Design Report for Manufacturing, Reliability and Economics

Team #2

Decreasing Electricity Usage at Cummins Technical Center

Members

Daniel Baker
(dpb11f@my.fsu.edu)
Warren Bell
(wab10@my.fsu.edu)
Daniel Carnrike
(dac10c@my.fsu.edu)
Kyle Fields
(krf11b@my.fsu.edu)
Marvin Fonseca
(mjf12g@my.fsu.edu)

Advisors/Sponsors/Faculty

Dr. Ordonez, Dr. Hays
Cummins Inc.
Dr. Gupta

04/03/15

Table of Contents

Table of Figures

Table of Tables

Abstract

The following report contains a design for manufacturing, design for reliability and a design for economics for Team's 2 proposed exhaust gas capturing power generation system for the Cummins Technical Center (CTC). Team 2 took many considerations when conducting the design in order to develop a feasible and cost effective system. The design for manufacturing describes how to assemble the overall system and an estimation of man power needed to install and manufacture individual components necessary for Team 2's system. Also, the estimation for reliability was calculated based on a real life system associated with this size. Finally, the report will have a cost breakdown for each component to show how cost effective each component is and total cost of the system which equated to $2,000,623. This report is tailored to the exhaust-power generation system designed by Team 2 and not the simulation code.

1. Introduction

Energy efficiency is a major concern for many businesses, especially for industrial businesses. In order to reduce energy consumption, the replacement of inefficient light bulbs, poor insulation, and piping are all fundamental ways to reduce energy consumption. Techniques used to reduce electricity usage range from implementing motion sensor lighting, maintaining up to date insulation and upgrading components to state of the art parts. Reducing energy consumption is a small step in making industrial companies more eco-friendly. Cummins, Inc. has made great strides to become an industry leader in recyclable energy practices that minimize impact on the environment. In 2011, Cummins, Inc. began to supplement some of its power sources in certain locations with solar panels and rerouting energy developed from their test cell dynamometers back into the grid. Also, Cummins, Inc. had an energy audit conducted for their technical center in order to reduce their initial energy consumption. Cummins Technical Center (CTC) is a large engine testing facility located at Columbus, Indiana. The facility is capable of testing 96 Cummins engines which contain many different engine families such as the ISB and ISX engine families. Engine applications for these specific engine families range from pick-up trucks to large train engines. Cummins, Inc. is at the forefront in making industrial technical centers more eco-friendly and less harmful to the environment.

Cummins, Inc. chose to sponsor a senior design team from Florida State University to further reduce their energy consumption by 10%. In order to reduce the CTC energy consumption, Team 2 has been assembled to generate the necessary ideas, conduct the required analysis and produce an energy savings plan. Team 2 focused on the development of multiple energy reduction areas for the CTC and created different ideas; these ideas can be referenced to previous reports such as Final Report I and can be located on the official website. Instead of trying to implement additional energy saving ideas for the spring semester, Team 2 focused on one major idea: capturing exhaust gases created by different engine families tested at the technical center. The following report contains a design report of manufacturing, reliability and economics. These different conditions were design for because of their importance. In order to have a feasible design, manufacturing the design is important. By optimizing the exhaust gas capturing system, Cummins, Inc. can manufacture the proposed design. Designing for reliability was another factor that was considered for worker and building safety. Without a safety factor, the design could be catastrophic for anyone working on the project. Finally, a design for economics was considered because the large investment required must have a positive return for the design to be feasible.

