALVE PRESSURE DROP BAR
1.87000

BLOCK: VAL-101 MODEL: HEATER

INLET STREAM: 25
OUTLET STREAM: 26
PROPERTY OPTION SET: UNIQ-RK UNIQUAC / REDLICH-KWONG
CHEMISTRY ID: C-1 - TRUE SPECIES

*** MASS AND ENERGY BALANCE ***

	IN	OUT	RELATIVE DIFF.
TOTAL BALANCE			
MOLE(KMOL/HR)	20282.8	20282.8	-0.538087E-14
MASS(KG/HR)	585064.	585064.	-0.194999E-13
ENTHALPY(CAL/SEC)	-0.907095E+07	-0.112910E+08	0.196624

*** CO2 EQUIVALENT SUMMARY ***

FEED STREAMS CO2E	3597.37	KG/HR
PRODUCT STREAMS CO2E	3597.37	KG/HR
NET STREAMS CO2E PRODUCTION	0.00000	KG/HR
UTILITIES CO2E PRODUCTION	0.00000	KG/HR
TOTAL CO2E PRODUCTION	0.00000	KG/HR

*** INPUT DATA ***

TWO PHASE TP FLASH
SPECIFIED TEMPERATURE C
46.2184
SPECIFIED PRESSURE BAR
1.40000
MAXIMUM NO. ITERATIONS
30

```
   CONVERGENCE TOLERANCE
0.000100000
```

U-O-S BLOCK SECTION

BLOCK: VAL-101 MODEL: HEATER (CONTINUED)

*** RESULTS ***

OUTLET TEMPERATURE	C	46.218
OUTLET PRESSURE	BAR	1.4000
HEAT DUTY	CAL/SEC	-0.22201E+07
OUTLET VAPOR FRACTION		1.0000

V-L PHASE EQUILIBRIUM :

COMP	F(I)	X(I)	Y(I)	K(I)
NITROGEN	0.77898	0.77898	0.78116	MISSING
CO	0.48089E-02	0.48089E-02	0.48223E-02	MISSING
O2	0.18538	0.18538	0.18589	MISSING
CO2	0.40300E-02	0.40300E-02	0.40413E-02	MISSING
IC4	0.47012E-10	0.47012E-10	0.47143E-10	MISSING
2-ME-C3	0.26808E-10	0.26808E-10	0.26883E-10	MISSING
1-C4	0.18652E-09	0.18652E-09	0.18704E-09	MISSING
N-BUTANE	0.17871E-02	0.17871E-02	0.17921E-02	MISSING
T2-C4	0.41560E-04	0.41560E-04	0.41676E-04	MISSING
C2-C4	0.15674E-04	0.15674E-04	0.15718E-04	MISSING
C5	0.55332E-07	0.55332E-07	0.55486E-07	MISSING
WATER	0.22174E-01	0.22174E-01	0.22236E-01	MISSING
MA(L)	0.27814E-02	0.27814E-02	0.11066E-12	MISSING

*** ASSOCIATED UTILITIES ***

UTILITY ID FOR ELECTRICITY	ELECT	
RATE OF CONSUMPTION	9295.0498	KW
COST	626.4864	$/HR

STREAM SECTION

SUBSTREAM ATTR PSD TYPE: PSD

INTERVAL	LOWER LIMIT		UPPER LIMIT	
1	5.0000-06	METER	6.0000-06	METER
2	6.0000-06	METER	7.0000-06	METER
3	7.0000-06	METER	8.0000-06	METER
4	8.0000-06	METER	9.0000-06	METER
5	9.0000-06	METER	1.0000-05	METER
6	1.0000-05	METER	1.1000-05	METER
7	1.1000-05	METER	1.2000-05	METER
8	1.2000-05	METER	1.3000-05	METER
9	1.3000-05	METER	1.4000-05	METER
10	1.4000-05	METER	1.5000-05	METER

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STREAM SECTION

1 10 11 12 13

STREAM ID	1	10	11	12	13
FROM :	----	E-104	VAL-100	T-101	P-102
TO :	P-100	VAL-100	T-101	P-102	----
TOTAL STREAM:					
KG/HR	1.0060+04	8239.2925	8239.2925	183.2028	183.2028
CAL/SEC	-1.6870+06	-1.4061+06	-1.4061+06	-3.0335+04	-3.0325+04
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	MIXED	LIQUID
COMPONENTS: KMOL/HR					
NITROGEN	0.0	0.0	0.0	0.0	0.0
CO	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
C3	0.8658	7.9258-31	7.9258-31	0.0	0.0
IC4	28.2251	9.5355-07	9.5355-07	1.1816-11	1.1816-11
2-ME-C3	0.8658	5.4378-07	5.4378-07	2.6583-11	2.6583-11
1-C4	0.3463	3.7837-06	3.7837-06	6.5317-10	6.5317-10
N-BUTANE	140.7791	139.5178	139.5178	2.0366	2.0366
T2-C4	0.8658	0.8581	0.8581	1.5118-02	1.5118-02
C2-C4	0.3463	0.3463	0.3463	2.8404-02	2.8404-02
C5	0.8658	0.8658	0.8658	0.8647	0.8647
WATER	0.0	0.0	0.0	0.0	0.0
MA(L)	0.0	0.0	0.0	0.0	0.0

MA(S)	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
KMOL/HR	173.1600	141.5880	141.5880	2.9448	2.9448
KG/HR	1.0060+04	8239.2925	8239.2925	183.2028	183.2028
L/MIN	294.0222	228.6366	228.6635	5.0637	5.0655
STATE VARIABLES:					
TEMP C	25.0000	1.8500	1.9142	13.2425	13.4582
PRES BAR	2.6340	3.9700	2.1000	1.2900	5.0000
VFRAC	0.0	0.0	0.0	1.5437-07	0.0
LFRAC	1.0000	1.0000	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-3.5072+04	-3.5752+04	-3.5752+04	-3.7084+04	-3.7072+04
CAL/GM	-603.7037	-614.3719	-614.3719	-596.0885	-595.8926
CAL/SEC	-1.6870+06	-1.4061+06	-1.4061+06	-3.0335+04	-3.0325+04
ENTROPY:					
CAL/MOL-K	-105.0836	-108.6478	-108.6322	-113.3994	-113.3890
CAL/GM-K	-1.8088	-1.8671	-1.8668	-1.8228	-1.8226
DENSITY:					
MOL/CC	9.8156-03	1.0321-02	1.0320-02	9.6925-03	9.6890-03
GM/CC	0.5702	0.6006	0.6005	0.6030	0.6028
AVG MW	58.0952	58.1920	58.1920	62.2123	62.2123
SUBSTREAM ATTRIBUTES:					
PSD					

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STREAM SECTION

14 15 16 17 18

STREAM ID	14	15	16	17	18
FROM :	T-101	P-103	P-104	E-105	----
TO :	P-103	P-104	E-105	M-100	C-100
TOTAL STREAM:					
KG/HR	8056.0897	8056.0897	8056.0897	8056.0897	5.7701+05
CAL/SEC	-1.3758+06	-1.3750+06	-1.3733+06	-7.0315+05	-9038.8476
SUBSTREAM: MIXED					
PHASE:	LIQUID	LIQUID	LIQUID	VAPOR	VAPOR
COMPONENTS: KMOL/HR					
NITROGEN	0.0	0.0	0.0	0.0	1.5800+04
CO	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	4200.0000
CO2	0.0	0.0	0.0	0.0	0.0
C3	0.0	0.0	0.0	0.0	0.0
IC4	9.5354-07	9.5354-07	9.5354-07	9.5354-07	0.0
2-ME-C3	5.4375-07	5.4375-07	5.4375-07	5.4375-07	0.0
1-C4	3.7831-06	3.7831-06	3.7831-06	3.7831-06	0.0
N-BUTANE	137.4812	137.4812	137.4812	137.4812	0.0
T2-C4	0.8429	0.8429	0.8429	0.8429	0.0
C2-C4	0.3179	0.3179	0.3179	0.3179	0.0
C5	1.1223-03	1.1223-03	1.1223-03	1.1223-03	0.0
WATER	0.0	0.0	0.0	0.0	0.0
MA(L)	0.0	0.0	0.0	0.0	0.0

```
   MA(S)                  0.0         0.0         0.0         0.0
0.0
 TOTAL FLOW:
   KMOL/HR              138.6432    138.6432    138.6432    138.6432
2.0000+04
   KG/HR               8056.0897   8056.0897   8056.0897   8056.0897
5.7701+05
   L/MIN                223.5944    223.7800    224.1441   5934.1396
8.1512+06
 STATE VARIABLES:
   TEMP   C               1.6566      2.1085      2.9915    375.0000
25.0000
   PRES   BAR             1.1000      5.0000     20.0000     19.9900
1.0133
   VFRAC                  0.0         0.0         0.0         1.0000
1.0000
   LFRAC                  1.0000      1.0000      1.0000      0.0
0.0
   SFRAC                  0.0         0.0         0.0         0.0
0.0
 ENTHALPY:
   CAL/MOL            -3.5724+04 -3.5704+04 -3.5658+04 -1.8258+04
-1.6270
   CAL/GM              -614.7937   -614.4593   -613.6631   -314.2158
-5.6394-02
   CAL/SEC            -1.3758+06 -1.3750+06 -1.3733+06 -7.0315+05
-9038.8476
 ENTROPY:
   CAL/MOL-K           -108.5749   -108.5374   -108.4963    -68.0683
1.0161
   CAL/GM-K              -1.8685     -1.8679     -1.8672     -1.1714
3.5220-02
 DENSITY:
   MOL/CC              1.0334-02  1.0326-02  1.0309-02  3.8939-04
4.0894-05
   GM/CC                  0.6005      0.6000      0.5990  2.2626-02
1.1798-03
 AVG MW                  58.1066     58.1066     58.1066     58.1066
28.8504
 SUBSTREAM ATTRIBUTES:
 PSD
```

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STREAM SECTION

19 2 20 21 22

STREAM ID	19	2	20	21	22
FROM :	C-100	P-100	E-106	C-101	E-107
TO :	E-106	E-100	C-101	E-107	M-100
TOTAL STREAM:					
KG/HR	5.7701+05	1.0060+04	5.7701+05	5.7701+05	5.7701+05
CAL/SEC	8.8497+06	-1.6869+06	5.4090+05	8.3881+06	1.3851+07
SUBSTREAM: MIXED					
PHASE:	VAPOR	LIQUID	VAPOR	VAPOR	VAPOR
COMPONENTS: KMOL/HR					
NITROGEN	1.5800+04	0.0	1.5800+04	1.5800+04	1.5800+04
CO	0.0	0.0	0.0	0.0	0.0
O2	4200.0000	0.0	4200.0000	4200.0000	4200.0000
CO2	0.0	0.0	0.0	0.0	0.0
C3	0.0	0.8658	0.0	0.0	0.0
IC4	0.0	28.2251	0.0	0.0	0.0
2-ME-C3	0.0	0.8658	0.0	0.0	0.0
1-C4	0.0	0.3463	0.0	0.0	0.0
N-BUTANE	0.0	140.7791	0.0	0.0	0.0
T2-C4	0.0	0.8658	0.0	0.0	0.0
C2-C4	0.0	0.3463	0.0	0.0	0.0
C5	0.0	0.8658	0.0	0.0	0.0
WATER	0.0	0.0	0.0	0.0	0.0
MA(L)	0.0	0.0	0.0	0.0	0.0

```
   MA(S)                  0.0        0.0        0.0        0.0
0.0
 TOTAL FLOW:
   KMOL/HR             2.0000+04   173.1600  2.0000+04  2.0000+04
2.0000+04
   KG/HR               5.7701+05  1.0060+04  5.7701+05  5.7701+05
5.7701+05
   L/MIN               2.9097+06   294.0537  1.7364+06  7.1483+05
9.0341+05
 STATE VARIABLES:
   TEMP   C             251.2044    25.0509    40.0000   240.3547
375.0000
   PRES   BAR             5.0000     3.3900     4.9900    20.0000
19.9900
   VFRAC                  1.0000     0.0        1.0000     1.0000
1.0000
   LFRAC                  0.0        1.0000     0.0        0.0
0.0
   SFRAC                  0.0        0.0        0.0        0.0
0.0
 ENTHALPY:
   CAL/MOL             1592.9550 -3.5070+04    97.3614  1509.8503
2493.2413
   CAL/GM                55.2143  -603.6614     3.3747    52.3338
86.4197
   CAL/SEC             8.8497+06 -1.6869+06  5.4090+05  8.3881+06
1.3851+07
 ENTROPY:
   CAL/MOL-K              1.8198  -105.0816    -1.8229    -1.1001
0.6008
   CAL/GM-K            6.3078-02    -1.8088 -6.3183-02 -3.8131-02
2.0824-02
 DENSITY:
   MOL/CC              1.1456-04  9.8145-03  1.9197-04  4.6631-04
3.6897-04
   GM/CC               3.3050-03     0.5702  5.5384-03  1.3453-02
1.0645-02
 AVG MW                  28.8504    58.0952    28.8504    28.8504
28.8504
 SUBSTREAM ATTRIBUTES:
 PSD
```

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STREAM SECTION

23 24 25 26 27

STREAM ID	23	24	25	26	27
FROM :	M-100	R-100	C-102	VAL-101	----
TO :	R-100	C-102	VAL-101	----	S-100
TOTAL STREAM:					
KG/HR	5.8506+05	5.8506+05	5.8506+05	5.8506+05	5.8506+05
CAL/SEC	1.3148+07	2.4967+06	-9.0709+06	-1.1291+07	-1.1291+07
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	VAPOR	MIXED	MIXED
COMPONENTS: KMOL/HR					
NITROGEN	1.5800+04	1.5800+04	1.5800+04	1.5800+04	1.5800+04
CO	0.0	97.5374	97.5374	97.5374	97.5374
O2	4200.0000	3759.9926	3759.9926	3759.9926	3759.9900
CO2	0.0	81.7403	81.7403	81.7403	81.7403
C3	0.0	0.0	0.0	0.0	0.0
IC4	9.5354-07	9.5354-07	9.5354-07	9.5354-07	9.5354-07
2-ME-C3	5.4375-07	5.4375-07	5.4375-07	5.4375-07	5.4375-07
1-C4	3.7831-06	3.7831-06	3.7831-06	3.7831-06	3.7831-06
N-BUTANE	137.4812	36.2475	36.2475	36.2475	36.2475
T2-C4	0.8429	0.8429	0.8429	0.8429	0.8430
C2-C4	0.3179	0.3179	0.3179	0.3179	0.3179
C5	1.1223-03	1.1223-03	1.1223-03	1.1223-03	1.1223-03
WATER	0.0	449.7541	449.7541	449.7541	449.7540
MA(L)	0.0	56.4142	56.4142	2.2382-09	0.0

MA(S)	0.0	0.0	0.0	56.4142	56.4142
TOTAL FLOW:					
KMOL/HR	2.0139+04	2.0283+04	2.0283+04	2.0283+04	2.0283+04
KG/HR	5.8506+05	5.8506+05	5.8506+05	5.8506+05	5.8506+05
L/MIN	9.0944+05	9.1528+05	4.1376+06	6.3900+06	6.3900+06
STATE VARIABLES:					
TEMP C	374.8628	375.0000	95.0250	46.2184	46.2184
PRES BAR	19.9900	20.0000	2.5000	1.4000	1.4000
VFRAC	1.0000	1.0000	1.0000	0.9972	0.9972
LFRAC	0.0	0.0	0.0	0.0	0.0
SFRAC	0.0	0.0	0.0	2.7814-03	2.7814-03
ENTHALPY:					
CAL/MOL	2350.3804	443.1325	-1610.0008	-2004.0433	-2004.0431
CAL/GM	80.9031	15.3624	-55.8151	-69.4757	-69.4756
CAL/SEC	1.3148+07	2.4967+06	-9.0709+06	-1.1291+07	-1.1291+07
ENTROPY:					
CAL/MOL-K	0.2091	0.6386	0.6386	0.6381	0.6381
CAL/GM-K	7.1978-03	2.2140-02	2.2140-02	2.2121-02	2.2121-02
DENSITY:					
MOL/CC	3.6907-04	3.6934-04	8.1701-05	5.2902-05	5.2902-05
GM/CC	1.0722-02	1.0654-02	2.3567-03	1.5260-03	1.5260-03
AVG MW	29.0518	28.8453	28.8453	28.8453	28.8453
SUBSTREAM ATTRIBUTES:					
PSD					
FRAC1	MISSING	0.0	0.0	0.0	3.1686-05
FRAC2	MISSING	0.0	0.0	0.0	1.3183-03
FRAC3	MISSING	0.0	0.0	0.0	2.1400-02
FRAC4	MISSING	0.0	0.0	0.0	0.1359

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STREAM SECTION

23 24 25 26 27 (CONTINUED)

STREAM ID	23	24	25	26	27
FRAC5	MISSING	0.0	0.0	0.0	0.3413
FRAC6	MISSING	0.0	0.0	0.0	0.3413
FRAC7	MISSING	0.0	0.0	0.0	0.1359
FRAC8	MISSING	0.0	0.0	0.0	2.1400-02
FRAC9	MISSING	0.0	0.0	0.0	1.3183-03
FRAC10	MISSING	0.0	0.0	0.0	3.1399-05

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STREAM SECTION

28 29 3 30 31

STREAM ID	28	29	3	30	31
FROM :	S-100	S-100	E-100	S-101	S-101
TO :	S-101	----	E-101	S-102	----
TOTAL STREAM:					
KG/HR	5.8320+05	1861.8835	1.0060+04	5.8047+05	2734.3957
CAL/SEC	-1.0702+07	-5.8854+05	-1.2780+06	-9.8364+06	-8.6433+05
SUBSTREAM: MIXED					
PHASE:	MIXED	SOLID	VAPOR	MIXED	SOLID
COMPONENTS: KMOL/HR					
NITROGEN	1.5800+04	0.0	0.0	1.5800+04	0.0
CO	97.5374	0.0	0.0	97.5374	0.0
O2	3759.9900	0.0	0.0	3759.9900	0.0
CO2	81.7403	0.0	0.0	81.7403	0.0
C3	0.0	0.0	0.8658	0.0	0.0
IC4	9.5354-07	0.0	28.2251	9.5354-07	0.0
2-ME-C3	5.4375-07	0.0	0.8658	5.4375-07	0.0
1-C4	3.7831-06	0.0	0.3463	3.7831-06	0.0
N-BUTANE	36.2475	0.0	140.7791	36.2475	0.0
T2-C4	0.8430	0.0	0.8658	0.8430	0.0
C2-C4	0.3179	0.0	0.3463	0.3179	0.0
C5	1.1223-03	0.0	0.8658	1.1223-03	0.0
WATER	449.7540	0.0	0.0	449.7540	0.0
MA(L)	0.0	0.0	0.0	0.0	0.0

