Creation of a CIP Method for the Heat Exchangers at Rolls-Royce

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Rolls-Royce produces various engines which must be tested prior to their distribution to ensure a high-quality product. The manufacturing plant contains four test cells where the engines can be subjected to high levels of torque and extreme temperatures. A heat exchanger is necessary in this testing system and over time, unwanted waste accumulates on the system's plates. The team is tasked with developing and implementing a system mounted on a mobile cart which can provide data to determine whether the plates need to be cleaned. For this cleaning system to work, it must fully saturate the heat exchanger in cleaning solution, making the choice of pump important to the planning process. Additionally, the pump must be able to handle liquid containing silt and other debris and possess a maximum flow rate allowing the plates to be saturated. The pump must have four connection points to the heat exchanger system, and the fitting nozzle to control the flow rate of the cleaning solution into the heat exchanger. The cleaning solution for the system must be strong enough to clean the waste from the heat exchanger, yet weak enough to not corrode the plates. Additionally, some cleaning solutions have standards regarding storage and disposal, which have considerable influence on the selection of an acceptable solution. The final design incorporates a workable pump, a suitable solution, and the supporting materials needed to sustain the system. Implementation of the design will include pressure testing and a cleaning system that will improve the life span and efficiency of the heat exchanger in each test cell.

Introduction

The Rolls-Royce plant in Graniteville, SC produces Series 883, 2000, and 4000 engines, each having their own assembly line. These engines range from 760-4000 hp.[1] They are used in many different types of machinery including those for power generation, mining and oil, and construction. Rolls-Royce has four test cells used to ensure their engines will function properly before they are distributed to the consumers. These test cells subject the engines to various temperatures and levels of torque. It is vital to ensure the proper functioning of the engine so they can be implemented into their systems immediately after delivery. Without complete testing of the engine in an environment similar to what it will be subject to after purchase, the company risks sending a faulty product and potentially injuring the customer or ruining the customer's machinery. Therefore, the test cell plays a major role in the plant and needs to be maintained properly.

Each of the four cells contains a heat exchanger to dissipate heat while testing the engines. The type of heat exchanger used by Rolls-Royce is the plate heat exchanger. This design is used by the plant due to its efficiency and compactness.[2] The plate design consists of end plates on the front and back cover, heat transfer plates, gaskets, and various nuts and bolts to secure a watertight seal.[2] The heat transfer plates have a pattern grooved into them to create a turbulent flow. The groove helps to increase the heat transfer characteristics of the system, and it makes the plates stronger.[2] The heat exchanger's gaskets dictate which fluid flows into which channel. The fluids are never mixed, but thermal energy from the hot fluid is transferred to the cool fluid through the metal plates.[2] The inlets and outlets of the heat exchanger system allow the fluids to flow in counterflow. This counterflow design is the most effective way to transfer heat between the fluids.[2]

A current problem at the Rolls Royce facility is cleaning the heat exchangers in their test cells. One of the heat exchangers present in the testing cells is shown in Figure 1. The heat exchangers are necessary to dissipate the heat produced when testing the engines in extremely high temperatures. However, the heat transfer systems can get a layer of waste from the engines which is difficult to clean from the plates. This waste, mostly carbonates, comes from ions in the tower water, the source of one of the liquids used during the heat transfer process. As the ions come out of the solution, they deposit onto the surface of the heat exchanger and build up over time. The waste makes the heat exchanger run less efficiently, dissipating less heat from the system. Traditionally, the entire heat exchanger has been taken apart in order to clean the waste from the plates. An outside company has typically been hired to carry out this process, which makes the job more expensive. There is also no test in place to measure the build-up of waste and determine when the heat exchanger needs to be cleaned. Without knowing how much waste is in the system, the employees tend to wait longer periods of time between cleanings. If the heat exchanger continues to be used without proper cleaning, heat will not be dissipated as efficiently as possible.

Figure 1: Heat exchanger in test cell.