2. Design for Manufacturing

The design for the Organic Rankine Cycle (ORC) was first assembled by creating the most important part of the system: the heat exchanger. The heat exchanger Team 2 designed is a shell and tube type heat exchanger. The heat exchanger is a 4-pass system with 30 tubes and 21 baffles. After the heat exchanger was assembled, the next part of the system was the turbine and the generator system. The turbine in the assembly is a visual representation of the Siemens SST-060 Series Steam turbine. The turbine was chosen according to the parameters of our system such as: mass flow rate of our working fluid (n-Butane), the pressure through the system, and the temperature that the working fluid leaves the heat exchanger. In order to have a higher efficiency, Team 2 chose to use AE 3000 Solar Thermal Collectors (STC) to increase the inlet temperature into the heat exchanger. By increasing the inlet temperature, the heat exchanger does not have to apply as much heat to the n-butane in order to reach the required temperature (145^{O}C). There are 500 STCs that are arranged in a rectangular form with 20 panels across by 25 panels long. The STCs are connected in series to avoid a separation of n-butane flow. Before the working fluid passes through the STC the n-butane goes to a compressor that will compress the working fluid to a pressure of 1.1 MPa. An assembled view of Team 2's design is shown in Figure 1.

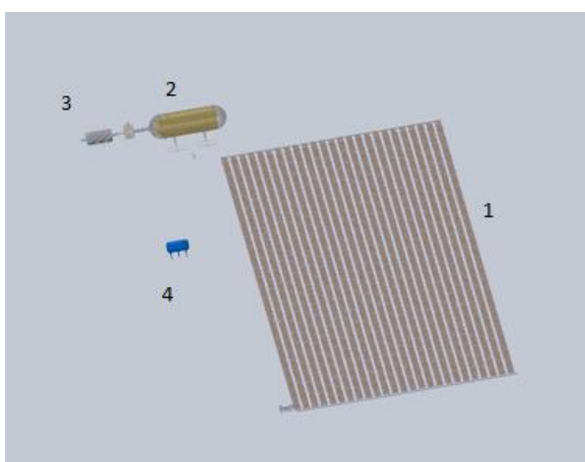

Figure 1: Exhaust Power Generation System

The large section consists of the 500 solar panels that are distributed throughout the roof of the CTC. On the left, is the heat exchanger, followed by the turbine generator system and the compressor is located in the middle of turbine and solar collectors. Sections 1, 2, 3 and 4 denote these.

It took more time than anticipated to design the system due to the large amount of individual parts that are in the assembly. The part that took the most amount of time for the assembly is the piping connecting the different components of the assembly due to the complexity and the size of the overall assembly. The design could be more complex by having a larger heat exchanger with more solar collectors to increase the overall efficiency of the system and it will increase the savings for Cummins, Inc. The problem of increasing the complexity of the organic cycle is the initial cost increases exponentially, making the system less feasible and heavier. The team analyzed different configurations for the systems and one of the configurations studied was a more complex system with a total savings of 10% of the total energy consumption of the Cummins Technical Center (CTC), but the weight of the heat exchanger alone will reach 132 tons making the heat exchanger costly and unfeasible for the CTC. Every part of the system was selected according to the parameters of our system. A thermal analysis for the heat exchanger simulation has been performed in Comsol Multiphysics 4.4 and will be included in the final report of the project. A simulation was done for the overall system that gives a daily analysis based on average weather conditions, temperature, and solar insolation of Columbus, Indiana.

3. Design for Reliability

In Team 2's system, there are several subsystems that are included: heat exchanger, power generation, solar collectors, compressor, and storage tank. The heat exchanger is the system that will transfer the energy from the exhaust gases of the testing engines to the working fluid n-butane. The shell of the heat exchanger has been designed to be able to handle the operating pressure of 1MPa as well as being correctly insulated so there is no heat loss to the exterior through the shell. The shell is also made out of steel and with proper maintenance, will be able to withstand the corrosion due to the impurities of the hot exhaust gases coming out of the engine. The pipes of the heat exchanger are made out of brass because it is cost effective, a good thermal conductor and will have no problem withstanding the pressure and temperatures that the heat exchanger is capable of achieving. The baffles are made out of steel and their main purpose in the heat exchanger is to redirect the hot exhaust gases in the heat exchanger in a path that will maximize the efficiency of the heat exchanger. The turbine that was chosen for the ORC is the Siemens SST-060 Series Steam Turbine. This turbine is able to handle the temperatures and pressure of our system without any problem as was confirmed with Siemens through their representatives. The operating pressures and temperatures of Team 2's system do not reach the maximum allowable pressures and temperature of the turbine, 13.1MPa and 510^{O}C, respectively. The solar collectors will help to improve the efficiency of the system by increasing the inlet temperature to the heat exchanger to achieve a higher output temperature and therefore a higher efficiency. Because of the large amount of tubing through the solar collector, the head loss through the piping has been considered in order to have no issues when the system is running.