MA(S)	37.4266	18.9876	0.0	9.5412	27.8855
TOTAL FLOW:					
KMOL/HR	2.0264+04	18.9876	173.1600	2.0236+04	27.8855
KG/HR	5.8320+05	1861.8835	1.0060+04	5.8047+05	2734.3957
L/MIN	6.8819+06	20.7148	2.9412+04	7.4551+06	30.4221
STATE VARIABLES:					
TEMP C	46.2184	46.2184	154.0000	46.2184	46.2184
PRES BAR	1.3000	1.4000	3.3800	1.2001	1.3000
VFRAC	0.9982	0.0	1.0000	0.9995	0.0
LFRAC	0.0	0.0	0.0	0.0	0.0
SFRAC	1.8470-03	1.0000	0.0	4.7150-04	1.0000
ENTHALPY:					
CAL/MOL	-1901.2038	-1.1159+05	-2.6570+04	-1749.8977	-1.1159+05
CAL/GM	-66.0590	-1137.9483	-457.3573	-61.0041	-1137.9483
CAL/SEC	-1.0702+07	-5.8854+05	-1.2780+06	-9.8364+06	-8.6433+05
ENTROPY:					
CAL/MOL-K	0.8521	-70.5555	-79.1707	1.1097	-70.5555
CAL/GM-K	2.9608-02	-0.7195	-1.3628	3.8684-02	-0.7195
DENSITY:					
MOL/CC	4.9075-05	1.5277-02	9.8124-05	4.5240-05	1.5277-02
GM/CC	1.4124-03	1.4980	5.7005-03	1.2977-03	1.4980
AVG MW	28.7804	98.0581	58.0952	28.6849	98.0581
SUBSTREAM ATTRIBUTES:					
PSD					
FRAC1	3.8082-05	1.9078-05	MISSING	7.4251-05	2.5707-05
FRAC2	1.5559-03	8.4990-04	MISSING	2.6305-03	1.1882-03
FRAC3	2.4365-02	1.5557-02	MISSING	3.5423-02	2.0581-02
FRAC4	0.1476	0.1128	MISSING	0.1836	0.1353

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STREAM SECTION

28 29 3 30 31 (CONTINUED)

STREAM ID	28	29	3	30	31
FRAC5	0.3514	0.3216	MISSING	0.3725	0.3441
FRAC6	0.3315	0.3608	MISSING	0.2986	0.3427
FRAC7	0.1241	0.1591	MISSING	9.4755-02	0.1342
FRAC8	1.8356-02	2.7399-02	MISSING	1.1837-02	2.0587-02
FRAC9	1.0607-03	1.8260-03	MISSING	5.7597-04	1.2265-03
FRAC10	2.3684-05	4.6606-05	MISSING	1.0791-05	2.8096-05

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STREAM SECTION

32 33 34 35 4

STREAM ID	32	33	34	35	4
FROM :	S-102	S-102	S-103	S-103	E-101
TO :	S-103	----	----	----	E-102
TOTAL STREAM:					
KG/HR	5.7978+05	687.3249	5.7960+05	181.1556	1.0060+04
CAL/SEC	-9.6182+06	-2.1726+05	-9.5600+06	-5.7263+04	-1.2392+06
SUBSTREAM: MIXED					
PHASE:	MIXED	SOLID	MIXED	SOLID	VAPOR
COMPONENTS: KMOL/HR					
NITROGEN	1.5800+04	0.0	1.5800+04	0.0	0.0
CO	97.5374	0.0	97.5374	0.0	0.0
O2	3759.9900	0.0	3759.9900	0.0	0.0
CO2	81.7403	0.0	81.7403	0.0	0.0
C3	0.0	0.0	0.0	0.0	0.8658
IC4	9.5354-07	0.0	9.5354-07	0.0	28.2251
2-ME-C3	5.4375-07	0.0	5.4375-07	0.0	0.8658
1-C4	3.7831-06	0.0	3.7831-06	0.0	0.3463
N-BUTANE	36.2475	0.0	36.2475	0.0	140.7791
T2-C4	0.8430	0.0	0.8430	0.0	0.8658
C2-C4	0.3179	0.0	0.3179	0.0	0.3463
C5	1.1223-03	0.0	1.1223-03	0.0	0.8658
WATER	449.7540	0.0	449.7540	0.0	0.0
MA(L)	0.0	0.0	0.0	0.0	0.0

MA(S)	2.5318	7.0094	0.6844	1.8474	0.0
TOTAL FLOW:					
KMOL/HR	2.0229+04	7.0094	2.0227+04	1.8474	173.1600
KG/HR	5.7978+05	687.3249	5.7960+05	181.1556	1.0060+04
L/MIN	8.1335+06	7.6470	8.9474+06	2.0155	3.1380+04
STATE VARIABLES:					
TEMP C	46.2184	46.2184	46.2184	46.2184	179.0000
PRES BAR	1.1000	1.2001	1.0000	1.1000	3.3700
VFRAC	0.9999	0.0	1.0000	0.0	1.0000
LFRAC	0.0	0.0	0.0	0.0	0.0
SFRAC	1.2516-04	1.0000	3.3834-05	1.0000	0.0
ENTHALPY:					
CAL/MOL	-1711.6791	-1.1159+05	-1701.4834	-1.1159+05	-2.5762+04
CAL/GM	-59.7217	-1137.9483	-59.3791	-1137.9483	-443.4441
CAL/SEC	-9.6182+06	-2.1726+05	-9.5600+06	-5.7263+04	-1.2392+06
ENTROPY:					
CAL/MOL-K	1.3078	-70.5555	1.5040	-70.5555	-77.3264
CAL/GM-K	4.5629-02	-0.7195	5.2489-02	-0.7195	-1.3310
DENSITY:					
MOL/CC	4.1452-05	1.5277-02	3.7678-05	1.5277-02	9.1970-05
GM/CC	1.1880-03	1.4980	1.0796-03	1.4980	5.3430-03
AVG MW	28.6609	98.0581	28.6546	98.0581	58.0952
SUBSTREAM ATTRIBUTES:					
PSD					
FRAC1	1.4529-04	4.8590-05	2.8169-04	9.4767-05	MISSING
FRAC2	4.4288-03	1.9809-03	7.3480-03	3.3474-03	MISSING
FRAC3	5.0898-02	2.9834-02	7.1682-02	4.3198-02	MISSING
FRAC4	0.2240	0.1690	0.2664	0.2083	MISSING

STREAM SECTION

32 33 34 35 4 (CONTINUED)

STREAM ID	32	33	34	35	4
FRAC5	0.3842	0.3682	0.3842	0.3842	MISSING
FRAC6	0.2596	0.3127	0.2174	0.2752	MISSING
FRAC7	6.9194-02	0.1040	4.8372-02	7.6907-02	MISSING
FRAC8	7.2347-03	1.3499-02	4.2040-03	8.3574-03	MISSING
FRAC9	2.9350-04	6.7800-04	1.4111-04	3.4995-04	MISSING
FRAC10	4.5635-06	1.3040-05	1.8057-06	5.5851-06	MISSING

STREAM SECTION

5 6 7 8 9

STREAM ID	5	6	7	8	9
FROM :	E-102	E-103	T-100	P-101	T-100
TO :	E-103	T-100	P-101	----	E-104
TOTAL STREAM:					
KG/HR	1.0060+04	1.0060+04	1820.4684	1820.4684	8239.2925
CAL/SEC	-1.1178+06	-1.0313+06	-3.1517+05	-3.1510+05	-1.3515+06
SUBSTREAM: MIXED					
PHASE:	VAPOR	VAPOR	LIQUID	LIQUID	MIXED
COMPONENTS: KMOL/HR					
NITROGEN	0.0	0.0	0.0	0.0	0.0
CO	0.0	0.0	0.0	0.0	0.0
O2	0.0	0.0	0.0	0.0	0.0
CO2	0.0	0.0	0.0	0.0	0.0
C3	0.8658	0.8658	0.8658	0.8658	7.9258-31
IC4	28.2251	28.2251	28.2251	28.2251	9.5355-07
2-ME-C3	0.8658	0.8658	0.8658	0.8658	5.4378-07
1-C4	0.3463	0.3463	0.3463	0.3463	3.7837-06
N-BUTANE	140.7791	140.7791	1.2613	1.2613	139.5178
T2-C4	0.8658	0.8658	7.7326-03	7.7326-03	0.8581
C2-C4	0.3463	0.3463	4.6227-06	4.6227-06	0.3463
C5	0.8658	0.8658	0.0	0.0	0.8658
WATER	0.0	0.0	0.0	0.0	0.0
MA(L)	0.0	0.0	0.0	0.0	0.0

MA(S)	0.0	0.0	0.0	0.0	0.0
TOTAL FLOW:					
KMOL/HR	173.1600	173.1600	31.5720	31.5720	141.5880
KG/HR	1.0060+04	1.0060+04	1820.4684	1820.4684	8239.2925
L/MIN	3.6832+04	4.0424+04	53.4919	53.5114	248.0995
STATE VARIABLES:					
TEMP C	251.0000	298.1500	12.8929	13.0621	41.9147
PRES BAR	3.3600	3.3500	2.5000	5.0000	3.9800
VFRAC	1.0000	1.0000	0.0	0.0	1.1077-08
LFRAC	0.0	0.0	1.0000	1.0000	1.0000
SFRAC	0.0	0.0	0.0	0.0	0.0
ENTHALPY:					
CAL/MOL	-2.3239+04	-2.1441+04	-3.5938+04	-3.5929+04	-3.4364+04
CAL/GM	-400.0155	-369.0636	-623.2578	-623.1174	-590.5265
CAL/SEC	-1.1178+06	-1.0313+06	-3.1517+05	-3.1510+05	-1.3515+06
ENTROPY:					
CAL/MOL-K	-72.1498	-68.8604	-107.4048	-107.3978	-103.9765
CAL/GM-K	-1.2419	-1.1853	-1.8627	-1.8626	-1.7868
DENSITY:					
MOL/CC	7.8357-05	7.1394-05	9.8370-03	9.8334-03	9.5115-03
GM/CC	4.5521-03	4.1477-03	0.5672	0.5670	0.5535
AVG MW	58.0952	58.0952	57.6609	57.6609	58.1920
SUBSTREAM ATTRIBUTES:					
PSD					

UTILITY SECTION

```
 UTILITY USAGE:  AIR-C     (GENERAL)
 -----------------------------------

  INPUT DATA:

    INLET TEMPERATURE                  25.0000  C
    OUTLET TEMPERATURE                 40.0000  C
    COOLING VALUE                       3.5827  CAL/GM
    PRICE                               0.0     $/KG
    INDEX TYPE                            FUEL

  RESULT:

    COOLING VALUE                       3.5827  CAL/GM
    INDEXED PRICE                      MISSING  $/KG

  THIS UTILITY IS PURCHASED

  THIS UTILITY IS NOT USED BY ANY COST OR UOS BLOCKS
```

UTILITY SECTION

UTILITY USAGE: AIR-H (GENERAL)

INPUT DATA:

INLET TEMPERATURE	25.0000	C
OUTLET TEMPERATURE	0.0	C
HEATING VALUE	3.5827	CAL/GM
PRICE	0.0	$/KG
INDEX TYPE	FUEL	

RESULT:

HEATING VALUE	3.5827	CAL/GM
INDEXED PRICE	MISSING	$/KG

THIS UTILITY IS PURCHASED

THIS UTILITY IS NOT USED BY ANY COST OR UOS BLOCKS

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UTILITY SECTION

UTILITY USAGE: CW (WATER)

INPUT DATA:

INLET TEMPERATURE	30.0000	C
OUTLET TEMPERATURE	40.0000	C
INLET PRESSURE	5.0000	BAR
OUTLET PRESSURE	4.9900	BAR
HEAT TRANSFER COEFFICIENT	6.7811-03	CAL/SEC-SQCM-K
PRICE	1.5826-09	$/CAL
INDEX TYPE	FUEL	

RESULT:

COOLING VALUE	9.9626	CAL/GM
INDEXED PRICE	1.5826-09	$/CAL

THIS UTILITY IS PURCHASED

USAGE:

BLOCK ID	MODEL	DUTY	USAGE RATE	COST
		CAL/SEC	KG/HR	$/HR
E-106	HEATER	8.3089+06	3.0024+06	47.3388
	TOTAL:	8.3089+06	3.0024+06	47.3388

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UTILITY SECTION

UTILITY USAGE: DOWA-H (GENERAL)

INPUT DATA:

INLET TEMPERATURE	380.0000	C
OUTLET TEMPERATURE	375.0000	C
HEAT TRANSFER COEFFICIENT	1.3562-02	CAL/SEC-SQCM-K
HEATING VALUE	3.0262	CAL/GM
PRICE	2.3697-08	$/CAL
INDEX TYPE	FUEL	

RESULT:

HEATING VALUE	3.0262	CAL/GM
INDEXED PRICE	2.3697-08	$/CAL

THIS UTILITY IS PURCHASED

USAGE:

BLOCK ID	MODEL	DUTY CAL/SEC	USAGE RATE KG/HR	COST $/HR
E-103	HEATER	8.6491+04	1.0289+05	7.3786
E-105	HEATER	6.7010+05	7.9717+05	57.1667
E-107	HEATER	5.4633+06	6.4992+06	466.0740
	TOTAL:	6.2199+06	7.3993+06	530.6193

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UTILITY SECTION

UTILITY USAGE: ELECT (ELECTRICITY)

INPUT DATA:

PRICE	6.7400-02	$/KWHR
INDEX TYPE	FUEL	

RESULT:

INDEXED PRICE	6.7400-02	$/KWHR

THIS UTILITY IS PURCHASED

USAGE:

BLOCK ID	MODEL	DUTY CAL/SEC	USAGE RATE KW	COST $/HR
VAL-101	HEATER	2.2201+06	9295.0498	626.4864
P-100	PUMP	131.0912	0.5489	3.6993-02
P-101	PUMP	78.8663	0.3302	2.2255-02
P-102	PUMP	11.0788	4.6385-02	3.1263-03
P-103	PUMP	748.3688	3.1333	0.2112
P-104	PUMP	1979.5900	8.2881	0.5586
C-100	COMPR	8.8588+06	3.7090+04	2499.8646
C-101	COMPR	7.8472+06	3.2854+04	2214.3929
C-102	COMPR	1.1568+07	4.8431+04	3264.2670
	TOTAL:	3.0497+07	1.2768+05	8605.8430

UTILITY SECTION

UTILITY USAGE: HPS (STEAM)

INPUT DATA:

INLET PRESSURE	42.0133	BAR
OUTLET PRESSURE	42.0133	BAR
INLET VAPOR FRACTION	1.0000	
OUTLET VAPOR FRACTION	0.0	
PRICE	5.6600	$/CAL
INDEX TYPE	FUEL	

RESULT:

HEATING VALUE	405.4015	CAL/GM
INDEXED PRICE	5.6600	$/CAL

THIS UTILITY IS PURCHASED

USAGE:

BLOCK ID	MODEL	DUTY CAL/SEC	USAGE RATE KG/HR	COST $/HR
E-102	HEATER	1.2136+05	1077.6498	2.4727+09
	TOTAL:	1.2136+05	1077.6498	2.4727+09

UTILITY SECTION

UTILITY USAGE: LPS (STEAM)

INPUT DATA:

INLET PRESSURE	6.0133	BAR
OUTLET PRESSURE	6.0133	BAR
INLET VAPOR FRACTION	1.0000	
OUTLET VAPOR FRACTION	0.0	
PRICE	8.4992-09	$/CAL
INDEX TYPE	FUEL	

RESULT:

HEATING VALUE	497.8481	CAL/GM
INDEXED PRICE	8.4992-09	$/CAL

THIS UTILITY IS PURCHASED

USAGE:

BLOCK ID	MODEL	DUTY CAL/SEC	USAGE RATE KG/HR	COST $/HR
E-100	HEATER	4.0883+05	2956.2920	12.5090
T-100	RADFRAC	2.7481+06	1.9872+04	84.0849
T-101	RADFRAC	1.2524+07	9.0565+04	383.2078
	TOTAL:	1.5681+07	1.1339+05	479.8017

UTILITY SECTION

UTILITY USAGE: MPS (STEAM)

INPUT DATA:

INLET PRESSURE	11.0133	BAR
OUTLET PRESSURE	11.0133	BAR
INLET VAPOR FRACTION	1.0000	
OUTLET VAPOR FRACTION	0.0	
PRICE	2.7800	$/CAL
INDEX TYPE	FUEL	

RESULT:

HEATING VALUE	477.2098	CAL/GM
INDEXED PRICE	2.7800	$/CAL

THIS UTILITY IS PURCHASED

USAGE:

BLOCK ID	MODEL	DUTY CAL/SEC	USAGE RATE KG/HR	COST $/HR
E-101	HEATER	3.8879+04	293.2964	3.8910+08
	TOTAL:	3.8879+04	293.2964	3.8910+08

UTILITY SECTION

UTILITY USAGE: R134A-C (REFRIGERANT)

INPUT DATA:

INLET TEMPERATURE	-5.0000	C
OUTLET TEMPERATURE	-5.0000	C
HEAT TRANSFER COEFFICIENT	1.3562-02	CAL/SEC-SQCM-K
COOLING VALUE	49.5128	CAL/GM
PRICE	3.5546-08	$/CAL
INDEX TYPE	FUEL	

RESULT:

COOLING VALUE	49.5128	CAL/GM
INDEXED PRICE	3.5546-08	$/CAL

THIS UTILITY IS PURCHASED

USAGE:

BLOCK ID	MODEL	DUTY CAL/SEC	USAGE RATE KG/HR	COST $/HR
E-104	HEATER	5.4575+04	3968.0463	6.9837
T-100	RADFRAC	3.3835+06	2.4601+05	432.9750
T-101	RADFRAC	1.2524+07	9.1062+05	1602.6787
	TOTAL:	1.5962+07	1.1606+06	2042.6374