To overcome these issues, the team has two main challenges to answer: monitoring waste build-up and implementing the cleaning design in each test cell. The first challenge presents a relatively simple answer. In order to determine when the heat exchangers need cleaning, a way to pressure test the system needs to be implemented. This pressure testing may be done without disassembling the heat exchanger. If this testing can be conducted, the heat exchangers could be checked for large amounts of waste more easily to ensure they were being cleaned when necessary. As a computerized testing system is already in place in the cells, the data from the pressure tests may be collected in the preexisting data acquisition system.

Another system to be implemented is a way to clean the plates without disassembling the heat exchangers. In industry, this type of cleaning system is known as a cleaning in place unit, or a CIP unit. The ability to easily clean the heat exchangers would cut down on cleaning costs and increase the heat transfer capabilities of the system. An important characteristic of the new cleaning system for the heat exchangers is its ability to move to each test cell. Therefore, the proposed cleaning system is a mobile cart. The mobile CIP unit would be used once the testing system indicates that the performance of the heat exchanger has fallen below a certain standard. The unit will be tied into the piping system of the heat exchanger to pump in and circulate the cleaning solution. The pump must be powerful enough to completely saturate the heat exchanger plates and fully flush the waste from the system. Pump power is thus another vital aspect of the cleaning cart. Insufficient power would result in the plates not being cleaned, and heat would not be dissipated from the test cell as efficiently.

Cleaning-In-Place

During the team's initial visit to the facility at Rolls-Royce, it was explained that an outside company has been hired before to clean the units using the CIP principle. While heat transfer efficiency increased in the short term, it soon dropped again as waste began to accumulate. After disassembling the heat exchanger, a significant amount of residue remained on both the hot and cold sides. Unfortunately, the company unknowingly channeled a path through the silt but informed Rolls Royce that the plates were completely cleaned. The connection used a three-quarter inch fitting nozzle and did not provide enough flow rate to properly clean and fully saturate the heat exchanger. Soon after, the heat exchanger performed as poorly as it did prior to cleaning.

To ensure the maximum efficiency of the heat exchanger, the plates must stay sufficiently clean by reducing the build-up of calcium carbonate. Fouling reduces the heat transfer within the heat exchanger. The CIP unit, together with a cleaning fluid, facilitates the cleaning of the plates in an efficient manner without dismantling the heat exchanger. Maintaining the efficiency of the heat exchangers will lengthen the lifespan of the heat exchanger and increase the reliability of the engine tests conducted at the Rolls Royce facility. CIP effectiveness is determined by cleaning time, strength of cleaning chemicals, the temperature of cleaning chemicals, and the amount of turbulence.

During CIP, the cleaning solution is pumped through the heat exchanger, where it is heated to the required temperature. The plate designs that facilitate heat transfer also create turbulence that aids in plate cleaning. The solution is then routed to the target system and back to the circulation tank included in the CIP module. This is time consuming and causes long periods of downtime for the user. The instruction manual states six steps to clean the heat exchanger in place. The first step is to drain both sides of the unit and if that is not possible, flush with water. The second step is to flush both sides with warm water at approximately 110° F and is performed until the effluent water is clear and free of the process fluid. The following step finishes the initial flush by draining the unit and connecting the CIP pump. The heat exchanger needs to be fully saturated for the cleaning to be successful. The manufacturer states that the best way for this to happen is to start from the bottom to top to ensure wetting of all surfaces with cleaning solution.[3] To achieve full saturation, valves will be machined into the current pipes, likely at the locations shown in Figure 2. The locations shown in Figure 2 are sites that will potentially house the necessary valves. These valves will connect to the CIP unit and allow for the necessary maintenance. The nozzle is connected to the valve positions shown in Figure 2.

Figure 3 displays the path of the CIP solution and indicates the relative position of the control valves, circled in red. The unit shows that the solution starts from the bottom and flows upwards. There will be four points for the unit to connect to the heat-exchanger, with two connections on each side of the heat exchanger. The unit being designed has specifications that will need to be followed. The size of the unit is constrained by the size of the hallway housing the four heat exchangers. The unit will have to be able to hold the solution tank, which must be large enough to contain enough solution to saturate the heat exchanger.

Figure 2. Potential sites for valves: tower water side (left) and antifreeze side (right).