One of the possible failures of the system would be that the working fluid is highly flammable making a potential for explosion. The system is well insulated from any outside interaction and greatly reduces this risk. Also, the regular operating conditions throughout the system (1.1 MPa and 145^{O}C) maintain n-butane as a superheated vapor throughout the system. The turbine is made to work with ORC working fluids and is used in Siemens own ORC systems.

FEA analysis was performed in the weakest parts of the system which were the support of the heat exchanger due to the high loads it must withstand, and the tubes inside the heat exchanger because they are made out of brass, which is relatively weak compared to steel. The results of the FEA analysis were satisfactory and each part had a factor of safety higher than 10. Figure 2 shows the stress analysis performed to the supports of the heat exchanger. The supports are made out of one inch steel, the stress analysis conducted with the entire weight of the heat exchanger (45Mg) concentrated on the support system. In reality, the weight will be distributed throughout the support system.

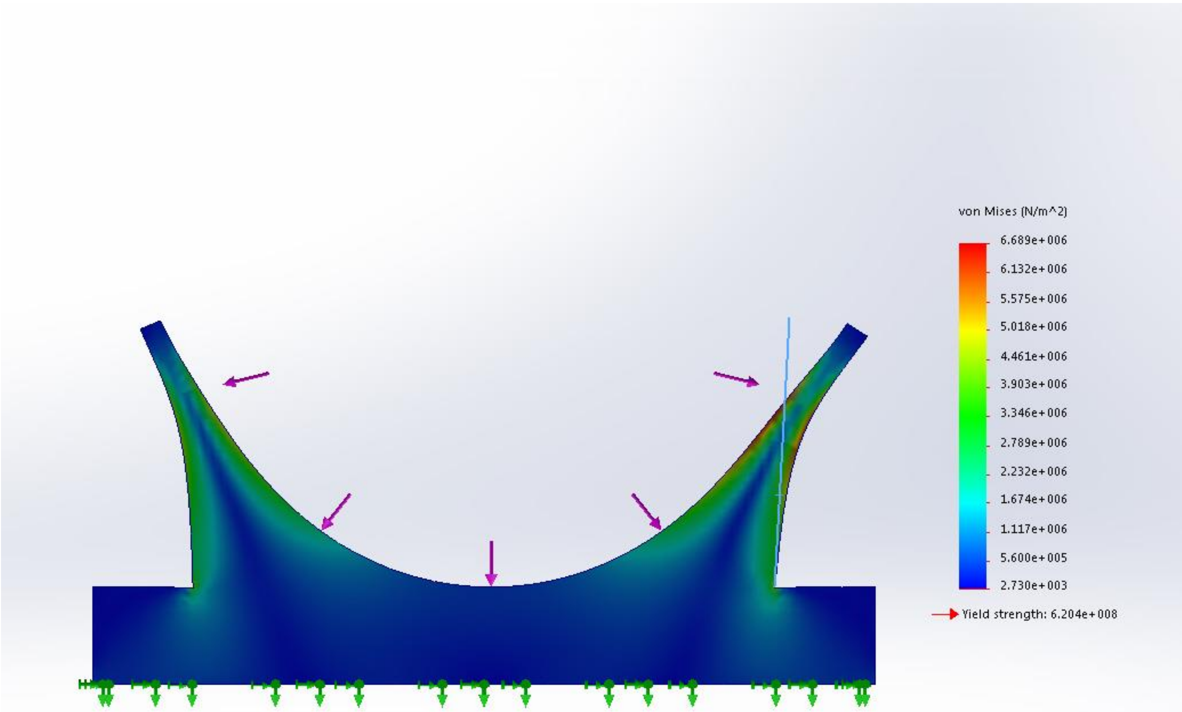

Figure 2: Stress Analysis for Support Beam

Figure 3 shows the material displacement in a brass pipe with the smallest diameter in the system experienced to the maximum pressure experienced by the system of 1.0 MPa. The magnification of the picture is more than two thousand.