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                             PROBLEM STATUS SECTION

 BLOCK STATUS
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*****************************************************************
***********
 *
*
 * Calculations were completed normally
*
 *
*
 * All Unit Operation blocks were completed normally
*
 *
*
 * All streams were flashed normally
*
 *
*
 * All Utility blocks were completed normally
*
 *
*
 * All Convergence blocks were completed normally
*
 *
*
 * Properties estimation was completed normally
*
 *
*

*****************************************************************
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APPENDIX II. DETAILED CALCULATIONS

- Heat exchanger sizing

$$\boldsymbol{Area = \frac{Q}{LMTD \cdot U}}$$

$$\boldsymbol{Area = \frac{5840122\ (\frac{BTU}{hr})}{42.61079\ \circ F \cdot 200\ (\frac{BTU}{ft^2 \cdot hr\ \cdot \circ F})} = 685.29\ ft^2}$$

- Reaction kinetics in Aspen Plus
  - Activation energy E:
    - Given E/R

$$\boldsymbol{E = (E/R) * R}$$

$$\boldsymbol{E = 8677\ [K] * 0.008314\ \left[\frac{kJ}{K * mol}\right] = 72.14\ kJ/mol}$$

  - Coefficient A for driving force constant
    - Given K_{diss} or K_{sorpt} = K_{eq}

$$\boldsymbol{A = ln(K_{eq})}$$

$$\boldsymbol{A = ln(0.42 * 10^{-4}) = -10.0778}$$

    - When a kinetic term in Aspen K_{eq} = 0, the coefficient A approaches -∞. The lowest number allowed in Aspen is -1e34, so that was the input for the coefficient A.

$$\boldsymbol{A = ln(0) \rightarrow\ -\infty}$$

- Diameter of nozzle
  - Mach number (Ma)

$$\boldsymbol{Ma = \sqrt{\frac{2}{k-1}\left[\left(\frac{P_0}{P}\right)^{\frac{k-1}{k}} - 1\right]}}$$

$$\boldsymbol{Ma = \sqrt{\frac{2}{1.4-1}\left[\left(\frac{2.5}{1.4}\right)^{\frac{1.4-1}{1.4}} - 1\right]} = 0.949}$$

  - Inlet area of nozzle (A)

$$\boldsymbol{A = \frac{Q}{u} = \frac{68.96\ m^3/s}{61\ m/s} = 1.13\ m^2}$$

- Area of nozzle throat (A_0)

$$\frac{A}{A_0} = \frac{1}{Ma}\left[\frac{1 + \frac{k-1}{2}(Ma)^2}{1 + \frac{k-1}{2}}\right]^{\frac{k+1}{2(k-1)}}$$

$$\frac{1.13}{A_0} = \frac{1}{0.949}\left[\frac{1 + \frac{1.4-1}{2}(0.949)^2}{1 + \frac{1.4-1}{2}}\right]^{\frac{1.4+1}{2(1.4-1)}} \rightarrow A_0 = 1.128\ m^2$$

- Diameter of nozzle throat (d_0)

$$d_0 = \sqrt{\frac{4A_0}{\pi}} = \sqrt{\frac{4(1.128\ m^2)}{\pi}} = 1.199\ m$$

Stream	Feed1	Top	Bottom
Stage	87	1	150
Pressure (N/m2)	250000	250000	250000
Vapour fraction (-)	1.00000	0.000000	0.000000
Temperature (K)	298.150	285.463	299.285
Enthalpy (J/kmol)	0.000000	-2.097E+07	-2.088E+07
Entropy (J/kmol/K)	-3104.14	-56214.7	-52462.3
Total molar flow (kmol/s)	0.0481000	0.00816997	0.0399300
Total mass flow (kg/s)	2.79768	0.471303	2.32638
Vapour std.vol.flow (m3/s)	1.13951		
Liquid std.vol.flow (m3/s)		8.4069E-04	0.00398399
Mole flows (kmol/s)			
propane	2.4050E-04	2.4050E-04	0.000000
isobut	0.00784059	0.00784058	2.1849E-11
1-but	9.6227E-05	8.8881E-05	7.3454E-06
n but	0.0391049	5.5991E-12	0.0391049
trans	2.4050E-04	5.6476E-16	2.4050E-04
cis	9.6227E-05	4.0249E-20	9.6227E-05
2-methy	2.4050E-04	0.000000	2.4050E-04
pentane	2.4050E-04	2.8760E-27	2.4050E-04
Mole fractions (-)			
propane	0.00500019	0.0294382	0.000000
isobut	0.163006	0.959683	5.4720E-10
1-but	0.00200057	0.0108791	1.8395E-04
n but	0.812992	6.8533E-10	0.979336
trans	0.00500019	6.9127E-14	0.00602327
cis	0.00200057	4.9265E-18	0.00240990
2-methy	0.00500019	0.000000	0.00602327
pentane	0.00500019	3.5202E-25	0.00602327
Mass flows (kg/s)			
propane	0.0106055	0.0106055	0.000000
isobut	0.455711	0.455710	1.2699E-09
1-but	0.00539894	0.00498681	4.1212E-04
n but	2.27286	3.2543E-10	2.27285
trans	0.0134940	3.1686E-14	0.0134940
cis	0.00539894	2.2582E-18	0.00539893
2-methy	0.0168676	0.000000	0.0168676
pentane	0.0173525	2.0750E-25	0.0173525
Mass fractions (-)			
propane	0.00379081	0.0225025	0.000000
isobut	0.162889	0.966917	5.4589E-10
1-but	0.00192979	0.0105809	1.7715E-04
n but	0.812406	6.9050E-10	0.976992
trans	0.00482328	6.7232E-14	0.00580043
cis	0.00192979	4.7915E-18	0.00232074
2-methy	0.00602914	0.000000	0.00725059
pentane	0.00620245	4.4027E-25	0.00745901

Figure II-1: ChemSep Data for Distillation Column 1

Stream	Feed1	Top	Bottom
Stage	3	1	20
Pressure (N/m2)	110000	110000	110000
Vapour fraction (-)	0.000000	0.000000	0.000000
Temperature (K)	275.000	274.804	290.049
Enthalpy (J/kmol)	-2.462E+07	-2.458E+07	-2.543E+07
Entropy (J/kmol/K)	-61675.9	-62347.7	-47808.0
Total molar flow (kmol/s)	0.0401640	0.0393461	8.1800E-04
Total mass flow (kg/s)	2.34002	2.28621	0.0538068
Vapour std.vol.flow (m3/s)			
Liquid std.vol.flow (m3/s)	0.00400738	0.00392047	8.6907E-05
Mole flows (kmol/s)			
n but	0.0393423	0.0390139	3.2838E-04
trans-	2.4196E-04	2.3988E-04	2.0891E-06
cis-	9.6811E-05	9.1414E-05	5.3966E-06
2-methyl-1-bute	2.4100E-04	5.4282E-07	2.4045E-04
n-pen	2.4196E-04	2.9555E-07	2.4167E-04
Mole fractions (-)			
n but	0.979540	0.991559	0.401447
trans-	0.00602452	0.00609667	0.00255394
cis-	0.00241040	0.00232335	0.00659734
2-methyl-1-bute	0.00600039	1.3796E-05	0.293957
n-pen	0.00602452	7.5117E-06	0.295444
Mass flows (kg/s)			
n but	2.28665	2.26757	0.0190863
trans-	0.0135759	0.0134587	1.1721E-04
cis-	0.00543170	0.00512892	3.0278E-04
2-methyl-1-bute	0.0169021	3.8070E-05	0.0168640
n-pen	0.0174578	2.1324E-05	0.0174365
Mass fractions (-)			
n but	0.977194	0.991844	0.354719
trans-	0.00580162	0.00588689	0.00217839
cis-	0.00232122	0.00224341	0.00562723
2-methyl-1-bute	0.00722304	1.6652E-05	0.313417
n-pen	0.00746054	9.3273E-06	0.324058

Figure II-2: ChemSep Data for Distillation Column 2

APPENDIX III. SAFETY DATA SHEETS

Butane

Carbon Dioxide

Carbon Monoxide

Hydrogen

Maleic Anhydride

Nitrogen

Oxygen

Vanadium Oxide Catalyst

MATERIAL SAFETY DATA SHEET (MSDS)
BUTANE
Please ensure that this MSDS is received by an appropriate person

DATE: May 2015 | Version 3 |

Ref. No.: MS088

1 PRODUCT AND COMPANY IDENTIFICATION

Product Name	n-Butane iso-Butane
Chemical Formula	C_4H_{10}
Trade Names	Butane, Pure
Colour coding	Dulux Light Weatherwork, Grey body with Red (A11) circle, 250 mm diameter, below the valve.
Valve	OMECA: Brass 5/8 inch BSP left hand female (vapour outlet) Liquid outlet ¼ inch flare fitting
Company Identification	African Oxygen Limited 23 Webber Street Johannesburg, 2001 Tel No: (011) 490-0400 Fax No: (011) 490-0506
EMERGENCY NUMBER	**0860 020202 or (011) 873 4382 (24 hours)**

2 COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name	n-Butane Iso-Butane
Chemical Family	Aliphatic hydrocarbons
CAS No.	106-97-8
UN No.	1969
ERG No.	115
Hazard Warning	2 A Flammable Gas

3 HAZARDS IDENTIFICATION

Main Hazards

All cylinders are portable gas containers, and must be regarded as pressure vessels at all times. Vaporised Butane liquid is highly flammable and can form explosive mixtures with air. The flammability limits in air are 1,8 -8,4% by volume. Vaporised Butane does not support life. It can act as a simple asphyxiant by diluting the concentration of oxygen in air to below levels necessary to support life. Exposure to the liquid phase could result in serious cold burns.

Adverse Health Effects

Butane is non-toxic. Prolonged inhalation of high concentrations has an anaesthetic effect, but could also act as a simple asphyxiant by displacing oxygen in the air to below levels necessary to support life.

Chemical Hazards

On complete combustion no hazardous compounds are formed.

Biological Hazards

Contact with the liquid phase could result in frostbite.

Vapour Inhalation

Since vaporised Butane acts as a simple asphyxiant, death may result from errors in judgement, confusion, or loss of consciousness which prevents self-rescue. At low oxygen concentrations, unconsciousness and death may occur in seconds without warning.

Eye Contact

Vapour Phase	None
Liquid Phase	Serious cold burns could result

Skin Contact

Vapour Phase	None
Liquid Phase	Frostbite

Ingestion

Liquid Phase	Serious cold burns could result

Label Elements

Hazard Pictograms

Hazard category 1

Danger

Extremely flammable gas

Precautionary Statements:

P210:	Keep away from heat/sparks/open flames/hot surfaces
P377:	Leaking gas fire: Do not extinguish unless leak can be stop safely
P381:	Eliminate all sources of ignition
P403:	Store in well ventilated place

4 FIRST AID MEASURES

Prompt medical attention is mandatory in all cases of overexposure to vaporised Butane. Rescue personnel should be equipped with self-contained breathing apparatus. In case of frostbite from contact with the liquid phase, place the frost-bitten part in warm water, about 40-42◦C. If warm water is not available, wrap the affected part gently in blankets. Encourage the patient to exercise the affected part whilst it is being warmed. Do not remove clothing while frosted. Conscious persons should be assisted to an uncontaminated area and inhale fresh air. Quick removal from the contaminated area is most important. Unconscious persons should be removed to an uncontaminated area, and given mouth-to-mouth resuscitation and supplemental oxygen.

Eye Contact

Liquid Phase - Immediately flush with large quantities of tepid water, or with sterile saline solution. Seek medical attention.

Skin Contact

Liquid Phase – See above for handling of frostbite.

Ingestion

No known effect.

5 FIRE FIGHTING MEASURES

Extinguishing Media

Do not extinguish fire unless the leakage can be stopped. Do not use water jet. Use dry chemical, CO_2 or foam.

Specific Hazards

The rupturing cylinders or bulk containers due to excessive exposure to a fire could result in a BLEVE (Boiling Liquid Expanding Vapour Explosion), with disastrous effects. As the flammability limits in air for Butane are 1,8 - 8,4% by volume, extreme care must be taken when handling leaks.

Emergency Actions

If possible, shut off the source of the spillage. Evacuate area. Post notices "NO NAKED LIGHTS - NO SMOKING". Prevent liquid or vapour from entering sewers, basements and work-pits. Keep cylinders or bulk vessels cool by spraying with water if exposed to a fire. If tanker has overturned, do not attempt to right or move it. CONTACT THE NEAREST AFROX BRANCH.

Protective Clothing

AFROX
A Member of The Linde Group

MATERIAL SAFETY DATA SHEET (MSDS)
BUTANE
Please ensure that this MSDS is received by an appropriate person

Ref. No.: MS088

Self-contained breathing apparatus, safety gloves, goggles and shoes or boots should be worn when handling containers.

Environmental Precautions

Vaporised Butane is heavier than air and could form pockets of oxygen-deficient atmosphere in low-lying areas.

6 ACCIDENTAL RELEASE MEASURES

Personal Precautions

Do not enter any area where Butane has been spilled unless tests have shown that it is safe to do so.

Environmental Precautions

The danger of widespread formation of explosive Butane/Air mixtures should be taken into account. Accidental ignition could result in a massive explosion.

Small Spills

DO NOT extinguish the fire unless the leakage can be stopped immediately. Once the fire has been extinguished and all spills have been stopped, ventilate the area.

Large Spills

Stop the source if it can be done without risk. Contain the leaking liquid with sand or earth, or disperse with special water/fog spray nozzle. Allow to evaporate. Take the precautions as listed above under "Emergency Actions". Restrict access to the area until completion of the clean-up procedure. Ventilate the area using forced draught if necessary. All electrical equipment should be flameproof.

7 HANDLING AND STORAGE

Cylinders containing Butane should only be handled and stored in the vertical position. Cylinders should never be rolled. Do not allow cylinders to slide or come into contact with sharp edges, and they should be handled carefully. Ensure that cylinders are stored away from other oxidants. Comply with all local legislation. Keep out of reach of children.

8 EXPOSURE CONTROLS/PERSONAL PROTECTION

Occupational Exposure Hazards

As vapourised Butane is a simple asphyxiant, avoid any areas where spillage has taken place. Only enter once testing has proved the atmosphere to be.

Engineering Control Measures

Engineering control measures are preferred to reduce exposure to oxygen depleted atmospheres. General methods include forced-draught ventilation, separate from other exhaust ventilation systems. Ensure that sufficient fresh air enters at, or near, floor level. Ensure that all electrical equipment is flameproof.

Personal Protection

Self-contained breathing apparatus should always be worn when entering area where oxygen depletion may have occurred. Safety goggles, gloves and shoes, or boots, should be worn when handling containers.

Skin Wear loose-fitting overalls, preferably without pockets.

9 PHYSICAL AND CHEMICAL PROPERTIES

PHYSICAL DATA

Chemical Symbol	C_4H_{10}
Molecular Weight	58,124
Specific volume @ 20°C & 101,325 kPa	398 ml/g
Boiling point @ 101,32 kPa	- 0,5°C
Density, gas @ 20°C & 101,35 kPa	2,544 kg/m^3
Relative density (Air = 1)	2,11
Auto-ignition temperature	430°C
Flammability limits in air	1,8 - 8,4% (by volume)
Colour	None
Taste	None
Odour	Slight

10 STABILITY AND REACTIVITY

Conditions to avoid

The dilution of the oxygen concentration in the atmosphere to levels which cannot support life. The formation of explosive gas/air mixtures.

Incompatible Materials

Any common, commercially available metals may be used with Butane as it is non-corrosive, though installations must be designed to withstand the pressures involved and must comply with all state and local regulations.

Hazardous Decomposition Products

The formation of carbon monoxide may occur when incomplete combustion occurs.

11 TOXICOLOGICAL INFORMATION

Acute Toxicity	TLV 600 vpm
Skin & Eye contact	No known effect
Chronic Toxicity	No known effect
Carcinogenicity	Severe cold burns can result in carcinoma
Mutagenicity	No known effect
Reproductive Hazards	No known effect

(For further information see Section 3. Adverse Health effects)

12 ECOLOGICAL INFORMATION

Vaporised Butane is heavier than air, and can cause pockets of oxygen-depleted atmosphere in low-lying areas. It does not pose a hazard to the ecology, unless the gas/air mixture is ignited.

13 DISPOSAL CONSIDERATIONS

Disposal Methods

Personnel familiar with the gas and the procedures for disposal, as with other gases, should only undertake disposal of Butane. Contact supplier for instructions. In general, should it become necessary to dispose of Butane, the best procedure, as for other flammable gases, is to burn it in any suitable burning unit available in the plant. This should be done in accordance with the appropriate regulations.

Disposal of Packaging

The gas supplier must only handle the disposal of containers.

14 TRANSPORT INFORMATION

ROAD TRANSPORTATION	
UN No	1969
ERG No	115
Hazchem warning	2 A Flammable Gas
SEA TRANSPORTATION	
IMDG	1969
Class	2.1
Label	Flammable Gas
AIR TRANSPORTATION	
ICAO/IATA Code	1969
Class	2.1
Packaging instructions	
- Cargo	200
- Passenger	Forbidden
Maximum quantity allowed	
- Cargo	150 kg
- Passenger	Forbidden

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MATERIAL SAFETY DATA SHEET (MSDS)
BUTANE
Please ensure that this MSDS is received by an appropriate person

DATE: May 2015 Version 3

Ref. No.: MS088

15 REGULATORY INFORMATION

Hazard Statement	Description
H220	Extremely flammable gas

National legislation: OHSAct & Regulations 85 of 1993
Refer to SABS 10234 Globally Harmonized System of classification and labelling of Chemicals (GHS) for explanation of the above.

16 OTHER INFORMATION

Bibliography

Compressed Gas Association, Arlington, Virginia
Handbook of Compressed Gases – 3rd Edition
Matheson. Matheson Gas Data Book – 6th Edition

17 EXCLUSION OF LIABILITY

Information contained in this publication is accurate at the date of publication. The company does not accept liability arising from the use of this information, or the use, application, adaptation or process of any products described herein.