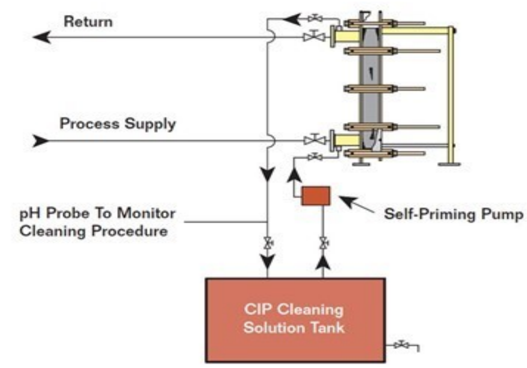


Figure 3: Cleaning-in-place flowchart

It will also house the pump as well as the variable frequency drive (VFD) unit that will be installed with the pump. The VFD, discussed in more detail in the Pump Section, was specifically requested by the Rolls-Royce contact. In order to be compatible with the four heat exchangers, the CIP system must also be mobile and use common, interchangeable parts. Therefore, all the heat-exchangers will need the same specifications for the inlets and outlets when connected to the unit.

Pumps

The key component to this design is the pump selection. Several factors dictate this selection. While rinsing the heat exchanger, some silt will become loose and become part of the cleaning solution as it flows through the pump. Due to the silt mixing with the cleaning solution, the pump must be able to withstand a more viscous fluid than the cleaning solution alone. Another specification for the pump is its max flow rate. Max flow rate, or the highest rate at which the solution flows, influences how much of the silt build-up is loosened. A higher max flow rate allows for better removal of the silt. Additionally, the nozzle at the end of the pump influences the max flow rate. The nozzle can either restrict or add to the pump's ability to pump the solutions through the system.

Pumps can be made to operate based on specific needs of a certain machine. Two types of pumps were considered during this design process: centrifugal and positive displacement pump. The operation manual suggests a centrifugal pump be used to circulate the cleaning solution. Centrifugal pumps produced maximum efficiency when circulating cooling water or when operating as a boiler feed pump.[4] Centrifugal pumps are generally sized to operate at or near the best efficiency point at maximum flow. The maximum flow requirements, however, frequently occur for a very short time period during the operating cycle. Some method of flow control is thus required. The traditional method of flow control has used valves, which increase system pressure, inherently waste energy, and generally cause the centrifugal pump to operate at reduced efficiencies.[5] VFDs can achieve reduced flow by providing variable speed pump operation. VFDs enable reduced system pressure and operation near the pump's Best Efficiency Point. In addition, the gain in efficiency granted by the VFD could reduce maintenance costs.[5]

Alternatively, a positive displacement pump, suggested by a Rolls-Royce industry partner, also offers many benefits. According to Purcell, John E. and Silvaggio, Joseph A., a positive displacement pump resolved a number of issues for an aluminum can manufacturer. This superiority was due to the pump's insensitivity of flow rate in relation to change in pressure and improved the uniformity of a coating applied to the inside of the cans.[4] In another example, a centrifugal pump was chosen to boost the suction pressure of a high-pressure fuel pump on a gas turbine due to the variable flow abilities of the centrifugal pump matching the variable demand. Positive displacement pumps were also preferred for unloading tanker trucks. The pump excels due to its self-priming characteristics and relative insensitivity to large changes in the viscosity or specific gravity of the liquid being pumped. This characteristic may be a factor in the Rolls-Royce project due to the build-up of silt and other materials.

The comparison of positive displacement and centrifugal pump illustrates diverse benefits and drawbacks to either pump type depending on its application. Because of the wide range of uses for positive displacement pumps, the design of the CIP system initially utilized a positive displacement pump. Unfortunately, the cost for a positive displacement pump is usually higher than a centrifugal pump. After further discussion with the industry partner and a financial review, a centrifugal pump was selected as the most economical choice that still allowed for efficient power.

The pump that best suits the needs of the design is the AMT model 4260-98 close coupled end suction centrifugal in stainless steel wetted construction. This pump has 3" NPT ports with 7.5 HP at 3500 RPM. The pump would require a VFD in order to attain the low pressure that is required to properly saturate the heat exchanger, allowing the cleaning solution to be properly applied. This requirement was not an issue, as the facility contact specifically requested it to be incorporated into the design. The pump will need to be placed below the reservoir in order to keep the pump from dry running as it is not self-priming. In summary, the centrifugal pump can perform similar to the positive displacement pump with only minor modifications.