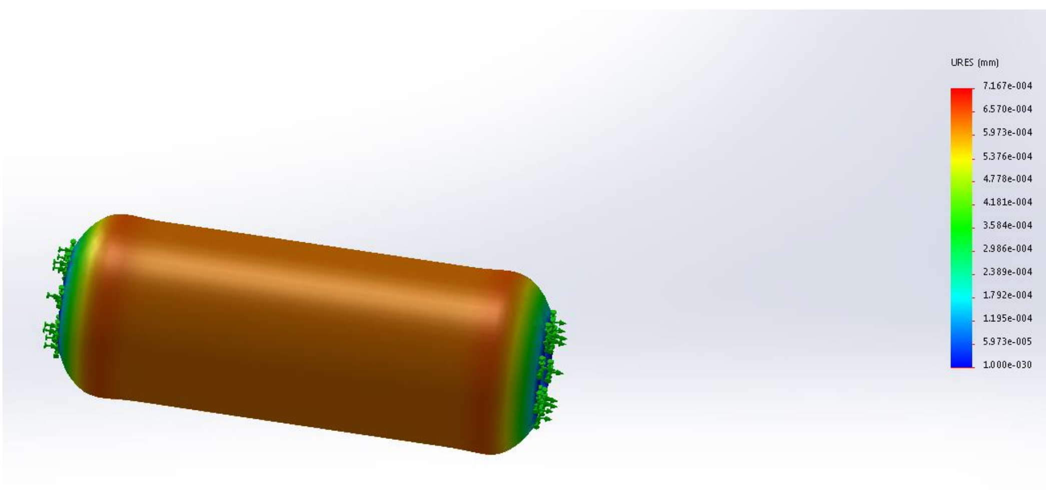

Figure 3: Pressure Analysis for Heat Exchanger Pipe

Figure 3 shows that the maximum material deflection experienced by the piping is $7.17 * 10^{\wedge} - 4$ mm deflection. The piping does not deform from the pressure in the piping which proves that the system is reliable to withstand the pressures. The final analysis that was conducted was a stress analysis on the piping material to determine if any plastic deformation or fracture occurred caused by the pressures.

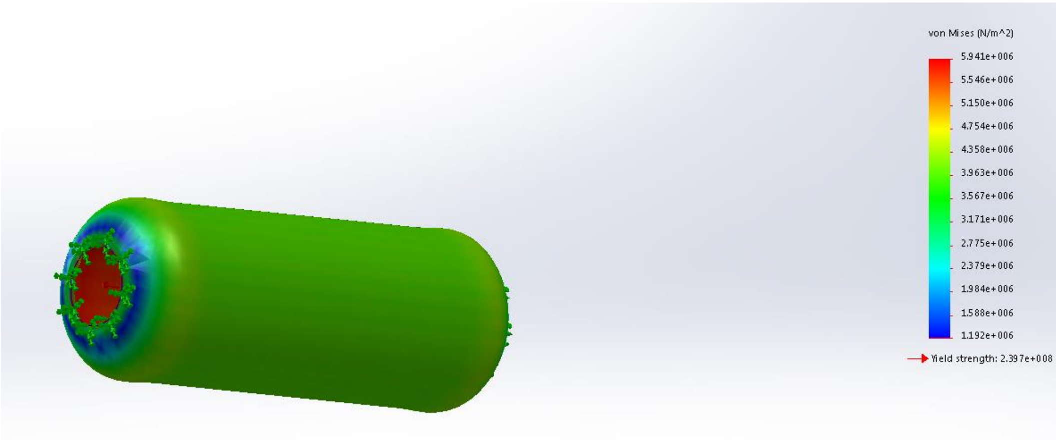

Figure 4: Stress Analysis on Piping

As Figure 4 displayed, the stresses experience by the piping material does not exceed the yield stress of the brass and can be considered a reliable system.