SAFETY DATA SHEET

Airgas
an Air Liquide company

Carbon Dioxide

Section 1. Identification

GHS product identifier	:	Carbon Dioxide
Chemical name	:	Carbon dioxide, gas
Other means of identification	:	Carbonic, Carbon Dioxide, Carbonic Anhydride, R744, Carbon Dioxide USP
Product type	:	Gas.
Product use	:	Synthetic/Analytical chemistry and Medical use.
Synonym	:	Carbonic, Carbon Dioxide, Carbonic Anhydride, R744, Carbon Dioxide USP
SDS #	:	001013
Supplier's details	:	Airgas USA, LLC and its affiliates 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
24-hour telephone	:	1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : GASES UNDER PRESSURE - Liquefied gas
Simple asphyxiant.

GHS label elements

Hazard pictograms :

Signal word : Warning

Hazard statements : Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.
May increase respiration and heart rate.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Always keep container in upright position.

Prevention : Use and store only outdoors or in a well ventilated place.

Response : Not applicable.

Storage : Protect from sunlight. Store in a well-ventilated place.

Disposal : Not applicable.

Hazards not otherwise classified : In addition to any other important health or physical hazards, this product may displace oxygen and cause rapid suffocation.
May cause frostbite.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : Carbon dioxide, gas

Other means of identification : Carbonic, Carbon Dioxide, Carbonic Anhydride, R744, Carbon Dioxide USP

Product code : 001013

CAS number/other identifiers

CAS number : 124-38-9

Ingredient name	%	CAS number
Carbon Dioxide	100	124-38-9

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Skin contact : Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : No known significant effects or critical hazards.

Inhalation : No known significant effects or critical hazards.

Skin contact : No known significant effects or critical hazards.

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

Specific treatments : No specific treatment.

Section 4. First aid measures

Protection of first-aiders	: No action shall be taken involving any personal risk or without suitable training. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media	: Use an extinguishing agent suitable for the surrounding fire.
Unsuitable extinguishing media	: None known.
Specific hazards arising from the chemical	: Contains gas under pressure. In a fire or if heated, a pressure increase will occur and the container may burst or explode.
Hazardous thermal decomposition products	: Decomposition products may include the following materials: carbon dioxide carbon monoxide
Special protective actions for fire-fighters	: Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool.
Special protective equipment for fire-fighters	: Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel	: No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Avoid breathing gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.
For emergency responders	: If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".
Environmental precautions	: Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill	: Immediately contact emergency personnel. Stop leak if without risk.
Large spill	: Immediately contact emergency personnel. Stop leak if without risk. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

Protective measures	: Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Avoid breathing gas. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement. Avoid contact with eyes, skin and clothing. Empty containers retain product residue and can be hazardous.

Section 7. Handling and storage

Advice on general occupational hygiene : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.

Conditions for safe storage, including any incompatibilities : Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F). Keep container tightly closed and sealed until ready for use. See Section 10 for incompatible materials before handling or use.

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
Carbon Dioxide	**ACGIH TLV (United States, 3/2017). Oxygen Depletion [Asphyxiant].** STEL: 54000 mg/m³ 15 minutes. STEL: 30000 ppm 15 minutes. TWA: 9000 mg/m³ 8 hours. TWA: 5000 ppm 8 hours. **NIOSH REL (United States, 10/2016).** STEL: 54000 mg/m³ 15 minutes. STEL: 30000 ppm 15 minutes. TWA: 9000 mg/m³ 10 hours. TWA: 5000 ppm 10 hours. **OSHA PEL (United States, 6/2016).** TWA: 9000 mg/m³ 8 hours. TWA: 5000 ppm 8 hours. **OSHA PEL 1989 (United States, 3/1989).** STEL: 54000 mg/m³ 15 minutes. STEL: 30000 ppm 15 minutes. TWA: 18000 mg/m³ 8 hours. TWA: 10000 ppm 8 hours.

Appropriate engineering controls : Good general ventilation should be sufficient to control worker exposure to airborne contaminants.

Environmental exposure controls : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.

Skin protection

Section 8. Exposure controls/personal protection

Hand protection	: Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.
Body protection	: Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Other skin protection	: Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Respiratory protection	: Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Section 9. Physical and chemical properties

Appearance

Physical state	: Gas. [Compressed gas.]	
Color	: Colorless.	
Odor	: Odorless.	
Odor threshold	: Not available.	
pH	: Not available.	
Melting point	: Sublimation temperature: -79°C (-110.2 to °F)	
Boiling point	: Not available.	
Critical temperature	: 30.85°C (87.5°F)	
Flash point	: [Product does not sustain combustion.]	
Evaporation rate	: Not available.	
Flammability (solid, gas)	: Not available.	
Lower and upper explosive (flammable) limits	: Not available.	
Vapor pressure	: 830 (psig)	
Vapor density	: 1.53 (Air = 1)	Liquid Density@BP: Solid density = 97.5 lb/ft3 (1562 kg/m3)
Specific Volume (ft^3/lb)	: 8.7719	
Gas Density (lb/ft^3)	: 0.114	
Relative density	: Not applicable.	
Solubility	: Not available.	
Solubility in water	: Not available.	
Partition coefficient: n-octanol/water	: 0.83	
Auto-ignition temperature	: Not available.	
Decomposition temperature	: Not available.	
Viscosity	: Not applicable.	
Flow time (ISO 2431)	: Not available.	
Molecular weight	: 44.01 g/mole	

Section 10. Stability and reactivity

Reactivity	: No specific test data related to reactivity available for this product or its ingredients.
Chemical stability	: The product is stable.
Possibility of hazardous reactions	: Under normal conditions of storage and use, hazardous reactions will not occur.
Conditions to avoid	: No specific data.
Incompatible materials	: No specific data.
Hazardous decomposition products	: Under normal conditions of storage and use, hazardous decomposition products should not be produced.
Hazardous polymerization	: Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Not available.

Irritation/Corrosion

Not available.

Sensitization

Not available.

Mutagenicity

Not available.

Carcinogenicity

Not available.

Reproductive toxicity

Not available.

Teratogenicity

Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Information on the likely routes of exposure	: Not available.

Potential acute health effects

Eye contact	: No known significant effects or critical hazards.
Inhalation	: No known significant effects or critical hazards.
Skin contact	: No known significant effects or critical hazards.

Section 11. Toxicological information

Ingestion : As this product is a gas, refer to the inhalation section.

Symptoms related to the physical, chemical and toxicological characteristics

Eye contact : No specific data.
Inhalation : No specific data.
Skin contact : No specific data.
Ingestion : No specific data.

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

Potential immediate effects : Not available.
Potential delayed effects : Not available.

Long term exposure

Potential immediate effects : Not available.
Potential delayed effects : Not available.

Potential chronic health effects

Not available.

General : No known significant effects or critical hazards.
Carcinogenicity : No known significant effects or critical hazards.
Mutagenicity : No known significant effects or critical hazards.
Teratogenicity : No known significant effects or critical hazards.
Developmental effects : No known significant effects or critical hazards.
Fertility effects : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Product/ingredient name	$LogP_{ow}$	BCF	Potential
Carbon Dioxide	0.83	-	low

Mobility in soil

Soil/water partition coefficient (K_{OC}) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	TDG	Mexico	IMDG	IATA
UN number	UN1013	UN1013	UN1013	UN1013	UN1013
UN proper shipping name	CARBON DIOXIDE	CARBON DIOXIDE	CARBON DIOXIDE	CARBON DIOXIDE	CARBON DIOXIDE
Transport hazard class(es)	2.2 	2.2 	2.2 	2.2 	2.2 
Packing group	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Additional information

DOT Classification : **Limited quantity** Yes.
Quantity limitation Passenger aircraft/rail: 75 kg. Cargo aircraft: 150 kg.

TDG Classification : Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2).
Explosive Limit and Limited Quantity Index 0.125
Passenger Carrying Road or Rail Index 75

IATA : **Quantity limitation** Passenger and Cargo Aircraft: 75 kg. Cargo Aircraft Only: 150 kg.

Special precautions for user : **Transport within user's premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Transport in bulk according to Annex II of MARPOL and the IBC Code : Not available.

Section 15. Regulatory information

U.S. Federal regulations : **TSCA 8(a) CDR Exempt/Partial exemption**: This material is listed or exempted.

Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs) : Not listed

Section 15. Regulatory information

Clean Air Act Section 602 Class I Substances	: Not listed
Clean Air Act Section 602 Class II Substances	: Not listed
DEA List I Chemicals (Precursor Chemicals)	: Not listed
DEA List II Chemicals (Essential Chemicals)	: Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

SARA 311/312

Classification : Refer to Section 2: Hazards Identification of this SDS for classification of substance.

State regulations

Massachusetts	: This material is listed.
New York	: This material is not listed.
New Jersey	: This material is listed.
Pennsylvania	: This material is listed.

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

Montreal Protocol (Annexes A, B, C, E)

Not listed.

Stockholm Convention on Persistent Organic Pollutants

Not listed.

Rotterdam Convention on Prior Informed Consent (PIC)

Not listed.

UNECE Aarhus Protocol on POPs and Heavy Metals

Not listed.

Inventory list

Australia	: This material is listed or exempted.
Canada	: This material is listed or exempted.
China	: This material is listed or exempted.
Europe	: This material is listed or exempted.
Japan	: **Japan inventory (ENCS)**: This material is listed or exempted. **Japan inventory (ISHL)**: This material is listed or exempted.
Malaysia	: Not determined.
New Zealand	: This material is listed or exempted.
Philippines	: This material is listed or exempted.
Republic of Korea	: This material is listed or exempted.
Taiwan	: This material is listed or exempted.
Thailand	: Not determined.
Turkey	: This material is listed or exempted.
United States	: This material is listed or exempted.
Viet Nam	: Not determined.

Section 16. Other information

Hazardous Material Information System (U.S.A.)

Health	/	1
Flammability		0
Physical hazards		3

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS® ratings and the associated label are not required on SDSs or products leaving a facility under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered trademark and service mark of the American Coatings Association, Inc.

The customer is responsible for determining the PPE code for this material. For more information on HMIS® Personal Protective Equipment (PPE) codes, consult the HMIS® Implementation Manual.

National Fire Protection Association (U.S.A.)

Reprinted with permission from NFPA 704-2001, Identification of the Hazards of Materials for Emergency Response Copyright ©1997, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject which is represented only by the standard in its entirety.

Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
GASES UNDER PRESSURE - Liquefied gas	Expert judgment

History

Date of printing : 2/12/2018

Date of issue/Date of revision : 2/12/2018

Date of previous issue : 4/25/2017

Version : 0.03

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

Notice to reader

Section 16. Other information

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

SAFETY DATA SHEET

Carbon Monoxide

Airgas
an Air Liquide company

Section 1. Identification

GHS product identifier : Carbon Monoxide

Chemical name : carbon monoxide

Other means of identification : Carbon oxide (CO); CO; Exhaust gas; Flue gas; Carbonic oxide; Carbon oxide; Carbone (oxyde de); Carbonio (ossido di); Kohlenmonoxid; Kohlenoxyd; Koolmonoxyde; NA 9202; Oxyde de carbone; UN 1016; Wegla tlenek; Carbon monooxide

Product type : Gas.

Product use : Synthetic/Analytical chemistry.

Synonym : Carbon oxide (CO); CO; Exhaust gas; Flue gas; Carbonic oxide; Carbon oxide; Carbone (oxyde de); Carbonio (ossido di); Kohlenmonoxid; Kohlenoxyd; Koolmonoxyde; NA 9202; Oxyde de carbone; UN 1016; Wegla tlenek; Carbon monooxide

SDS # : 001014

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : FLAMMABLE GASES - Category 1
GASES UNDER PRESSURE - Compressed gas
ACUTE TOXICITY (inhalation) - Category 3
TOXIC TO REPRODUCTION (Fertility) - Category 1
TOXIC TO REPRODUCTION (Unborn child) - Category 1
SPECIFIC TARGET ORGAN TOXICITY (REPEATED EXPOSURE) - Category 1

GHS label elements

Hazard pictograms :

Signal word : Danger

Hazard statements : Extremely flammable gas.
Contains gas under pressure; may explode if heated.
Toxic if inhaled.
May damage fertility or the unborn child.
Causes damage to organs through prolonged or repeated exposure.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Approach suspected leak area with caution.

Section 2. Hazards identification

Prevention	: Obtain special instructions before use. Do not handle until all safety precautions have been read and understood. Wear protective gloves. Wear eye or face protection. Wear protective clothing. Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking. Use only outdoors or in a well-ventilated area. Do not breathe gas. Do not eat, drink or smoke when using this product. Wash hands thoroughly after handling.
Response	: Get medical attention if you feel unwell. IF exposed or concerned: Get medical attention. IF INHALED: Remove person to fresh air and keep comfortable for breathing. Call a POISON CENTER or physician. Leaking gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if safe to do so.
Storage	: Store locked up. Protect from sunlight. Store in a well-ventilated place.
Disposal	: Dispose of contents and container in accordance with all local, regional, national and international regulations.
Hazards not otherwise classified	: In addition to any other important health or physical hazards, this product may displace oxygen and cause rapid suffocation.

Section 3. Composition/information on ingredients

Substance/mixture	: Substance
Chemical name	: carbon monoxide
Other means of identification	: Carbon oxide (CO); CO; Exhaust gas; Flue gas; Carbonic oxide; Carbon oxide; Carbone (oxyde de); Carbonio (ossido di); Kohlenmonoxid; Kohlenoxyd; Koolmonoxyde; NA 9202; Oxyde de carbone; UN 1016; Wegla tlenek; Carbon monooxide
Product code	: 001014

CAS number/other identifiers

CAS number : 630-08-0

Ingredient name	%	CAS number
carbon monoxide	100	630-08-0

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact	: Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention.
Inhalation	: Remove victim to fresh air and keep at rest in a position comfortable for breathing. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention. If necessary, call a poison center or physician. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.
Skin contact	: Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Continue to rinse for at least 10 minutes. Get medical attention. Wash clothing before reuse. Clean shoes thoroughly before reuse.
Ingestion	: As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Section 4. First aid measures

Potential acute health effects

Eye contact	: Contact with rapidly expanding gas may cause burns or frostbite.
Inhalation	: Toxic if inhaled.
Skin contact	: Contact with rapidly expanding gas may cause burns or frostbite.
Frostbite	: Try to warm up the frozen tissues and seek medical attention.
Ingestion	: As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact	: No specific data.
Inhalation	: Adverse symptoms may include the following:, reduced fetal weight, increase in fetal deaths, skeletal malformations
Skin contact	: Adverse symptoms may include the following:, reduced fetal weight, increase in fetal deaths, skeletal malformations
Ingestion	: Adverse symptoms may include the following:, reduced fetal weight, increase in fetal deaths, skeletal malformations

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician	: Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.
Specific treatments	: No specific treatment.
Protection of first-aiders	: No action shall be taken involving any personal risk or without suitable training. If it is suspected that fumes are still present, the rescuer should wear an appropriate mask or self-contained breathing apparatus. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Wash contaminated clothing thoroughly with water before removing it, or wear gloves.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media	: Use an extinguishing agent suitable for the surrounding fire.
Unsuitable extinguishing media	: None known.
Specific hazards arising from the chemical	: Contains gas under pressure. Extremely flammable gas. In a fire or if heated, a pressure increase will occur and the container may burst, with the risk of a subsequent explosion.
Hazardous thermal decomposition products	: Decomposition products may include the following materials: carbon dioxide carbon monoxide
Special protective actions for fire-fighters	: Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool. If involved in fire, shut off flow immediately if it can be done without risk. If this is impossible, withdraw from area and allow fire to burn. Fight fire from protected location or maximum possible distance. Eliminate all ignition sources if safe to do so.
Special protective equipment for fire-fighters	: Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel	: Accidental releases pose a serious fire or explosion hazard. No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Shut off all ignition sources. No flares, smoking or flames in hazard area. Do not breathe gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.
For emergency responders	: If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".
Environmental precautions	: Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill	: Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment.
Large spill	: Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

Protective measures	: Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Avoid exposure - obtain special instructions before use. Avoid exposure during pregnancy. Do not handle until all safety precautions have been read and understood. Do not get in eyes or on skin or clothing. Do not breathe gas. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment. Use only non-sparking tools. Empty containers retain product residue and can be hazardous. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
Advice on general occupational hygiene	: Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.
Conditions for safe storage, including any incompatibilities	: Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Store locked up. Eliminate all ignition sources. Keep container tightly closed and sealed until ready for use. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F).

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Section 8. Exposure controls/personal protection

Ingredient name	Exposure limits
carbon monoxide	**California PEL for Chemical Contaminants (*Table AC-1*) (United States).** PEL: 25 ppm 8 hours. CEIL: 200 ppm **ACGIH TLV (United States, 3/2017).** TWA: 25 ppm 8 hours. TWA: 29 mg/m³ 8 hours. **OSHA PEL 1989 (United States, 3/1989).** TWA: 35 ppm 8 hours. TWA: 40 mg/m³ 8 hours. CEIL: 200 ppm CEIL: 229 mg/m³ **NIOSH REL (United States, 10/2016).** TWA: 35 ppm 10 hours. TWA: 40 mg/m³ 10 hours. CEIL: 200 ppm CEIL: 229 mg/m³ **OSHA PEL (United States, 6/2016).** TWA: 50 ppm 8 hours. TWA: 55 mg/m³ 8 hours.

Appropriate engineering controls : Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapor or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

Environmental exposure controls : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.

Skin protection

Hand protection : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.

Body protection : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product. When there is a risk of ignition from static electricity, wear anti-static protective clothing. For the greatest protection from static discharges, clothing should include anti-static overalls, boots and gloves.

Section 8. Exposure controls/personal protection

Other skin protection	: Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Respiratory protection	: Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Section 9. Physical and chemical properties

Appearance	
Physical state	: Gas. [Compressed gas.]
Color	: Colorless.
Odor	: Odorless.
Odor threshold	: Not available.
pH	: Not available.
Melting point	: -211.6°C (-348.9°F)
Boiling point	: -191.52°C (-312.7°F)
Critical temperature	: -140.15°C (-220.3°F)
Flash point	: Not available.
Evaporation rate	: Not available.
Flammability (solid, gas)	: Extremely flammable in the presence of the following materials or conditions: open flames, sparks and static discharge and oxidizing materials.
Lower and upper explosive (flammable) limits	: Lower: 10.9% Upper: 74.2%
Vapor pressure	: Not available.
Vapor density	: 0.97 (Air = 1)
Specific Volume (ft^3/lb)	: 13.8889
Gas Density (lb/ft^3)	: 0.072
Relative density	: Not applicable.
Solubility	: Not available.
Solubility in water	: Not available.
Partition coefficient: n-octanol/water	: Not available.
Auto-ignition temperature	: 607°C (1124.6°F)
Decomposition temperature	: Not available.
Viscosity	: Not applicable.
Flow time (ISO 2431)	: Not available.
Molecular weight	: 28.01 g/mole
Aerosol product	
Heat of combustion	: -10101818 J/kg

Section 10. Stability and reactivity

Reactivity	: No specific test data related to reactivity available for this product or its ingredients.
Chemical stability	: The product is stable.
Possibility of hazardous reactions	: Under normal conditions of storage and use, hazardous reactions will not occur.

