Honda Senior Capstone Report

Sponsor: Honda
Client Mentor:
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Team Members:
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SoET Mentor:
Professor Fred Berry
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Executive Summary of Project

Honda Manufacturing of Indiana (HMIN) is a plant in Greensburg, Indiana that produces Honda Civics, Insights, and CR-Vs. There is a significant amount of natural gas used at the Paint Department of the HMIN. This natural gas is used for Volatile Organic Compounds (VOCs) [5] abatement processes. VOC destruction is done using Regenerative Thermal Oxidizers (RTOs) [1]. The process of pollutant destruction requires very high temperatures, therefore, requiring high amounts of natural gas [1]. The paint department of the plant is looking for ways to implement heat recovery systems into the RTOs used by the plant. The goal of the Polytechnic Capstone Team 18 is to do an efficiency analysis of the current systems by running heat transfer calculations, and find solutions that will conserve energy lost in terms of heat loss. The team currently recommends that the best way to conserve this energy would be to use the heat from the RTO to either preheat it or heat up something else in the factory. Areas where the heat can be used potentially include boilers, paint booth inlet air, temperature control during winters.

SECTION 1: Project Background and History

1.1 Statement of Problem

There is not a lot of heat energy leakage (5% from the design calculations) from the RTOs in HMIN. [1] The team plans to make the system more efficient by analyzing different heat harvesting and preservation techniques by running simulations. The team's goal consists of being able to trap and reuse some of the heat since this could significantly reduce the amount of natural gas needed to heat a boiler, ovens, or the RTO. This heat could also be used to preheat these operations to reduce fuel and cost to get them up to an operating temperature. Another potential use of this heat could be to control room temperatures in the factory during winters or to control temperatures of the paint booths since they require strong temperature and pressure control.

1.2 Working and Survey of Competing Product

Detailed working of the RTO at Honda is shown in **Figure 1** [2]. The Heat Exchange Media currently used at Honda is made of ceramic. Honda is currently using Catalytic Products Air Regenerative Thermal Oxidizer. This Oxidizer is 95% efficient because every 3 minutes the process of air flow reserves change directions allowing heat captured to be used for incoming air.

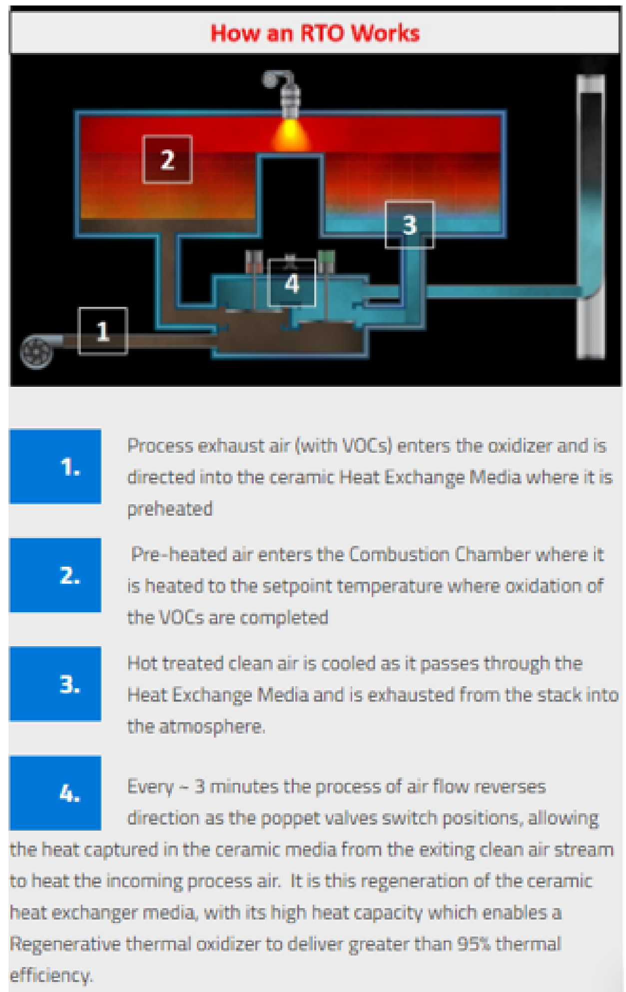


Figure 1: Working of an RTO [2]

There are some ways in which heat recovery can be used in other RTOs.

1. One way that this can be done is by simply adding one or two heat recovery loops in the RTOs. These loops can preheat the Process Exhaust Air using the heat from the Exhausted steam.