4. Design for Economics

The initial cost of most components was determined by contacting the manufacturer to determine the price. The heat exchanger cost was determined using an initial cost equation [1]

$$C = 1800D^{2.5}L + 350DL + 1950 \qquad \text{Equation 1}$$

Where L is the length and D is the diameter of the shell side of the heat exchanger. This equation incorporates the initial cost of the shell, tubing, and an initial cleaning fee. The initial prices for each component are listed in Table 1.

Table 1 – Initial Cost of Individual ORC Components

Component	Price
Heat Exchanger	$ 591,950.00
Turbine	$ 500,000.00
Compressor	$ 450,000.00
Storage Tank	$ 1,965.00
1600 Gal of n-Butane	$ 1,040.00
Solar Collector	$ 400,000.00
Piping	$ 2,000.00

After calculating initial costs on all the components, the analysis of shipping and installation costs was completed. The shipping costs were done using the uship website where the distance and weight of the shipped component were used to provide an average shipping cost [2]. The initial location for each component was taken from the company websites for the turbine, compressor, and storage tank. Since the heat exchanger is custom and needs to be manufactured, the team's sponsor provided information of a nearby shipyard where it would be possible to manufacture [3]. The piping location was found by using a local pipe distributer in Indiana. The solar collector location was determined by using a solar collector manufacturer, Nusun Solar and they are also located in Indiana. The shipping costs are shown in Table 2.

Table 2 – Shipping Cost of Individual Component

Component	Shipping Cost
Heat Exchanger	$ 5,700.00
Turbine	$ 230.00
Compressor	$ 512.00
Solar Collector	$ 121.00
Piping	$ 173.00
Storage Tank	$ 445.00
1600 Gal of n-Butane	$ 143.00

Installation costs were approximated by estimating the time and man power needed to complete the installation. The time for installation was assumed to be one month since the system is so large and it was determined that one engineer and a team of ten skilled workers would be needed to install the system. Assuming that they would be working a 40 hour work week for 4 weeks at an average price per hour, the total installation cost was determined to be $46,400 [4]. Figure 2 shows a pie chart of all the initial costs. These costs total to $2,000,623.00.

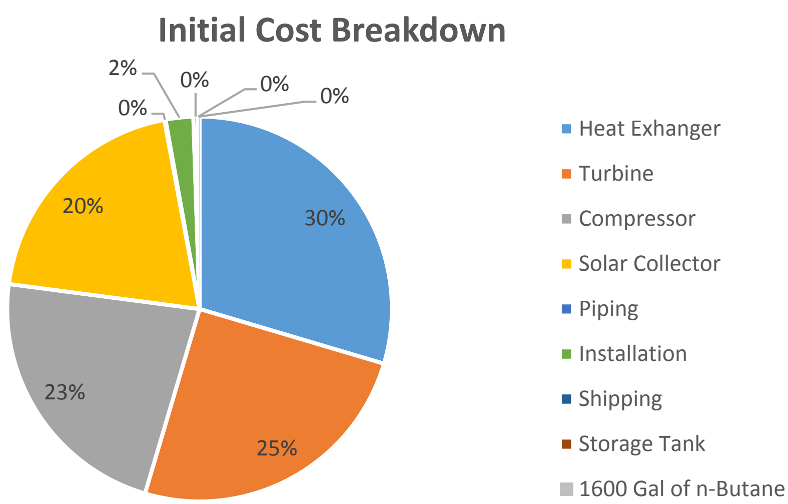

Figure 5: Initial Cost Breakdown of all costs

Finally, the maintenance cost was determined by using data from average maintenance costs for the turbine and compressor. The heat exchanger maintenance was calculated by using the equations from Conco Consulting Corp. that specializes in the monitoring of heat exchanger performance and maintenance [5]. The annual maintenance cost was determined to be $250,000 a year. The initial and annual costs were plotted on the same plot as the money gained from the generated energy of the system in Figure 3. The plot shows a breakeven point of 23 years. After this time the system will be generating a profit for Cummins. This shows that economically the overall system is a feasible option for Cummins. It should be noted that this cost analysis did not take into account the present and future value of the dollar, which will be included in the final report for the project.