Section 10. Stability and reactivity

Conditions to avoid : Avoid all possible sources of ignition (spark or flame). Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition.

Incompatible materials : Oxidizers

Hazardous decomposition products : Under normal conditions of storage and use, hazardous decomposition products should not be produced.

Hazardous polymerization : Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Product/ingredient name	Result	Species	Dose	Exposure
carbon monoxide	LC50 Inhalation Gas.	Rat	3760 ppm	1 hours

Irritation/Corrosion

Not available.

Sensitization

Not available.

Mutagenicity

Not available.

Carcinogenicity

Not available.

Reproductive toxicity

Not available.

Teratogenicity

Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Name	Category	Route of exposure	Target organs
carbon monoxide	Category 1	Not determined	Not determined

Aspiration hazard

Not available.

Information on the likely routes of exposure : Routes of entry anticipated: Inhalation.

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.

Inhalation : Toxic if inhaled.

Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.

Ingestion : As this product is a gas, refer to the inhalation section.

Symptoms related to the physical, chemical and toxicological characteristics

Section 11. Toxicological information

Eye contact : No specific data.

Inhalation : Adverse symptoms may include the following:, reduced fetal weight, increase in fetal deaths, skeletal malformations

Skin contact : Adverse symptoms may include the following:, reduced fetal weight, increase in fetal deaths, skeletal malformations

Ingestion : Adverse symptoms may include the following:, reduced fetal weight, increase in fetal deaths, skeletal malformations

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Long term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Potential chronic health effects

Not available.

General : Causes damage to organs through prolonged or repeated exposure.

Carcinogenicity : No known significant effects or critical hazards.

Mutagenicity : No known significant effects or critical hazards.

Teratogenicity : May damage the unborn child.

Developmental effects : No known significant effects or critical hazards.

Fertility effects : May damage fertility.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Not available.

Mobility in soil

Soil/water partition coefficient (K_{OC}) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	TDG	Mexico	IMDG	IATA
UN number	UN1016	UN1016	UN1016	UN1016	UN1016
UN proper shipping name	CARBON MONOXIDE, COMPRESSED	CARBON MONOXIDE, COMPRESSED	CARBON MONOXIDE, COMPRESSED	CARBON MONOXIDE, COMPRESSED	CARBON MONOXIDE, COMPRESSED
Transport hazard class(es)	2.3 (2.1)	2.3 (2.1)	2.3 (2.1)	2.3 (2.1)	2.3 (2.1)
Packing group	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Additional information

DOT Classification : Toxic - Inhalation hazard Zone D
Limited quantity Yes.
Quantity limitation Passenger aircraft/rail: Forbidden. Cargo aircraft: 25 kg.
Special provisions 4

TDG Classification : Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2), 2.13-2.17 (Class 2).
Explosive Limit and Limited Quantity Index 0
ERAP Index 500
Passenger Carrying Ship Index Forbidden
Passenger Carrying Road or Rail Index Forbidden

IATA : **Quantity limitation** Passenger and Cargo Aircraft: Forbidden. Cargo Aircraft Only: Forbidden.

Special precautions for user : **Transport within user's premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Transport in bulk according to Annex II of MARPOL and the IBC Code : Not available.

Section 15. Regulatory information

U.S. Federal regulations	: **TSCA 8(a) CDR Exempt/Partial exemption**: Not determined
Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs)	: Not listed
Clean Air Act Section 602 Class I Substances	: Not listed
Clean Air Act Section 602 Class II Substances	: Not listed
DEA List I Chemicals (Precursor Chemicals)	: Not listed
DEA List II Chemicals (Essential Chemicals)	: Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

SARA 311/312

Classification : Refer to Section 2: Hazards Identification of this SDS for classification of substance.

State regulations

Massachusetts	: This material is listed.
New York	: This material is not listed.
New Jersey	: This material is listed.
Pennsylvania	: This material is listed.

California Prop. 65

⚠ **WARNING**: This product can expose you to Carbon monoxide, which is known to the State of California to cause birth defects or other reproductive harm. For more information go to www.P65Warnings.ca.gov.

Ingredient name	No significant risk level	Maximum acceptable dosage level
Carbon monoxide	-	-

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

Montreal Protocol (Annexes A, B, C, E)

Not listed.

Stockholm Convention on Persistent Organic Pollutants

Not listed.

Rotterdam Convention on Prior Informed Consent (PIC)

Not listed.

UNECE Aarhus Protocol on POPs and Heavy Metals

Not listed.

Inventory list

Australia	: This material is listed or exempted.
Canada	: This material is listed or exempted.
China	: This material is listed or exempted.

Section 15. Regulatory information

Europe	: This material is listed or exempted.
Japan	: **Japan inventory (ENCS)**: This material is listed or exempted. **Japan inventory (ISHL)**: Not determined.
Malaysia	: Not determined.
New Zealand	: This material is listed or exempted.
Philippines	: This material is listed or exempted.
Republic of Korea	: This material is listed or exempted.
Taiwan	: This material is listed or exempted.
Thailand	: Not determined.
Turkey	: Not determined.
United States	: This material is listed or exempted.
Viet Nam	: Not determined.

Section 16. Other information

Hazardous Material Information System (U.S.A.)

Health	*	3
Flammability		4
Physical hazards		3

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS® ratings and the associated label are not required on SDSs or products leaving a facility under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered trademark and service mark of the American Coatings Association, Inc.

The customer is responsible for determining the PPE code for this material. For more information on HMIS® Personal Protective Equipment (PPE) codes, consult the HMIS® Implementation Manual.

National Fire Protection Association (U.S.A.)

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Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
FLAMMABLE GASES - Category 1	Expert judgment
GASES UNDER PRESSURE - Compressed gas	According to package
ACUTE TOXICITY (inhalation) - Category 3	On basis of test data
TOXIC TO REPRODUCTION (Fertility) - Category 1	Expert judgment
TOXIC TO REPRODUCTION (Unborn child) - Category 1	Expert judgment
SPECIFIC TARGET ORGAN TOXICITY (REPEATED EXPOSURE) - Category 1	Expert judgment

History

Date of printing	: 11/29/2017

Section 16. Other information

Date of issue/Date of revision : 11/29/2017

Date of previous issue : 2/20/2017

Version : 1

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

Indicates information that has changed from previously issued version.

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

SAFETY DATA SHEET

Hydrogen

Airgas
an Air Liquide company

Section 1. Identification

GHS product identifier	: Hydrogen
Chemical name	: hydrogen
Other means of identification	: Dihydrogen; o-Hydrogen; p-Hydrogen; Molecular hydrogen; H2; UN 1049
Product type	: Gas.
Product use	: Synthetic/Analytical chemistry.
Synonym	: Dihydrogen; o-Hydrogen; p-Hydrogen; Molecular hydrogen; H2; UN 1049
SDS #	: 001026
Supplier's details	: Airgas USA, LLC and its affiliates 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
24-hour telephone	: 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status	: This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).
Classification of the substance or mixture	: FLAMMABLE GASES - Category 1 GASES UNDER PRESSURE - Compressed gas

GHS label elements

Hazard pictograms :

Signal word	: Danger
Hazard statements	: Extremely flammable gas. May form explosive mixtures with air. Contains gas under pressure; may explode if heated. May displace oxygen and cause rapid suffocation. Burns with invisible flame.

Precautionary statements

General	: Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Approach suspected leak area with caution.
Prevention	: Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.
Response	: Leaking gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if safe to do so.
Storage	: Protect from sunlight. Store in a well-ventilated place.
Disposal	: Not applicable.
Hazards not otherwise classified	: In addition to any other important health or physical hazards, this product may displace oxygen and cause rapid suffocation.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : hydrogen

Other means of identification : Dihydrogen; o-Hydrogen; p-Hydrogen; Molecular hydrogen; H2; UN 1049

Product code : 001026

CAS number/other identifiers

CAS number : 1333-74-0

Ingredient name	%	CAS number
hydrogen	100	1333-74-0

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Skin contact : Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

Specific treatments : No specific treatment.

Section 4. First aid measures

Protection of first-aiders : No action shall be taken involving any personal risk or without suitable training. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media : Use an extinguishing agent suitable for the surrounding fire.

Unsuitable extinguishing media : None known.

Specific hazards arising from the chemical : Contains gas under pressure. Extremely flammable gas. In a fire or if heated, a pressure increase will occur and the container may burst, with the risk of a subsequent explosion.

Hazardous thermal decomposition products : No specific data.

Special protective actions for fire-fighters : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool. If involved in fire, shut off flow immediately if it can be done without risk. If this is impossible, withdraw from area and allow fire to burn. Fight fire from protected location or maximum possible distance. Eliminate all ignition sources if safe to do so.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel : Accidental releases pose a serious fire or explosion hazard. No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Shut off all ignition sources. No flares, smoking or flames in hazard area. Avoid breathing gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.

For emergency responders : If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".

Environmental precautions : Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment.

Large spill : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

Protective measures : Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Avoid breathing gas. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
Use only non-sparking tools. Avoid contact with eyes, skin and clothing. Empty containers retain product residue and can be hazardous. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment.

Advice on general occupational hygiene : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.

Conditions for safe storage, including any incompatibilities : Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Eliminate all ignition sources. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F). Keep container tightly closed and sealed until ready for use. See Section 10 for incompatible materials before handling or use.

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
hydrogen	**California PEL for Chemical Contaminants (*Table AC-1*) (United States). Oxygen Depletion [Asphyxiant].** **ACGIH TLV (United States, 3/2017). Oxygen Depletion [Asphyxiant].**

Appropriate engineering controls : Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapor or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

Environmental exposure controls : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Section 8. Exposure controls/personal protection

Eye/face protection	: Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.
Skin protection	
Hand protection	: Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.
Body protection	: Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product. When there is a risk of ignition from static electricity, wear anti-static protective clothing. For the greatest protection from static discharges, clothing should include anti-static overalls, boots and gloves.
Other skin protection	: Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Respiratory protection	: Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Section 9. Physical and chemical properties

Appearance	
Physical state	: Gas
Color	: Colorless.
Odor	: Odorless.
Odor threshold	: Not available.
pH	: Not available.
Melting point	: -259.15°C (-434.5°F)
Boiling point	: -253°C (-423.4°F)
Critical temperature	: -240.15°C (-400.3°F)
Flash point	: Not available.
Evaporation rate	: Not available.
Flammability (solid, gas)	: Extremely flammable in the presence of the following materials or conditions: oxidizing materials.
Lower and upper explosive (flammable) limits	: Lower: 4% Upper: 76%
Vapor pressure	: Not available.
Vapor density	: 0.07 (Air = 1) Liquid Density@BP: 4.43 lb/ft3 (70.96 kg/m3)
Specific Volume (ft^3/lb)	: 12.0482
Gas Density (lb/ft^3)	: 0.083
Relative density	: Not applicable.
Solubility	: Not available.
Solubility in water	: Not available.
Partition coefficient: n-octanol/water	: Not available.
Auto-ignition temperature	: 500 to 571°C (932 to 1059.8°F)
Decomposition temperature	: Not available.

Section 9. Physical and chemical properties

Viscosity	: Not applicable.
Flow time (ISO 2431)	: Not available.
Molecular weight	: 2.02 g/mole
Aerosol product	
Heat of combustion	: -116486080 J/kg

Section 10. Stability and reactivity

Reactivity	: No specific test data related to reactivity available for this product or its ingredients.
Chemical stability	: The product is stable.
Possibility of hazardous reactions	: Under normal conditions of storage and use, hazardous reactions will not occur.
Conditions to avoid	: Avoid all possible sources of ignition (spark or flame). Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition.
Incompatible materials	: Oxidizers
Hazardous decomposition products	: Under normal conditions of storage and use, hazardous decomposition products should not be produced.
Hazardous polymerization	: Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Not available.

Irritation/Corrosion

Not available.

Sensitization

Not available.

Mutagenicity

Not available.

Carcinogenicity

Not available.

Reproductive toxicity

Not available.

Teratogenicity

Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Section 11. Toxicological information

Information on the likely routes of exposure : Not available.

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.
Inhalation : No known significant effects or critical hazards.
Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.
Ingestion : As this product is a gas, refer to the inhalation section.

Symptoms related to the physical, chemical and toxicological characteristics

Eye contact : No specific data.
Inhalation : No specific data.
Skin contact : No specific data.
Ingestion : No specific data.

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

Potential immediate effects : Not available.
Potential delayed effects : Not available.

Long term exposure

Potential immediate effects : Not available.
Potential delayed effects : Not available.

Potential chronic health effects

Not available.

General : No known significant effects or critical hazards.
Carcinogenicity : No known significant effects or critical hazards.
Mutagenicity : No known significant effects or critical hazards.
Teratogenicity : No known significant effects or critical hazards.
Developmental effects : No known significant effects or critical hazards.
Fertility effects : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Not available.

Section 12. Ecological information

Mobility in soil

Soil/water partition coefficient (K_{OC}) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	TDG	Mexico	IMDG	IATA
UN number	UN1049	UN1049	UN1049	UN1049	UN1049
UN proper shipping name	HYDROGEN, COMPRESSED	HYDROGEN, COMPRESSED	HYDROGEN COMPRESSED	HYDROGEN, COMPRESSED	HYDROGEN, COMPRESSED
Transport hazard class(es)	2.1	2.1	2.1	2.1	2.1
Packing group	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Additional information

DOT Classification : **Limited quantity** Yes.
Quantity limitation Passenger aircraft/rail: Forbidden. Cargo aircraft: 150 kg.

TDG Classification : Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2).
Explosive Limit and Limited Quantity Index 0.125
ERAP Index 3000
Passenger Carrying Ship Index Forbidden
Passenger Carrying Road or Rail Index Forbidden

IATA : **Quantity limitation** Passenger and Cargo Aircraft: Forbidden. Cargo Aircraft Only: 150 kg.

Special precautions for user : **Transport within user's premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Section 14. Transport information

Transport in bulk according to Annex II of MARPOL and the IBC Code	: Not available.

Section 15. Regulatory information

U.S. Federal regulations	: **TSCA 8(a) CDR Exempt/Partial exemption**: This material is listed or exempted. **Clean Air Act (CAA) 112 regulated flammable substances**: hydrogen
Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs)	: Not listed
Clean Air Act Section 602 Class I Substances	: Not listed
Clean Air Act Section 602 Class II Substances	: Not listed
DEA List I Chemicals (Precursor Chemicals)	: Not listed
DEA List II Chemicals (Essential Chemicals)	: Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ	: Not applicable.

SARA 311/312

Classification	: Refer to Section 2: Hazards Identification of this SDS for classification of substance.

State regulations

Massachusetts	: This material is listed.
New York	: This material is not listed.
New Jersey	: This material is listed.
Pennsylvania	: This material is listed.

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

Montreal Protocol (Annexes A, B, C, E)

Not listed.

Stockholm Convention on Persistent Organic Pollutants

Not listed.

Rotterdam Convention on Prior Informed Consent (PIC)

Not listed.

UNECE Aarhus Protocol on POPs and Heavy Metals

Not listed.

Inventory list

Australia	: This material is listed or exempted.
Canada	: This material is listed or exempted.
China	: This material is listed or exempted.
Europe	: This material is listed or exempted.
Japan	: **Japan inventory (ENCS)**: Not determined. **Japan inventory (ISHL)**: Not determined.

Section 15. Regulatory information

Malaysia	: This material is listed or exempted.
New Zealand	: This material is listed or exempted.
Philippines	: This material is listed or exempted.
Republic of Korea	: This material is listed or exempted.
Taiwan	: This material is listed or exempted.
Thailand	: Not determined.
Turkey	: Not determined.
United States	: This material is listed or exempted.
Viet Nam	: Not determined.

Section 16. Other information

Hazardous Material Information System (U.S.A.)

Health	/	1
Flammability		4
Physical hazards		3

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS® ratings and the associated label are not required on SDSs or products leaving a facility under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered trademark and service mark of the American Coatings Association, Inc.

The customer is responsible for determining the PPE code for this material. For more information on HMIS® Personal Protective Equipment (PPE) codes, consult the HMIS® Implementation Manual.

National Fire Protection Association (U.S.A.)

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Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
FLAMMABLE GASES - Category 1 GASES UNDER PRESSURE - Compressed gas	Expert judgment According to package

History

Date of printing	: 9/27/2018
Date of issue/Date of revision	: 9/27/2018
Date of previous issue	: 2/2/2018
Version	: 1

Section 16. Other information

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

Notice to reader

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Safety Data Sheet

acc. to NOM-018-STPS-2015 and NMX-R-019-SFCI-2011

MALEIC ANHYDRIDE

Version number: GHS 1.0 Date of compilation: 2017-06-05

SECTION 1: Identification

1.1 Product identifier

Identification of the substance	MALEIC ANHYDRIDE
CAS number	108-31-6

Synonyms: cis-butenodioic anhydride, Dihydro - 2,5 - dioxofuran, 2,5 - furandiona, Maleic Acid anhydride, MAA, MALA, Toxílc anhydride, Maleic Abhydride.

1.2 Relevant identified uses of the substance or mixture and uses advised against

Relevant identified uses	Industrial use

1.3 Details of the supplier of the safety data sheet

RETER Comercializadora de Productos Petroquímicos S.A. de C.V.
Km. 154 Carr. México - Veracruz
90640 San Cosme Xaloztoc, Tlaxcala
Mexico

Telephone: +52 241 413 0000
Website: www.grupoidesa.com

e-mail (competent person) jalvarez@idesa.com.mx (Juan Carlos Alvarez)

1.4 Emergency telephone number

Emergency information service

01-800-00-214-00
Tel. (55) 5559 1588 Cd. de México.
SETIQ

SECTION 2: Hazard(s) identification

2.1 Classification of the substance or mixture

Classification acc. to GHS

Section	Hazard class	Category	Hazard class and category	Hazard statement
3.1O	acute toxicity (oral)	4	Acute Tox. 4	H302
3.1D	acute toxicity (dermal)	5	Acute Tox. 5	H313
3.2	skin corrosion/irritation	1B	Skin Corr. 1B	H314
3.3	serious eye damage/eye irritation	1	Eye Dam. 1	H318
3.4R	respiratory sensitization	1	Resp. Sens. 1	H334
3.4S	skin sensitization	1	Skin Sens. 1	H317
3.9	specific target organ toxicity - repeated exposure	1	STOT RE 1	H372
4.1A	hazardous to the aquatic environment - acute hazard	3	Aquatic Acute 3	H402

For full text of abbreviations: see SECTION 16.