2. Another potential idea that can be implemented is running turbines using the steam generated to actually produce energy to run other machines or partially provide energy to run the RTO.

1.3 Scope of work

The goal of the Polytechnic Capstone Team 18 is to evaluate the feasibility of pulling energy from the RTO for potential reuse in other Paint Department Processes. The team will conduct an analysis of the current systems, and find solutions that will conserve energy.

The paint department of the plant is looking for ways to implement heat recovery systems into the RTOs used by the plant to decompose VOCs. This will improve efficiency of systems in the plant, and help reduce fuel costs. This system must meet the specification of the clients (HMIN). This will include overall size, payback period and total costs (Cost of manipulating the system for accomplishing the project including Maintenance and Repair Costs).

This will be done by brainstorming multiple solutions and analyzing each one to see which is the most energy and cost efficient for the client. To do this, the team will run simulations and analysis calculations for the heat harvesting and preservation system. The team would propose a design to allow for recovery and reuse of the heat generated.

1.4 Team Members

1.4.1 Team Bios

- **Arshpreet Singh** - Senior in Electrical Engineering Technology and Computer Science. Responsible for making sure all hardware and software programming works as efficiently and as fast as possible.
- **Charles Lee** - Senior, studying Audio Engineering Technology. Responsible for design simulation and hardware system works as efficiently and fast as possible.
- **Luke Winteregg** - Junior, studying Mechanical Engineering Technology. Responsible for the energy calculations to check the feasibility of the project.
- **Matthew Fogarty** - Senior in Mechanical Engineering Technology. Responsible for energy calculations and thermal efficiency calculations.

1.4.2 Team Charter

GroupMe is preferred for texting in short messages to share the team's sources or to meet with team members. The team uses Google Doc to discuss and write the report. The important documents will be saved to the Google Drive folder shared to the team members.

Meetings will be held at an agreed time and place. The team meets with the team's mentor, professor Fred Berry, every Monday at 6:30PM for the 2019 fall semester. For having contacts with Honda, e-mail would be used. To have a meeting with Honda, Honda prefers WebEx. Files are expected to be shared via email, or Google Drive link(s).

Throughout the project at each gate, the team will be using CATME to grade the teams performance for that section of the course. Below is the grading scale that will be used to evaluate team members:

1.4.2.1 CATME Grading Criteria

- Score of 1 is a non-participant in that assignment.
- Score of 2 is a team member that has partially completed their work.
- Score of 3 is completed work done below the expected quality.
- Score of 4 is average work. Given to a student that has completed work as expected.
- Score of 5 is above average work. If a team member does high quality work.

SECTION 2: Conceptual Development Stage

2.1 Exploratory Concepts

Currently, the team has designed three potential ideas to improve the thermal efficiency of the RTO.

- RTO Preheat

For the RTO preheat idea, the goal is to utilize heat from the exhaust of the RTO and reuse it to preheat the gas coming into the RTO as shown in **Figure 2** [3], the heat coming out of the Thermal Oxidizing Chamber is used to preheat the concentrated VOC air coming into the thermal oxidizing chamber. When the concentrated VOC comes preheated, it will require less energy to heat to the temperature required in the thermal oxidation chamber.

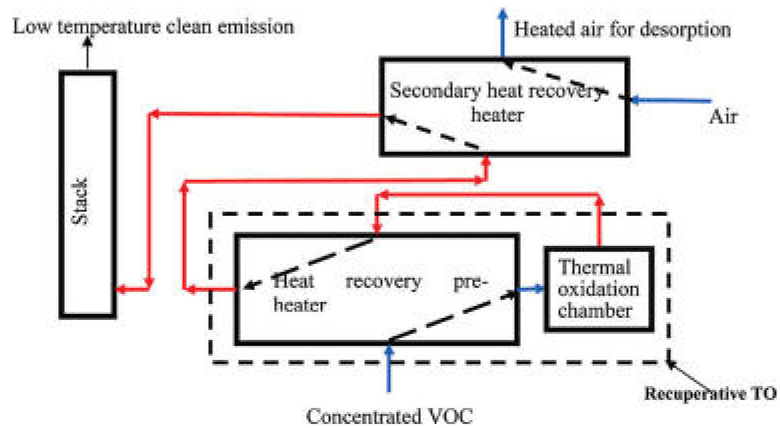


Figure 2: Thermal oxidizer with heat recovery [3]

- Oven Preheat Improvement

The Honda Manufacturing of Indiana plant currently has a heat exchanger attached to an RTO exhaust used to preheat the ovens in the paint department. The current system is an air to air heat exchanger which is not efficient, and using a heat exchanger that uses a water-glycol mix would greatly improve the thermal efficiency. As seen in **Figure 3** [4], there is a schematic of this system. A heat exchanger is used to gain heat energy from the RTO exhaust, which is taken to the ovens where the heat is distributed to the system with a heat exchanger. This reduces the energy required to preheat the oven, saving electricity costs.