Cleaning Solutions

Several cleaning solutions are available for selection. The selected solution must be able to clean the residue from both sides without corroding the metal plates. For this reason, dilute acids and RYDLYME are the favored options. The side of the heat exchanger channeling the antifreeze is coated in deteriorated antifreeze. On the side channeling tower water, the build-up likely contains calcium and possibly iron carbonates. A higher concentration of iron carbonate would require a stronger acid, such as phosphoric acid.[3] However, a strong acid may damage the metal. For this reason, hydrochloric acid should not be used with stainless steel. Additionally, phosphoric acid and sulfamic acid should not be used with titanium. All acidic solutions compatible with the metal in the heat exchanger are shown in Table 1.[5] All acidic solutions, regardless of the metal in the exchanger, should be limited to 4% concentration or less. For any cleaning solution, a pH probe should monitor the entire cleaning process. A low pH indicates that the acid is still active.[3] Solutions may be discharged into the water when the pH is between 5.5 and 9.[6] A pH in this range also signals that the cleaning solution has been neutralized and is no longer reacting well enough to remove the residual coating.[3] Care must be taken that an acidic solution with a lower pH than 5.5 is not discharged directly into the sewer. If the solution needs to be discarded before the process has reached the correct pH range, the solution must be treated to bring the pH to at least 5.5 before disposal.

In addition to reactivity, safety concerns and storage are also important considerations for the cleaning solution. RYDLYME is biodegradable and does not contain any hazardous chemicals. As such, it may be deposed of at any time in the process, will not result in physical harm should it be spilled, and does not require an SDS or special handling.[7] An acidic solution, however dilute, will require an SDS and conscientious handling. The stronger acids, such as hydrochloric or phosphoric, will require greater caution. For safety reasons, citric acid, being a weak acid and thus less hazardous, would be preferred over nitric acid, which is a strong oxidizer. If an acid is chosen, the operator will need to ensure that the pH is in the acceptable range before discharge. Storage of an acidic solution will also be a challenge, and any spills will require a procedure for cleaning. The low concentration would likely prevent any serious damage, but the hazardous classification of acids requires certain precautions to remain within Occupational Safety and Health Administration (OSHA) standards. Additionally, the final cleaning solution must be compatible with the chosen pump to avoid corrosion in the pump itself.

Table 1. Potential acids.

Fouling	Potential Cleaner
Calcium Sulphate, Silicates	Citric or Nitric Acid
Calcium Carbonate	Nitric Acid, Oakite 131
Alumina, Metal Oxides, Silt	Citric or Nitric Acid

The cleaning process is comprised of several steps, in addition to those mentioned earlier. The exchanger must first be drained of the treated water and antifreeze circulating within it. Storage containers for these solutions will be near the heat exchanger cell so that they can be put back into circulation. Both sides can be flushed with water if draining is not effective. This temperature must not rise above 140° F.[5] To ensure maximum saturation, about 10% to 15% of flowrate above the normal operation, it is recommended that the pump nozzle be somewhere between 1 and 2 inches to allow between 67 to 260 gpm.[5] If the pump or the nozzle is oversized, a speed controller will be necessary. At some point during the process, the flow must be reversed. When using an acidic solution, it is recommended to reverse the flow every thirty minutes. This back flushing clears out large debris or fibers and ensures that all surfaces within the heat exchanger are washed with the cleaning liquids.[3] The cleaning process is done when the pH holds steady between 5.5 and 9 for at least 30 minutes. The exchanger is then flushed with water. The pH of this step is also monitored to verify no reactive species remain in the exchanger and is complete when the pH is steady at 7.[3] This water may be drained, and the original fluid pumped back into the exchanger.