The most important adverse physicochemical, human health and environmental effects

Skin corrosion produces an irreversible damage to the skin; namely, visible necrosis through the epidermis and into the dermis. Delayed or immediate effects can be expected after short or long-term exposure. Spillage and fire water can cause pollution of watercourses.

2.2 Label elements

Labeling

- Signal word: danger
- Pictograms

GHS05, GHS07, GHS08

- Hazard statements

H302	Harmful if swallowed.
H313	May be harmful in contact with skin.
H314	Causes severe skin burns and eye damage.
H317	May cause an allergic skin reaction.
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled.
H372	Causes damage to organs through prolonged or repeated exposure.
H402	Harmful to aquatic life.

- Precautionary statements

P260	Do not breathe dust/fume/gas/mist/vapors/spray.
P280	Wear protective gloves/eye protection/face protection.
P303+P361+P353	IF ON SKIN (or hair): Take off immediately all contaminated clothing. Rinse skin with water/shower.
P305+P351+P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P342+P311	If experiencing respiratory symptoms: Call a POISON CENTER/doctor.
P363	Wash contaminated clothing before reuse.
P501	Dispose of contents/container to industrial combustion plant.

2.3 Other hazards

Results of PBT and vPvB assessment

According to the results of its assessment, this substance is not a PBT or a vPvB.

SECTION 3: Composition/information on ingredients

3.1 Substances

Name of substance	MALEIC ANHYDRIDE
Identifiers	
CAS No	108-31-6
Molecular formula	C4H2O3
Molar mass	98.06 $^{g}/_{mol}$

SECTION 4: First-aid measures

4.1 Description of first- aid measures

General notes

Do not leave affected person unattended. Remove victim out of the danger area. Keep affected person warm, still and covered. Take off immediately all contaminated clothing. In all cases of doubt, or when symptoms persist, seek medical advice. In case of unconsciousness place person in the recovery position. Never give anything by mouth.

Following inhalation

If breathing is irregular or stopped, immediately seek medical assistance and start first aid actions. In case of respiratory tract irritation, consult a physician. Provide fresh air.

Following skin contact

Wash with plenty of soap and water.

Following eye contact

Remove contact lenses, if present and easy to do. Continue rinsing. Irrigate copiously with clean, fresh water for at least 10 minutes, holding the eyelids apart.

Following ingestion

Rinse mouth with water (only if the person is conscious). Do NOT induce vomiting.

4.2 Most important symptoms and effects, both acute and delayed

Symptoms and effects are not known to date.

4.3 Indication of any immediate medical attention and special treatment needed

none

SECTION 5: Fire-fighting measures

5.1 Extinguishing media

Suitable extinguishing media

Water, Foam, Alcohol resistant foam, ABC-powder

Unsuitable extinguishing media

Water jet

5.2 Special hazards arising from the substance or mixture

Hazardous combustion products

Nitrogen oxides (NOx), Carbon monoxide (CO), Carbon dioxide (CO2)

5.3 Advice for firefighters

In case of fire and/or explosion do not breathe fumes. Co-ordinate firefighting measures to the fire surroundings. Do not allow firefighting water to enter drains or water courses. Collect contaminated firefighting water separately. Fight fire with normal precautions from a reasonable distance.

SECTION 6: Accidental release measures

6.1 Personal precautions, protective equipment and emergency procedures

For non-emergency personnel

Remove persons to safety.

For emergency responders

Wear breathing apparatus if exposed to vapors/dust/aerosols/gases.

6.2 Environmental precautions

Keep away from drains, surface and ground water. Retain contaminated washing water and dispose of it.

6.3 Methods and material for containment and cleaning up

Advices on how to contain a spill

Covering of drains, Take up mechanically

Advices on how to clean up a spill

Take up mechanically.

Other information relating to spills and releases

Place in appropriate containers for disposal. Ventilate affected area.

6.4 Reference to other sections

Hazardous combustion products: see section 5. Personal protective equipment: see section 9. Incompatible materials: see section 10. Disposal considerations: see section 13.

SECTION 7: Handling and storage

7.1 Precautions for safe handling

Recommendations

- Measures to prevent fire as well as aerosol and dust generation

Use local and general ventilation. Use only in well-ventilated areas. Ground/bond container and receiving equipment.

- Specific notes/details

Dust deposits may accumulate on all deposition surfaces in a technical room. The product in the delivered form is not dust explosion capable; the enrichment of fine dust however leads to the danger of dust explosion.

Advice on general occupational hygiene

Wash hands after use. Do not eat, drink and smoke in work areas. Remove contaminated clothing and protective equipment before entering eating areas. Never keep food or drink in the vicinity of chemicals. Never place chemicals in containers that are normally used for food or drink. Keep away from food, drink and animal feedingstuffs.

7.2 Conditions for safe storage, including any incompatibilities

Managing of associated risks

- Explosive atmospheres

Removal of dust deposits.

- Packaging compatibilities

Only packagings which are approved (e.g. acc. to the Dangerous Goods Regulations) may be used.

7.3 Specific end use(s)

See section 16 for a general overview.

SECTION 8: Exposure controls/personal protection

8.1 Control parameters

Occupational exposure limit values (Workplace Exposure Limits)

Country	Name of agent	CAS No	Identifier	TWA [ppm]	TWA [mg/m³]	STEL [ppm]	STEL [mg/m³]	Source
MX	maleic anhydride	108-31-6	VLE		0.01			NOM-010-STPS

Notation

STEL short-term exposure limit: a limit value above which exposure should not occur and which is related to a 15-minute period unless otherwise specified

TWA time-weighted average (long-term exposure limit): measured or calculated in relation to a reference period of 8 hours time-weighted average

Human health values

Relevant DNELs and other threshold levels

Endpoint	Threshold level	Protection goal, route of exposure	Used in	Exposure time
DNEL	0.4 mg/m³	human, inhalatory	worker (industry)	chronic - systemic effects
DNEL	0.8 mg/m³	human, inhalatory	worker (industry)	acute - systemic effects
DNEL	0.4 mg/m³	human, inhalatory	worker (industry)	chronic - local effects
DNEL	0.8 mg/m³	human, inhalatory	worker (industry)	acute - local effects

Environment values

Relevant PNECs and other threshold levels

Endpoint	Threshold level	Organism	Environmental compartment	Exposure time
PNEC	0.1 mg/l	aquatic organisms	freshwater	short-term (single instance)
PNEC	0.01 mg/l	aquatic organisms	marine water	short-term (single instance)
PNEC	44.6 mg/l	aquatic organisms	sewage treatment plant (STP)	short-term (single instance)
PNEC	0.334 mg/kg	aquatic organisms	freshwater sediment	short-term (single instance)
PNEC	0.033 mg/kg	aquatic organisms	marine sediment	short-term (single instance)
PNEC	0.042 mg/kg	terrestrial organisms	soil	short-term (single instance)

8.2 Exposure controls

Appropriate engineering controls
General ventilation.

Individual protection measures (personal protective equipment)

Eye/face protection
Wear eye/face protection.

Skin protection

- Hand protection
In the case of wanting to use the gloves again, clean them before taking off and air them well.

- Other protection measures
Take recovery periods for skin regeneration. Preventive skin protection (barrier creams/ointments) is recommended. Wash hands thoroughly after handling.

Respiratory protection
In case of inadequate ventilation wear respiratory protection.

Environmental exposure controls
Use appropriate container to avoid environmental contamination. Keep away from drains, surface and ground water.

SECTION 9: Physical and chemical properties

9.1 Information on basic physical and chemical properties

Appearance

Physical state	solid Crystaline.
Color	Colourless or White.
Odor	Irritant, Acre, Asphyxiant.

Other safety parameters

pH (value)	not applicable
Melting point/freezing point	53 °C
Initial boiling point and boiling range	200.1 °C at 1,014 hPa
Flash point	103 °C
Evaporation rate	not determined
Flammability (solid, gas)	this material is combustible, but will not ignite readily
Lower explosion limit (LEL)	57 g/m^3 , 1.4%.
Upper explosion limit (UEL)	290 g/m^3 , 7.1%.
Vapor pressure	15.1 Pa at 22 °C
Density	0.93 $^{g}/_{cm^3}$ at 20 °C

	Vapor density	this information is not available
	Solubility(ies)	
	- Water solubility	400 $^{g}/_{l}$ at 20 °C
	Partition coefficient	
	- n-octanol/water (log KOW)	-2.61 (19.8 °C) (ECHA)
	- Soil organic carbon/water (log KOC)	1.624 (ECHA)
	Auto-ignition temperature	not determined
	Decomposition temperature	290 °C (ECHA)
	Viscosity	not relevant (solid matter)
	Explosive properties	none
	Oxidizing properties	none
9.2	**Other information**	

SECTION 10: Stability and reactivity

10.1 Reactivity

Strong oxidizing agents (perchlorates, peroxides, chromates, sodium hypochlorite) - may react violently or explosively. Increased risk of fire and explosion.
Water: reacts slowly with cold water, quickly with hot water, producing heat. It forms maleic acid. Warm water may cause foam. .

10.2 Chemical stability

See below "Conditions to avoid".

10.3 Possibility of hazardous reactions

No known hazardous reactions.

10.4 Conditions to avoid

Metals of alkali (sodium or potassium), alkalis (eg sodium hydroxide or potassium hydroxide), alkaline earth metals, (Calcium, magnesium or barium), alkaline earth hydroxides (calcium hydroxide), amines (eg dimethylamine, triethylamine), pyridine, Quinoline, sodium or potassium carbonates, aqueous ammonia, ammonium hydroxide or ammonium salts-at temperatures over 150 DEG c, mixtures can react to produce carbon dioxide, heat and pressure. Under these conditions, a mixture can be explosive. Small amounts as low as 200 ppm of the above chemicals are sufficient to begin decomposition.
Olefins (eg, ethylene, propylene or diethylene) and the catalyst mixtures may be subjected to a copolymerization uncontrolled.
Strong reducing agents (eg, phosphorus, tin (II) chloride, metal hydrides) may react vigorously or violently. Increased risk of fire.
Alcohols-react to the esters of the form.
Static load, sparks, heat, other sources of ignition, generation of dust and moisture.

Hints to prevent fire or explosion

The product in the delivered form is not dust explosion capable; the enrichment of fine dust however leads to the danger of dust explosion.

10.5 Incompatible materials

Oxidizers

10.6 Hazardous decomposition products

Reasonably anticipated hazardous decomposition products produced as a result of use, storage, spill and heating are not known. Hazardous combustion products: see section 5.

SECTION 11: Toxicological information

11.1 Information on toxicological effects

Classification acc. to GHS

Acute toxicity

Harmful if swallowed. May be harmful in contact with skin.

- Acute toxicity estimate (ATE)

Oral	1,090 $^{mg}/_{kg}$
Dermal	2,620 $^{mg}/_{kg}$

Skin corrosion/irritation

Causes severe skin burns and eye damage.

Serious eye damage/eye irritation

Causes serious eye damage.

Respiratory or skin sensitization

May cause allergy or asthma symptoms or breathing difficulties if inhaled. May cause an allergic skin reaction.

Germ cell mutagenicity

Shall not be classified as germ cell mutagenic.

Carcinogenicity

Shall not be classified as carcinogenic.

Reproductive toxicity

Shall not be classified as a reproductive toxicant.

Specific target organ toxicity - single exposure

Shall not be classified as a specific target organ toxicant (single exposure).

Specific target organ toxicity - repeated exposure

Causes damage to organs through prolonged or repeated exposure.

Aspiration hazard

Shall not be classified as presenting an aspiration hazard.

SECTION 12: Ecological information

12.1 Toxicity

Harmful to aquatic life.

Aquatic toxicity (acute)

Endpoint	Value	Species	Exposure time
LC50	75 $^{mg}/_{l}$	fish	96 h
EC50	42.81 $^{mg}/_{l}$	aquatic invertebrates	48 h
ErC50	74.35 $^{mg}/_{l}$	algae	72 h

12.2 Persistence and degradability

Data are not available.

12.3 Bioaccumulative potential

Data are not available.

n-octanol/water (log KOW)	-2.61 (19.8 °C) (ECHA)

12.4 Mobility in soil

Data are not available.

Henry's law constant	0 $^{Pa\,m^3}/_{mol}$ at 25 °C
The Organic Carbon normalised adsorption coefficient	1.624 (ECHA)

12.5 Results of PBT and vPvB assessment

Data are not available.

12.6 Other adverse effects

Data are not available.

SECTION 13: Disposal considerations

13.1 Waste treatment methods

Sewage disposal-relevant information

Do not empty into drains. Avoid release to the environment. Refer to special instructions/safety data sheets.

Waste treatment of containers/packages

Only packagings which are approved (e.g. acc. to the Dangerous Goods Regulations) may be used. Completely emptied packages can be recycled. Handle contaminated packages in the same way as the substance itself.

Remarks

Please consider the relevant national or regional provisions. Waste shall be separated into the categories that can be handled separately by the local or national waste management facilities.

SECTION 14: Transport information

14.1	**UN number**	2215
14.2	**UN proper shipping name**	MALEIC ANHYDRIDE
14.3	**Transport hazard class(es)**	
	Class	8 (corrosive substances)
14.4	**Packing group**	III (substance presenting low danger)
14.5	**Environmental hazards**	non-environmentally hazardous acc. to the dangerous goods regulations

14.6 Special precautions for user
There is no additional information.

14.7 Transport in bulk according to Annex II of MARPOL and the IBC Code
The cargo is not intended to be carried in bulk.

Information for each of the UN Model Regulations

Transport information - National regulations - Additional information (UN RTDG)

UN number	2215
Proper shipping name	MALEIC ANHYDRIDE
Class	8
Packing group	III
Danger label(s)	8

Special provisions (SP)	- (UN RTDG)
Excepted quantities (EQ)	E0 (UN RTDG)
Limited quantities (LQ)	0 (UN RTDG)

International Maritime Dangerous Goods Code (IMDG)

UN number	2215
Proper shipping name	MALEIC ANHYDRIDE
Class	8
Packing group	III
Danger label(s)	8

Special provisions (SP)	-
Excepted quantities (EQ)	E0
Limited quantities (LQ)	0
EmS	F-A, S-B
Stowage category	A

Segregation group	1 - Acids

International Civil Aviation Organization (ICAO-IATA/DGR)

UN number	2215
Proper shipping name	Maleic anhydride
Class	8
Packing group	III
Danger label(s)	8

Excepted quantities (EQ)	E1
Limited quantities (LQ)	5 kg

SECTION 15: Regulatory information

15.1 Safety, health and environmental regulations specific for the product in question

There is no additional information.

National regulations (United States)

Toxic Substance Control Act (TSCA) substance is listed

SARA TITLE III (Superfund Amendment and Reauthorization Act)

- List of Extremely Hazardous Substances (40 CFR 355) (EPCRA Section 302 and 304)
not listed

- Specific Toxic Chemical Listings (40 CFR 372) (EPCRA Section 313)

Toxics Release Inventory: Specific Toxic Chemical Listings

Name acc. to inventory	CAS No	Remarks	Effective date
maleic anhydride	108-31-6		1986-12-31

CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act)

- Section 102(A) Hazardous Substances (40 CFR 302.4)

Name of substance	CAS No	Remarks	Statutory code	Final RQ pounds (Kg)
maleic anhydride	108-31-6		1 3 4	5000 (2270)

Legend

1	"1" indicates that the statutory source is section 311(b)(2) of the Clean Water Act
3	"3" indicates that the source is section 112 of the Clean Air Act
4	"4" indicates that the source is section 3001 of the Resource Conservation and Recovery Act (RCRA)

Clean Air Act

not listed

New Jersey Worker and Community Right to Know Act N.J.S.A. 34:5A-1 et. seq.

Right to Know Hazardous Substance List			
Name acc. to inventory	**CAS No**	**Remarks**	**Classifications**
maleic anhydride	108-31-6		CO R1

Legend

CO Corrosive

R1 Reactive - First Degree

California Environmental Protection Agency (Cal/EPA): Proposition 65 Chemicals known to the State to cause cancer or reproductive toxicity

not listed

15.2 Chemical Safety Assessment

No Chemical Safety Assessment has been carried out for this substance.

SECTION 16: Other information, including date of preparation or last revision

Abbreviations and acronyms

Abbr.	Descriptions of used abbreviations
CAS	Chemical Abstracts Service (service that maintains the most comprehensive list of chemical substances)
DGR	Dangerous Goods Regulations (see IATA/DGR)
DNEL	Derived No-Effect Level
EmS	Emergency Schedule
GHS	"Globally Harmonized System of Classification and Labelling of Chemicals" developed by the United Nations
IATA	International Air Transport Association
IATA/DGR	Dangerous Goods Regulations (DGR) for the air transport (IATA)
ICAO	International Civil Aviation Organization
IMDG	International Maritime Dangerous Goods Code
MARPOL	International Convention for the Prevention of Pollution from Ships (abbr. of "Marine Pollutant")
NOM-010-STPS	NORMA Oficial Mexicana NOM-010-STPS: Agentes quimicos contaminantes del ambiente laboral-Reconocimiento, evaluación y control
PBT	Persistent, Bioaccumulative and Toxic
PNEC	Predicted No-Effect Concentration
ppm	Parts per million
STEL	Short-term exposure limit
TWA	Time-weighted average
VLE	Permissible exposure limit
vPvB	Very Persistent and very Bioaccumulative

MALEIC ANHYDRIDE

Key literature references and sources for data

Norma Oficial Mexicana NOM-018-STPS-2015, Sistema armonizado para la identificación y comunicación de peligros y riesgos por sustancias químicas peligrosas en los centros de trabajo y NMX-R-019-SCFI-2011 Sistema Armonizado de Clasificación y Comunicación de Peligros de los Productos Químicos.

.