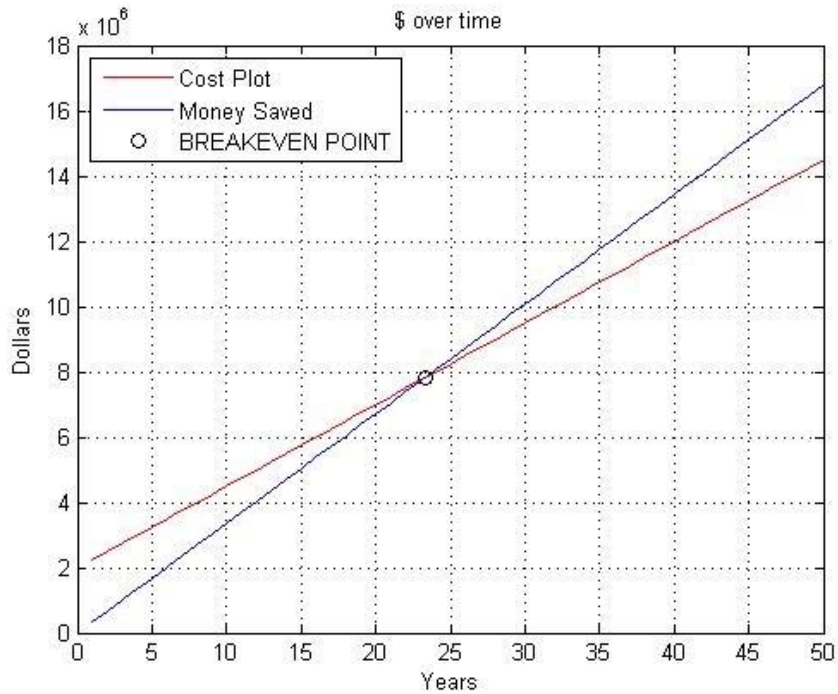

Figure 6: Time (years) to Payoff Initial and Annual Costs

5. Conclusion

In conclusion, the exhaust power generation system is a reliable system. There is no fracture within the piping material or major deflection. Also, the stresses that the piping experience is well below the yield stress of brass. The results showed how reliable the heat exchanger was for this design. The heat exchanger was the only system that was capable of being analyzed via SolidWorks because this was the component custom designed by Team 2. The other components such as the turbine, compressor, and the solar collectors were optimized from a professional business and are considered a reliable product. The overall cost of the system was $2,000,623.00 with a payback time around 23 years. This takes into account assembly man hours, materials, components and transportations to highlight the main contributors of cost. The most expensive part of the system is the heat exchanger. Ultimately, there is power to be collected from the exhaust gases as the analysis concludes. However, based on the weight of the system, this system would not be recommended for the CTC's roof and should be based on the ground.

References

[1] Janna, William S. "Shell and Tube Heat Exchangers." *Design of Fluid Thermal Systems*. 3rd ed. Boston: PWS Pub., 1998. Print.

[2] "Shipping Cost." *Uship*. Web. 3 Apr. 2015. <https://www.uship.com/>.

[3] Avry, Peter. "Economic Implementation of the Organic Rankine Cycle." Web. 3 Apr. 2015. <http://aceee.org/files/proceedings/2011/data/papers/0085-000077.pdf>.

[4] "SST-060 Series Siemens Steam Turbines." *SST-060 Compact Steam Turbine*. Web. 3 Apr. 2015.<http://www.energy.siemens.com/us/en/fossil-power-generation/steam-turbines/sst-060.htm>.

[5] Putnam, Richard E. "Optimizing the Cleaning of Heat Exchangers." *Conco Consulting Corp.* Web. 3 Apr. 2015.< www.concosystems.com/.../optimizing-cleaning-heat-exchangers.pdf>.