The choice of cleaner will also determine the amount of time the cycle needs for effective cleaning. The process will take at least two hours and may run longer depending on the strength of the cleaning solution. If the pH rises to 5.5 before 2 hours, more solution will need to be added and the cleaning time will be extended. For an acidic solution, the 4% concentration generally works effectively enough that the process may be completed within two hours. This concentration is also strong enough that it is sufficient for the entire process and will not require any additions during the cycle.[3] RYDLYME requires the periodic addition of water throughout the cleaning cycle to maintain solution volume within the exchanger. As the calcium deposits begin to dissolve or break off, the volume within the exchanger will increase. The cycle will take at least an hour longer with RYDLYME.[7]

A trade-off analysis was conducted to identify the best choice based on the criteria of corrosivity, potential safety hazards, cleaning capability, ease of disposal, and ease of storage. As corrosive behavior and safety hazards can have large implications on both the equipment and the workers, these two categories received the highest weights of 5 and 4 respectively. As the efficiency of the CIP system relies heavily on the chosen solution, cleaning capability received a weight of 3. Environmental concerns and regulations dictated that ease of disposal receive a weight of least 2. Ease of storage received a weight of 1, as these procedures are provided by the solution manufacturers. Performance of a solution in a given category is ranked 1-4, with 1 being a poor score and 4 an excellent score. The results of the trade-off analysis are shown in Table 2.

Table 2. Trade-off analysis of potential cleaning solution

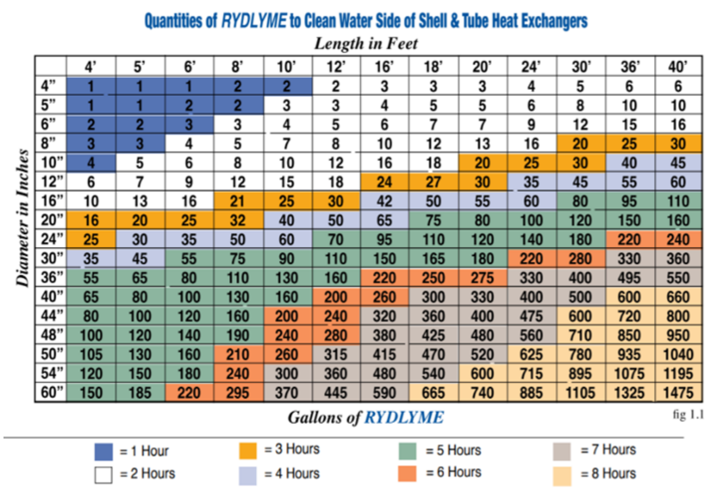
Criteria	Weight	Citric Acid	Nitric Acid	Hydrochloric Acid	RYDLYME
Ease of Disposal	2	4	3	1	4
Cleaning Capability	3	1	3	4	3
Corrosive	5	3	2	1	4
Ease of Storage	1	2	2	1	3
Safety Hazards	4	3	2	1	4
Overall Score		40	35	24	56

After reviewing the previous considerations, RYDLYME appeared to be the best choice of cleaner. Being biodegradable, this solution will circumvent several of the considerations that must be taken into account with an acidic solution. The solution will not corrode the heat exchanger or the pump. It can be flushed at any point during the process without violating a safety code or causing harm to the environment. It also lacks any special requirements for storage or cleanup. Produced by Apex Engineering, the solution also does not need to be treated to reach a carefully controlled concentration. Though this solution will require some minor additional efforts during the cleaning process, the safety of the solution renders it the best choice.

The amount of RYDLYME to be used must be calculated using the size of the heat exchanger and mixed with an equal amount of water (Figure 4). As the heat exchangers in question are plate heat exchangers, not shell or tube heat exchangers, the volume must be calculated from eq. 1, though Figure 4 may give an estimate of the cleaning time.

$$\frac{\frac{Width \times Height \times Thickness\ of\ plate\ pack}{1728} \times 3.75}{2} \qquad \text{eq. (1)}$$

With this equation, the maximum volume of needed RYDLYME was determined to be 20.2 gallons based on four diagrams provided by Rolls-Royce. Other calculated volumes were 14.4, 16.3, and 18.5 gallons for the smaller heat exchangers. Thus, the total volume of solution for the entire process will be 40.4 gallons. Based on this figure, the size of the reservoir for the CIP is 50 gallons. Using the maximum amount of RYDLYME as 20.2 gallons, Figure 4 indicates that the process will take approximately three hours for a heat exchanger of this size. The smaller heat exchangers may only need as few as two hours.