UN Recommendations on the Transport of Dangerous Good. International Maritime Dangerous Goods Code (IMDG). Dangerous Goods Regulations (DGR) for the air transport (IATA).

List of relevant phrases (code and full text as stated in chapter 2 and 3)

Code	Text
H302	Harmful if swallowed.
H313	May be harmful in contact with skin.
H314	Causes severe skin burns and eye damage.
H317	May cause an allergic skin reaction.
H318	Causes serious eye damage.
H334	May cause allergy or asthma symptoms or breathing difficulties if inhaled.
H372	Causes damage to organs through prolonged or repeated exposure.
H402	Harmful to aquatic life.

Disclaimer

THIS INFORMATION IS BASED UPON CALCULATED DATA. THE COMPANY HAS NO LIABILITY FOR DAMAGES SUFFERED BY THE PURCHASER OR OTHER PERSONS IN HANDLING OF THESE MATERIALS IF SAFETY INSTRUCTIONS WERE NOT FOLLOWED. THE COMPANY HAS NO LIABILITY FOR MISUSE OF THIS MATERIAL, EVEN IF THE SAFETY INSTRUCTIONS WERE FOLLOWED. PURCHASER IS RESPONSIBLE FOR THE USE OF THIS MATERIAL. THIS SAFETY DATA SHEET IS PREPARED IN ACCORDANCE WITH THE GUIDELINES OF THE CURRENT MEXICAN OFFICIAL STANDARD.CONFIDENTIAL INFORMATION ABOUT THE COMPOSITION WAS OMITTED.

SAFETY DATA SHEET

Airgas
an Air Liquide company

Nitrogen

Section 1. Identification

GHS product identifier : Nitrogen

Chemical name : nitrogen

Other means of identification : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

Product type : Gas.

Product use : Synthetic/Analytical chemistry.

Synonym : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

SDS # : 001040

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : GASES UNDER PRESSURE - Compressed gas

GHS label elements

Hazard pictograms :

Signal word : Warning

Hazard statements : Contains gas under pressure; may explode if heated.
May displace oxygen and cause rapid suffocation.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction.

Prevention : Not applicable.

Response : Not applicable.

Storage : Protect from sunlight. Store in a well-ventilated place.

Disposal : Not applicable.

Hazards not otherwise classified : In addition to any other important health or physical hazards, this product may displace oxygen and cause rapid suffocation.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : nitrogen

Other means of identification : nitrogen (dot); nitrogen gas; Nitrogen NF, Nitrogen FG

Product code : 001040

CAS number/other identifiers

CAS number : 7727-37-9

Ingredient name	%	CAS number
Nitrogen	100	7727-37-9

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband. In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.

Skin contact : Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : In case of inhalation of decomposition products in a fire, symptoms may be delayed. The exposed person may need to be kept under medical surveillance for 48 hours.

Specific treatments : No specific treatment.

Section 4. First aid measures

Protection of first-aiders : No action shall be taken involving any personal risk or without suitable training. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media : Use an extinguishing agent suitable for the surrounding fire.

Unsuitable extinguishing media : None known.

Specific hazards arising from the chemical : Contains gas under pressure. In a fire or if heated, a pressure increase will occur and the container may burst or explode.

Hazardous thermal decomposition products : Decomposition products may include the following materials: nitrogen oxides

Special protective actions for fire-fighters : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel : No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Avoid breathing gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.

For emergency responders : If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".

Environmental precautions : Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill : Immediately contact emergency personnel. Stop leak if without risk.

Large spill : Immediately contact emergency personnel. Stop leak if without risk. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

Protective measures : Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Avoid breathing gas. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
Avoid contact with eyes, skin and clothing. Empty containers retain product residue and can be hazardous.

Section 7. Handling and storage

Advice on general occupational hygiene : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.

Conditions for safe storage, including any incompatibilities : Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F). Keep container tightly closed and sealed until ready for use. See Section 10 for incompatible materials before handling or use.

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
Nitrogen	**ACGIH TLV (United States, 3/2017). Oxygen Depletion [Asphyxiant].**

Appropriate engineering controls : Good general ventilation should be sufficient to control worker exposure to airborne contaminants.

Environmental exposure controls : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.

Skin protection

Hand protection : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.

Body protection : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Other skin protection : Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Section 8. Exposure controls/personal protection

Respiratory protection	: Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Section 9. Physical and chemical properties

Appearance	
Physical state	: Gas. [Compressed gas.]
Color	: Colorless.
Odor	: Odorless.
Odor threshold	: Not available.
pH	: Not available.
Melting point	: -210.01°C (-346°F)
Boiling point	: -196°C (-320.8°F)
Critical temperature	: -146.95°C (-232.5°F)
Flash point	: [Product does not sustain combustion.]
Evaporation rate	: Not available.
Flammability (solid, gas)	: Not available.
Lower and upper explosive (flammable) limits	: Not available.
Vapor pressure	: Not available.
Vapor density	: 0.967 (Air = 1) Liquid Density@BP: 50.46 lb/ft3 (808.3 kg/m3)
Specific Volume (ft^3/lb)	: 13.8889
Gas Density (lb/ft^3)	: 0.072
Relative density	: Not applicable.
Solubility	: Not available.
Solubility in water	: Not available.
Partition coefficient: n-octanol/water	: 0.67
Auto-ignition temperature	: Not available.
Decomposition temperature	: Not available.
Viscosity	: Not applicable.
Flow time (ISO 2431)	: Not available.
Molecular weight	: 28.02 g/mole

Section 10. Stability and reactivity

Reactivity	: No specific test data related to reactivity available for this product or its ingredients.
Chemical stability	: The product is stable.
Possibility of hazardous reactions	: Under normal conditions of storage and use, hazardous reactions will not occur.
Conditions to avoid	: No specific data.
Incompatible materials	: No specific data.
Hazardous decomposition products	: Under normal conditions of storage and use, hazardous decomposition products should not be produced.

Hazardous polymerization	:	Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Not available.

Irritation/Corrosion

Not available.

Sensitization

Not available.

Mutagenicity

Not available.

Carcinogenicity

Not available.

Reproductive toxicity

Not available.

Teratogenicity

Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Information on the likely routes of exposure	:	Not available.

Potential acute health effects

Eye contact	:	Contact with rapidly expanding gas may cause burns or frostbite.
Inhalation	:	No known significant effects or critical hazards.
Skin contact	:	Contact with rapidly expanding gas may cause burns or frostbite.
Ingestion	:	As this product is a gas, refer to the inhalation section.

Symptoms related to the physical, chemical and toxicological characteristics

Eye contact	:	No specific data.
Inhalation	:	No specific data.
Skin contact	:	No specific data.
Ingestion	:	No specific data.

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

Potential immediate effects	:	Not available.
Potential delayed effects	:	Not available.

Long term exposure

Section 11. Toxicological information

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Potential chronic health effects

Not available.

General : No known significant effects or critical hazards.

Carcinogenicity : No known significant effects or critical hazards.

Mutagenicity : No known significant effects or critical hazards.

Teratogenicity : No known significant effects or critical hazards.

Developmental effects : No known significant effects or critical hazards.

Fertility effects : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Product/ingredient name	$LogP_{ow}$	BCF	Potential
Nitrogen	0.67	-	low

Mobility in soil

Soil/water partition coefficient (K_{OC}) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	TDG	Mexico	IMDG	IATA
UN number	UN1066	UN1066	UN1066	UN1066	UN1066
UN proper shipping name	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED	NITROGEN, COMPRESSED
Transport hazard class(es)	2.2 	2.2 	2.2 	2.2 	2.2 
Packing group	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Additional information

DOT Classification : **Limited quantity** Yes.
Quantity limitation Passenger aircraft/rail: 75 kg. Cargo aircraft: 150 kg.

TDG Classification : Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2).
Explosive Limit and Limited Quantity Index 0.125
Passenger Carrying Road or Rail Index 75

IATA : **Quantity limitation** Passenger and Cargo Aircraft: 75 kg. Cargo Aircraft Only: 150 kg.

Special precautions for user : **Transport within user's premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Transport in bulk according to Annex II of MARPOL and the IBC Code : Not available.

Section 15. Regulatory information

U.S. Federal regulations : **TSCA 8(a) CDR Exempt/Partial exemption**: This material is listed or exempted.

Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs) : Not listed

Clean Air Act Section 602 Class I Substances : Not listed

Clean Air Act Section 602 Class II Substances : Not listed

DEA List I Chemicals (Precursor Chemicals) : Not listed

DEA List II Chemicals (Essential Chemicals) : Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

Section 15. Regulatory information

SARA 311/312

Classification : Refer to Section 2: Hazards Identification of this SDS for classification of substance.

State regulations

Massachusetts	: This material is listed.
New York	: This material is not listed.
New Jersey	: This material is listed.
Pennsylvania	: This material is listed.

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

Montreal Protocol (Annexes A, B, C, E)

Not listed.

Stockholm Convention on Persistent Organic Pollutants

Not listed.

Rotterdam Convention on Prior Informed Consent (PIC)

Not listed.

UNECE Aarhus Protocol on POPs and Heavy Metals

Not listed.

Inventory list

Australia	: This material is listed or exempted.
Canada	: This material is listed or exempted.
China	: This material is listed or exempted.
Europe	: This material is listed or exempted.
Japan	: **Japan inventory (ENCS)**: Not determined. **Japan inventory (ISHL)**: Not determined.
Malaysia	: Not determined.
New Zealand	: This material is listed or exempted.
Philippines	: This material is listed or exempted.
Republic of Korea	: This material is listed or exempted.
Taiwan	: This material is listed or exempted.
Thailand	: Not determined.
Turkey	: Not determined.
United States	: This material is listed or exempted.
Viet Nam	: Not determined.

Section 16. Other information

Hazardous Material Information System (U.S.A.)

Health	/	0
Flammability		0
Physical hazards		3

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS® ratings and the associated label are not required on SDSs or products leaving a facility under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered trademark and service mark of the American Coatings Association, Inc.

Section 16. Other information

The customer is responsible for determining the PPE code for this material. For more information on HMIS® Personal Protective Equipment (PPE) codes, consult the HMIS® Implementation Manual.

National Fire Protection Association (U.S.A.)

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Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
GASES UNDER PRESSURE - Compressed gas	Expert judgment

History

Date of printing : 1/30/2018

Date of issue/Date of revision : 1/30/2018

Date of previous issue : 5/26/2016

Version : 0.03

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973 as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

Indicates information that has changed from previously issued version.

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

SAFETY DATA SHEET

Airgas
an Air Liquide company

Oxygen

Section 1. Identification

GHS product identifier	:	Oxygen
Chemical name	:	oxygen
Other means of identification	:	Molecular oxygen; Oxygen molecule; Pure oxygen; O2; UN 1072; Dioxygen; Oxygen USP, Aviator's Breathing Oxygen (ABO)
Product type	:	Gas.
Product use	:	Synthetic/Analytical chemistry.
Synonym	:	Molecular oxygen; Oxygen molecule; Pure oxygen; O2; UN 1072; Dioxygen; Oxygen USP, Aviator's Breathing Oxygen (ABO)
SDS #	:	001043
Supplier's details	:	Airgas USA, LLC and its affiliates 259 North Radnor-Chester Road Suite 100 Radnor, PA 19087-5283 1-610-687-5253
24-hour telephone	:	1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status	:	This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).
Classification of the substance or mixture	:	OXIDIZING GASES - Category 1 GASES UNDER PRESSURE - Compressed gas

GHS label elements

Hazard pictograms :

Signal word	:	Danger
Hazard statements	:	May cause or intensify fire; oxidizer. Contains gas under pressure; may explode if heated.

Precautionary statements

General	:	Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Open valve slowly. Use only with equipment cleaned for Oxygen service.
Prevention	:	Keep away from clothing, incompatible materials and combustible materials. Keep reduction valves, valves and fittings free from oil and grease.
Response	:	In case of fire: Stop leak if safe to do so.
Storage	:	Protect from sunlight. Store in a well-ventilated place.
Disposal	:	Not applicable.
Hazards not otherwise classified	:	None known.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : oxygen

Other means of identification : Molecular oxygen; Oxygen molecule; Pure oxygen; O2; UN 1072; Dioxygen; Oxygen USP, Aviator's Breathing Oxygen (ABO)

Product code : 001043

CAS number/other identifiers

CAS number : 7782-44-7

Ingredient name	%	CAS number
oxygen	100	7782-44-7

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Skin contact : Flush contaminated skin with plenty of water. Remove contaminated clothing and shoes. Get medical attention if symptoms occur. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : As this product is a gas, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : As this product is a gas, refer to the inhalation section.

Over-exposure signs/symptoms

Eye contact : No specific data.

Inhalation : No specific data.

Skin contact : No specific data.

Ingestion : No specific data.

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

Specific treatments : No specific treatment.

Section 4. First aid measures

Protection of first-aiders : No action shall be taken involving any personal risk or without suitable training. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media : Use an extinguishing agent suitable for the surrounding fire.

Unsuitable extinguishing media : None known.

Specific hazards arising from the chemical : Contains gas under pressure. Oxidizing material. This material increases the risk of fire and may aid combustion. Contact with combustible material may cause fire. In a fire or if heated, a pressure increase will occur and the container may burst or explode.

Hazardous thermal decomposition products : No specific data.

Special protective actions for fire-fighters : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool. If involved in fire, shut off flow immediately if it can be done without risk.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel : No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Shut off all ignition sources. No flares, smoking or flames in hazard area. Avoid breathing gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.

For emergency responders : If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".

Environmental precautions : Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment.

Large spill : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

Section 7. Handling and storage

Protective measures : Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Avoid breathing gas. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
Avoid contact with eyes, skin and clothing. Empty containers retain product residue and can be hazardous. Keep away from clothing, incompatible materials and combustible materials. Keep reduction valves free from grease and oil.

Advice on general occupational hygiene : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.

Conditions for safe storage, including any incompatibilities : Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F). Separate from reducing agents and combustible materials. Store away from grease and oil. Keep container tightly closed and sealed until ready for use. See Section 10 for incompatible materials before handling or use.

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
oxygen	None.

Appropriate engineering controls : Good general ventilation should be sufficient to control worker exposure to airborne contaminants.

Environmental exposure controls : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.

Skin protection

Hand protection : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.

Section 8. Exposure controls/personal protection

Body protection	: Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Other skin protection	: Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.
Respiratory protection	: Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use. Respirator selection must be based on known or anticipated exposure levels, the hazards of the product and the safe working limits of the selected respirator.

Section 9. Physical and chemical properties

Appearance	
Physical state	: Gas. [Compressed gas.]
Color	: Colorless. Blue.
Odor	: Odorless.
Odor threshold	: Not available.
pH	: Not available.
Melting point	: -218.4°C (-361.1°F)
Boiling point	: -183°C (-297.4°F)
Critical temperature	: -118.15°C (-180.7°F)
Flash point	: [Product does not sustain combustion.]
Evaporation rate	: Not available.
Flammability (solid, gas)	: Extremely flammable in the presence of the following materials or conditions: reducing materials, combustible materials and organic materials.
Lower and upper explosive (flammable) limits	: Not available.
Vapor pressure	: Not available.
Vapor density	: 1.1 (Air = 1)
Specific Volume (ft^3/lb)	: 12.0482
Gas Density (lb/ft^3)	: 0.083
Relative density	: Not applicable.
Solubility	: Not available.
Solubility in water	: Not available.
Partition coefficient: n-octanol/water	: 0.65
Auto-ignition temperature	: Not available.
Decomposition temperature	: Not available.
Viscosity	: Not applicable.
Flow time (ISO 2431)	: Not available.
Molecular weight	: 32 g/mole

Section 10. Stability and reactivity

Reactivity	: No specific test data related to reactivity available for this product or its ingredients.
Chemical stability	: The product is stable.
Possibility of hazardous reactions	: Hazardous reactions or instability may occur under certain conditions of storage or use. Conditions may include the following: contact with combustible materials Reactions may include the following: risk of causing fire

Conditions to avoid : No specific data.

Incompatible materials : Highly reactive or incompatible with the following materials:
combustible materials
reducing materials
grease
oil

Hazardous decomposition products : Under normal conditions of storage and use, hazardous decomposition products should not be produced.

Hazardous polymerization : Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Not available.

Irritation/Corrosion

Not available.

Sensitization

Not available.

Mutagenicity

Not available.

Carcinogenicity

Not available.

Reproductive toxicity

Not available.

Teratogenicity

Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Information on the likely routes of exposure : Not available.

Potential acute health effects

Eye contact : Contact with rapidly expanding gas may cause burns or frostbite.
Inhalation : No known significant effects or critical hazards.
Skin contact : Contact with rapidly expanding gas may cause burns or frostbite.
Ingestion : As this product is a gas, refer to the inhalation section.

Symptoms related to the physical, chemical and toxicological characteristics

Section 11. Toxicological information

Eye contact : No specific data.
Inhalation : No specific data.
Skin contact : No specific data.
Ingestion : No specific data.

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

Potential immediate effects : Not available.
Potential delayed effects : Not available.

Long term exposure

Potential immediate effects : Not available.
Potential delayed effects : Not available.

Potential chronic health effects

Not available.

General : No known significant effects or critical hazards.
Carcinogenicity : No known significant effects or critical hazards.
Mutagenicity : No known significant effects or critical hazards.
Teratogenicity : No known significant effects or critical hazards.
Developmental effects : No known significant effects or critical hazards.
Fertility effects : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Product/ingredient name	$LogP_{ow}$	BCF	Potential
oxygen	0.65	-	low

Mobility in soil

Soil/water partition coefficient (K_{OC}) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	TDG	Mexico	IMDG	IATA
UN number	UN1072	UN1072	UN1072	UN1072	UN1072
UN proper shipping name	OXYGEN, COMPRESSED	OXYGEN, COMPRESSED	OXYGEN, COMPRESSED	OXYGEN, COMPRESSED	OXYGEN, COMPRESSED
Transport hazard class(es)	2.2 (5.1)	2.2	2.2 (5.1)	2.2 (5.1)	2.2 (5.1)
Packing group	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.

"Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product."

Additional information

DOT Classification : **Limited quantity** Yes.
Quantity limitation Passenger aircraft/rail: 75 kg. Cargo aircraft: 150 kg.
Special provisions A52

TDG Classification : Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2), 2.23-2.25 (Class 5).
Explosive Limit and Limited Quantity Index 0.125
ERAP Index 3000
Passenger Carrying Ship Index 50
Passenger Carrying Road or Rail Index 75
Special provisions 42

IATA : **Quantity limitation** Passenger and Cargo Aircraft: 75 kg. Cargo Aircraft Only: 150 kg.