Quantities of RYDLYME to Clean Water Side of Shell & Tube Heat Exchangers

Length in Feet / Diameter in Inches

	4'	5'	6'	8'	10'	12'	16'	18'	20'	24'	30'	36'	40'
4"	1	1	1	2	2	2	3	3	3	4	5	6	6
5"	1	1	2	2	3	3	4	5	5	6	8	10	10
6"	2	2	3	3	4	5	6	7	7	9	12	15	16
8"	3	3	4	5	7	8	10	12	13	16	20	25	30
10"	4	5	6	8	10	12	16	18	20	25	30	40	45
12"	6	7	9	12	15	18	24	27	30	35	45	55	60
16"	10	13	16	21	25	30	42	50	55	60	80	95	110
20"	16	20	25	32	40	50	65	75	80	100	120	150	160
24"	25	30	35	50	60	70	95	110	120	140	180	220	240
30"	35	45	55	75	90	110	150	165	180	220	280	330	360
36"	55	65	80	110	130	160	220	250	275	330	400	495	550
40"	65	80	100	130	160	200	260	300	330	400	500	600	660
44"	80	100	120	160	200	240	320	360	400	475	600	720	800
48"	100	120	140	190	240	280	380	425	480	560	710	850	950
50"	105	130	160	210	260	315	415	470	520	625	780	935	1040
54"	120	150	180	240	300	360	480	540	600	715	895	1075	1195
60"	150	185	220	295	370	445	590	665	740	885	1105	1325	1475

Gallons of RYDLYME

fig 1.1

Figure 4: Calculation to determine time and volume of RYDLYME.

Design of CIP System

The list of materials needed to assemble the CIP system are found in Table 3. The AMT heavy duty centrifugal pump and VFD will be used to circulate the solution throughout the heat exchanger. The GFCI switch, extension cord, and 230V receptacle will supply power to both the pump and the VFD. As the facility currently lacks an outlet capable of directly supplying this voltage, a 230V receptacle will need to be added to satisfy the pump's power demands. Other materials needed for the CIP system include valves, fittings, hoses, and the circulation tank to connect the CIP system to the heat exchanger. The cart will allow facility members to easily move and connect the system to each heat exchanger. Each of these parts are crucial to develop a highly functioning CIP system.

Table 3. Bill of materials.

CIP	AMT Heavy Duty Centrifugal Pump 3" fitting 2' x 4′ heavy-duty plastic cart with 8" wheels 50-gallon circulation bucket with drain valve Three 3" diameter 10′ hoses
Supporting Materials	20′ extension cord GFCI with weatherproof switch VFD 230V receptacle
Heat Exchanger Materials	4 Shut-off Valves for each 6" piping

Conclusion and Future Work

The design of a mobile CIP system to be used on heat exchangers at Rolls Royce incorporated the selection of an appropriate pump, cleaning solution, and the supporting materials. Centrifugal and positive displacement pumps offer many solutions to problems faced in this project. Though a positive displacement pump was favored initially for superior performance, the more economical centrifugal pump AMT model 4260-98 was selected for the final design. Modification with a VFD will allow this model to reach the needed performance level. The design process then moved to the selection of an appropriate cleaning liquid. Several varieties of acidic solutions were evaluated based on corrosivity, potential safety hazards, cleaning capability, ease of disposal, and ease of storage. After a thorough review of cleaning solutions, RYDLYME appeared as the ideal cleaning solution for the CIP. Though some additional steps are needed during the CIP process, the practicality of storage and safety propel it to the forefront of the choices. Based on both the size of the heat exchangers and the strength of the cleaning solution, the maximum volume of RYDLYME needed to fully saturate the exchangers was determined to be 20.2 gallons. A bill of materials was compiled to include all of the supporting materials, such as pipe fittings, hoses, and valves. The system components must now be assembled, and the heat exchangers fitted with valves. After implementing the CIP system, the effectiveness of the design may be determined by running through the cleaning process and comparing the resulting exchanger performance with performance history of each exchanger. If the system brings the exchangers to the desired performance level, a cleaning schedule may then be devised through a time-dependent study on exchanger efficiency.

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