Special precautions for user : **Transport within user's premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Transport in bulk according to Annex II of MARPOL and the IBC Code : Not available.

U.S. Federal regulations	:	**TSCA 8(a) CDR Exempt/Partial exemption**: This material is listed or exempted.
Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs)	:	Not listed
Clean Air Act Section 602 Class I Substances	:	Not listed
Clean Air Act Section 602 Class II Substances	:	Not listed
DEA List I Chemicals (Precursor Chemicals)	:	Not listed
DEA List II Chemicals (Essential Chemicals)	:	Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

SARA 311/312

Classification : Refer to Section 2: Hazards Identification of this SDS for classification of substance.

State regulations

Massachusetts	:	This material is listed.
New York	:	This material is not listed.
New Jersey	:	This material is listed.
Pennsylvania	:	This material is listed.

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

Montreal Protocol (Annexes A, B, C, E)

Not listed.

Stockholm Convention on Persistent Organic Pollutants

Not listed.

Rotterdam Convention on Prior Informed Consent (PIC)

Not listed.

UNECE Aarhus Protocol on POPs and Heavy Metals

Not listed.

Inventory list

Australia	:	This material is listed or exempted.
Canada	:	This material is listed or exempted.
China	:	This material is listed or exempted.
Europe	:	This material is listed or exempted.
Japan	:	**Japan inventory (ENCS)**: Not determined. **Japan inventory (ISHL)**: Not determined.
Malaysia	:	Not determined.
New Zealand	:	This material is listed or exempted.
Philippines	:	This material is listed or exempted.
Republic of Korea	:	This material is listed or exempted.

Section 15. Regulatory information

Taiwan	: This material is listed or exempted.
Thailand	: Not determined.
Turkey	: Not determined.
United States	: This material is listed or exempted.
Viet Nam	: Not determined.

Section 16. Other information

Hazardous Material Information System (U.S.A.)

Health	/	0
Flammability		0
Physical hazards		3

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS® ratings and the associated label are not required on SDSs or products leaving a facility under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered trademark and service mark of the American Coatings Association, Inc.

The customer is responsible for determining the PPE code for this material. For more information on HMIS® Personal Protective Equipment (PPE) codes, consult the HMIS® Implementation Manual.

National Fire Protection Association (U.S.A.)

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Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

Procedure used to derive the classification

Classification	Justification
OXIDIZING GASES - Category 1 GASES UNDER PRESSURE - Compressed gas	Expert judgment According to package

History

Date of printing	: 2/3/2018
Date of issue/Date of revision	: 2/3/2018
Date of previous issue	: 1/27/2017
Version	: 0.03

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973

Section 16. Other information

as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

Indicates information that has changed from previously issued version.

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

Material Safety Data Sheet
Vanadium(IV) oxide, 99.9%

MSDS# 51831

Section 1 - Chemical Product and Company Identification

MSDS Name:	Vanadium(IV) oxide, 99.9%
Catalog Numbers:	AC201720000, AC201720100
Synonyms:	Vanadium sesquioxide; Vanadium trioxide; Vanadic oxide
Company Identification:	Acros Organics BVBA Janssen Pharmaceuticalaan 3a 2440 Geel, Belgium
Company Identification: (USA)	Acros Organics One Reagent Lane Fair Lawn, NJ 07410
For information in the US, call:	800-ACROS-01
For information in Europe, call:	+32 14 57 52 11
Emergency Number, Europe:	+32 14 57 52 99
Emergency Number US:	201-796-7100
CHEMTREC Phone Number, US:	800-424-9300
CHEMTREC Phone Number, Europe:	703-527-3887

Section 2 - Composition, Information on Ingredients

CAS#:	12036-21-4
Chemical Name:	Vanadium(IV) oxide
%:	99.9
EINECS#:	234-841-1

Hazard Symbols: XI

Risk Phrases: 36/37/38

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Warning! The toxicological properties of this material have not been fully investigated. May be harmful if swallowed, inhaled, or absorbed through the skin. Causes eye, skin, and respiratory tract irritation. Target Organs: Lungs, eyes, skin.

Potential Health Effects

Eye:	Causes eye irritation.
Skin:	Causes skin irritation. May be harmful if absorbed through the skin.
Ingestion:	Causes gastrointestinal irritation with nausea, vomiting and diarrhea. May be harmful if swallowed.
Inhalation:	Causes respiratory tract irritation. May be harmful if inhaled.
Chronic:	May produce scattered allergy-like eczematous skin lesions symptomatic of vanadium toxicity.

Section 4 - First Aid Measures

Eyes:	Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower eyelids. Get medical aid.

Skin:	Get medical aid. Flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes.
Ingestion:	If victim is conscious and alert, give 2-4 cupfuls of milk or water. Get medical aid.
Inhalation:	Remove from exposure and move to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.
Notes to Physician:	

Section 5 - Fire Fighting Measures

General Information:	As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Substance is noncombustible.
Extinguishing Media:	For small fires, use dry chemical, carbon dioxide, water spray or alcohol-resistant foam.
Autoignition Temperature:	Not available
Flash Point:	Not available
Explosion Limits: Lower:	Not available
Explosion Limits: Upper:	Not available
NFPA Rating:	health: 2; flammability: 0; instability: 0;

Section 6 - Accidental Release Measures

General Information:	Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks:	Sweep up, then place into a suitable container for disposal. Avoid generating dusty conditions. Provide ventilation.

Section 7 - Handling and Storage

Handling:	Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Use with adequate ventilation. Minimize dust generation and accumulation. Avoid contact with eyes, skin, and clothing. Avoid breathing dust.
Storage:	Store in a cool, dry place. Store in a tightly closed container.

Section 8 - Exposure Controls, Personal Protection

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Vanadium(IV) oxide	none listed	none listed	none listed

OSHA Vacated PELs: Vanadium(IV) oxide: None listed

Engineering Controls:

Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use adequate ventilation to keep airborne concentrations low.

Exposure Limits

Personal Protective Equipment

Eyes:	Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.
Skin:	Wear appropriate protective gloves to prevent skin exposure.
Clothing:	Wear appropriate protective clothing to prevent skin exposure.
Respirators:	Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.

Section 9 - Physical and Chemical Properties

Physical State: Solid

Color: dark green

Vapor Pressure: Not available
Vapor Density: Not available
Evaporation Rate: Not available
Viscosity: Not available
Boiling Point: Not available
Freezing/Melting Point: 1970 deg C (3,578.00°F)
Decomposition Temperature: Not available
Solubility in water: Insoluble
Specific Gravity/Density: 4.330 g/cm3
Molecular Formula: O4V2
Molecular Weight: 165.88

Section 10 - Stability and Reactivity

Chemical Stability:	Stable under normal temperatures and pressures.
Conditions to Avoid:	Dust generation.
Incompatibilities with Other Materials	Not available
Hazardous Decomposition Products	Vanadium oxide (VOx) gases.
Hazardous Polymerization	Has not been reported.

Section 11 - Toxicological Information

RTECS#:	CAS# 12036-21-4: None listed
LD50/LC50:	RTECS: Not available. Other: See similar chemicals, vanadium(III) oxide and vanadium(V) oxide.
Carcinogenicity:	Vanadium(IV) oxide - Not listed as a carcinogen by ACGIH, IARC, NTP, or CA Prop 65.

Section 12 - Ecological Information

Not available

Section 13 - Disposal Considerations

Dispose of in a manner consistent with federal, state, and local regulations.

Section 14 - Transport Information

US DOT
Shipping Name: Please contact Fisher Scientific for shipping information
Hazard Class:
UN Number:
Packing Group:
Canada TDG
Shipping Name: Not available
Hazard Class:
UN Number:
Packing Group:

Section 15 - Regulatory Information

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols: XI

Risk Phrases:

R 36/37/38 Irritating to eyes, respiratory system and skin.

Safety Phrases:

S 26 In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.
S 36/37/39 Wear suitable protective clothing, gloves and eye/face protection.

WGK (Water Danger/Protection)

CAS# 12036-21-4: Not available

Canada

CAS# 12036-21-4 is listed on Canada's NDSL List

Canadian WHMIS Classifications: D1B, D2B

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations and the MSDS contains all of the information required by those regulations.

CAS# 12036-21-4 is not listed on Canada's Ingredient Disclosure List.

US Federal

TSCA

CAS# 12036-21-4 is listed on the TSCA Inventory.

Section 16 - Other Information

MSDS Creation Date: 9/02/1997

Revision #5 Date 7/20/2009

APPENDIX IV. TECHNICAL SPECIFICATION PFD SHEETS

NEUCHEM
—our word is our bond—

TECHNICAL DATA SHEET
MALEIC ANHYDRIDE

PROPERTY	SPECIFICATION
PURITY, %	99.5% MIN
COLOR, MOLTEN STATE	15 APHA MAX
COLOR, HEAT STABILITY (140°C FOR 2 HOURS)	30 APHA MAX
MELTING POINT, °C	52.5°C MIN
ASH, %	0.003% MAX
IRON, PPM	3 PPM MAX
FREE ACIDITY (AS MALEIC ACID), %	0.2% MAX
APPEARANCE OF SOLID PRODUCT	WHITE SOLID BRIQUETTES OR FLAKES

2062 UNION STREET, SUITE 300 SAN FRANCISCO, CA 94123
T 415 345 9310 • F 415 345 9350 • ADMIN@NEUCHEM.COM

APPENDIX V. CAPCOST PROFITABILITY ANALYSIS

Table V-1: Equipment Capital Cost

Compressors	Compressor Type	Power (kW)	# Spares	MOC		
C-101	Centrifugal	32900	0	Stainless Steel		
C-100	Centrifugal	37100	0	Stainless Steel		
Drives	**Drive Type**	**Power (kW)**	**# Spares**			
D-101	Electric - Explosion Proof	32900	0			
D-102	Electric - Explosion Proof	37100	0			
Dust Collectors	**Type**	**Gas Flowrate m^3/s)**				
Dc-101	Cyclone	115				
Dc-102	Cyclone	124				
Dc-103	Cyclone	136				
Dc-100	Cyclone	107				
Exchangers	**Exchanger Type**	**Shell Pressure (barg)**	**Tube Pressure (barg)**		**MOC**	**Area (m^2)**
E-100	Floating Head	3.37	3.37		Stainless Steel/ Stainless Steel	63.7
E-101	Floating Head	3.36	3.36		Stainless Steel/ Stainless Steel	21.8
E-102	Floating Head	3.35	3.35		Stainless Steel/ Stainless Steel	30.2
E-103	Floating Head	3.35	3.35		Stainless Steel/ Stainless Steel	30
E-104	Floating Head	3.97	3.97		Stainless Steel/ Stainless Steel	21.5
E-105	Floating Head	20	20		Stainless Steel/ Stainless Steel	43.2

E-106	Floating Head	4.99	4.99		Stainless Steel/ Stainless Steel	246
E-107	Floating Head	20	20		Stainless Steel/ Stainless Steel	235
Pump	**Type**	**Power (kW)**	**# Spares**		**Discharge Pressure (barg)**	
P-101	Centrifugal	0.297	0	Stainless Steel	3.99	
P-102	Centrifugal	0.042	0	Stainless Steel	3.99	
P-103	Centrifugal	3.13	0	Stainless Steel	3.99	
P-104	Centrifugal	7.46	0	Stainless Steel	19	
P-100	Centrifugal	0.494	0	Stainless Steel	2.38	
Reactors	**Type**	**Volume (m^3)**				
R-101	Autoclave	27.6				
Towers	**Tower Description**	**Height (m)**	**Diamete r (m)**	**Tower MOC**	**Demister MOC**	**Pressur e (barg)**
T-101	18 Stainless Steel Sieve Trays	11	7.68	Stainless Steel		0.277
T-100	148 Stainless Steel Sieve Trays	90.2	3.66	Stainless Steel		2.97
Turbines	**Turbine Type**	**Power (kW)**	**# Spares**	**MOC**		
J-101	Axial	4000	12	Carbon Steel		
User Added Equipment	**Description**	**BMF_0**	**Actual BMF**			
Z-101	Nozzle V-101	2.25	2.25			

Compressors	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Module Cost
C-101	$18,800,000	$51,600,000	$8,980,000	$24,600,000

C-100	$21,600,000	$59,200,000	$10,300,000	$28,200,000
Drives	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Module Cost**
D-101	$2,860,000	$4,290,000	$2,860,000	$4,290,000
D-102	$3,290,000	$4,930,000	$3,290,000	$4,930,000
Dust Collectors	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Module Cost**
Dc-101	$93,500	$268,000	$93,500	$268,000
Dc-102	$98,700	$282,000	$98,700	$282,000
Dc-103	$105,000	$299,000	$105,000	$299,000
Dc-100	$89,000	$255,000	$89,000	$255,000
Exchangers	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Module Cost**
E-100	$80,200	$181,000	$29,400	$96,600
E-101	$68,200	$154,000	$25,000	$82,200
E-102	$69,300	$156,000	$25,400	$83,500
E-103	$69,300	$156,000	$25,400	$83,500
E-104	$68,200	$154,000	$25,000	$82,200
E-105	$78,200	$173,000	$26,700	$87,900
E-106	$155,000	$349,000	$56,700	$186,000
E-107	$161,000	$357,000	$55,000	$181,000
Pump	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Module Cost**
P-101	$7,630	$16,600	$3,350	$10,800
P-102	$7,630	$16,600	$3,350	$10,800
P-103	$8,850	$19,300	$3,880	$12,600
P-104	$14,300	$28,500	$4,880	$15,800
P-100	$7,630	$16,600	$3,350	$10,800
Reactors	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Module Cost**
R-101	$218,000	$871,000	$218,000	$871,000

Towers	Purchased Equipment Cost	Bare Module Cost	Base Equipment Cost	Base Bare Module Cost
T-101	$4,700,000	$6,760,000	$2,120,000	$3,440,000
T-100	$6,080,000	$10,800,000	$2,140,000	$4,590,000
Turbines	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Module Cost**
J-101	$6,860,000	$24,000,000	$6,860,000	$24,000,000
User Added Equipment	**Purchased Equipment Cost**	**Bare Module Cost**	**Base Equipment Cost**	**Base Bare Module Cost**
Z-101	$34,100	$76,725		
Totals	**$65,589,640**	**$165,332,600**	**$37,441,610**	**$96,968,700**
Total Module Cost	**$195,100,000**			
Total Grass Roots Cost	**$243,600,000**			
Total Equipment Cost	**$65,589,640**		`	
Lang Factor	**4.74**			
Lang Factor Cost	**$310,900,000**			

Table V-2: Economic Options – fixed capital investment

Cost of Land	$ -
Taxation Rate	45%
Annual Interest Rate	10%
Salvage Value	$19,510,000
Working Capital	$23,800,000
FCI_L	$195,100,000
Total Module Factor	1.18
Grass Roots Factor	0.50

Table V-3: Economic Information Calculated From Given Information

Revenue From Sales	$70,035,708
C_{RM} (Raw Materials Costs)	$41,858,661
C_{UT} (Cost of Utilities)	$39,100,000
C_{WT} (Waste Treatment Costs)	$ -
C_{OL} (Cost of Operating Labor)	$1,271,290

Table V-4: Factors Used in Calculation of Cost of Manufacturing (COM_d)
Comd = 0*FCIL + 0*COL + 1*(CUT + CWT + CRM)

Multiplying factor for FCIL	0.18
Multiplying factor for C_{OL}	2.73
Factors for C_{UT}, C_{WT}, and C_{RM}	1.23
COM_d	$138,167,775

Table V-5: Factors Used in Calculation of Working Capital
Working Capital = $A*C_{RM} + B*FCI_L + C*C_{OL}$

A	0.10
B	0.10
C	0.10
Project Life (Years after Startup)	10
Construction period	2

Table V-6: Distribution of Fixed Capital Investment (must sum to one)

End of year One	60%
End of year Two	40%
End of year Three	
End of year Four	
End of year Five	

Table V-7: Calculation of Cumulative Cash Flow Diagram

Year	Investment	d_k	FCI_L-Sd_k	R	COM_d	$(R-COM_d-d_k)*(1-t)+d_k$
0	0.00		195.10			
0	0.00		195.10			
1	117.06		195.10			
2	78.04		195.10			
2	23.80		195.10			
3		39.02	156.08	70.04	138.17	(19.91)
4		62.43	93.65	70.04	138.17	(9.38)
5		37.46	56.19	70.04	138.17	(20.62)
6		22.44	33.75	70.04	138.17	(27.38)
7		22.44	11.32	70.04	138.17	(27.38)
8		11.32	-	70.04	138.17	(32.38)
9			-	70.04	138.17	(37.47)
10			-	70.04	138.17	(37.47)
11			-	70.04	138.17	(37.47)
12			-	70.04	138.17	(26.74)
12						

Year	Cash Flow (Non-discounted)	Cash Flow (discounted)	Cumulative Cash Flow (discounted)	Cumulative Cash Flow (Non-discounted)
0	0.00	0.00	0.00	0.00
0	0.00	0.00	0.00	0.00
1	(117.06)	(106.42)	(106.42)	(117.06)
2	(78.04)	(64.50)	(170.91)	(195.10)
2	(23.80)	(19.67)	(190.58)	(218.90)
3	(19.91)	(14.96)	(205.54)	(238.81)
4	(9.38)	(6.41)	(211.95)	(248.19)
5	(20.62)	(12.80)	(224.75)	(268.81)
6	(27.38)	(15.45)	(240.20)	(296.18)
7	(27.38)	(14.05)	(254.25)	(323.56)
8	(32.38)	(15.11)	(269.36)	(355.94)
9	(37.47)	(15.89)	(285.25)	(393.41)
10	(37.47)	(14.45)	(299.70)	(430.89)
11	(37.47)	(13.13)	(312.83)	(468.36)
12	(26.74)	(8.52)	(321.35)	(495.10)
12	23.80	7.58	(313.77)	(471.30)

Table V-8: Discounted Profitability Criterion

Net Present Value (millions)	(131.77)
Discounted Cash Flow Rate of Return	NA
Discounted Payback Period (years)	Undefined

Table V-9: Non-Discounted Profitability Criteria

Cumulative Cash Position (millions)	(471.30)
Rate of Return on Investment	-24.16%
Payback Period (years)	Undefined