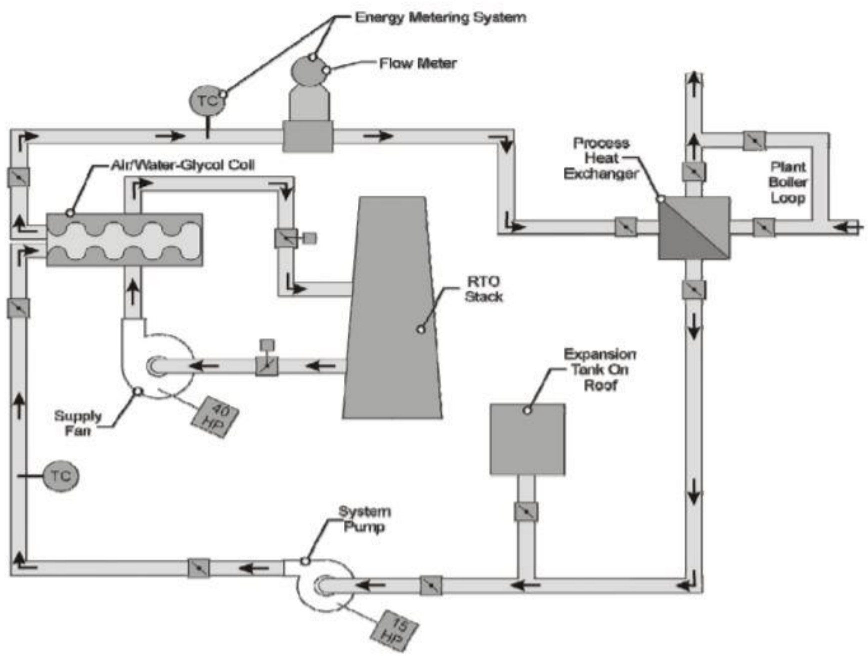


Figure 3. Schematic of an Oven Preheat Loop Installed in an RTO [4]

- Boiler Preheat

For the boiler preheat idea, the goal is to utilize heat from the exhaust of the RTO and reuse it to preheat the water coming into the boilers. The heat leaving the Thermal Oxidizing Chamber is captured using a water glycol mix and sent to the boiler water inlet through a pipe and warms the water with a water to water heat exchanger entering so less fuel has to be used to heat the water. The process would be similar to **Figure 3** [4], except the mix would go to a boiler instead of an oven.

2.2 Requirements Matrix

The following requirements matrix is what the client specified to the team for what the client wanted as the result of the project. Since the team's client is Honda, the restrictions put on this project were very limited. The team was strongly advised that if the price paid by the company would be worth the gains to Honda, (as in with a strong payback period and efficiency) HMIN would implement it. For the client, cost, size and other such requirements were deemed unnecessary.

Table 1 Requirements Matrix

	Requirement	Description	Test
1	Cost	Cost of manipulating the system for accomplishing the project including Maintenance and Repair Costs. There is an open Budget Based on Returns.	Calculate the potential cost of materials, man-hours needed, production and equipment.
2	Payback Period	Potential Time in years needed to payback initial cost. Also includes Carbon Footprint. Ideal: 2 Years or fewer Maximum: 5 Years	Calculate the potential time in years needed for the initial cost to be paid back.
3	Weight	Below 6000 lbs	Simulation material weights would be made to design specifications/ material specification given by the client

2.3 Detailed Concept Designs

The team decided to approach the problem statement in the following way:

1. Brainstorming Ideas and Conceptual Designs
2. Narrowing down the designs to 3 Conceptual Designs
3. Running Design Selection Process on these three designs
4. Choosing one Final Conceptual Design

The team first decided to look at what the team knows from the measurements:

- RTO Inlet Temperature = 71°F
- RTO Outlet Temperature= 171°F to 250°F
- Boiler Outlet Temperature= 161°F to 163°F
- Boiler Inlet Temperature = 176°F
- Boiler Flow Rate: 350gpm

Then, the team decided to answer the following questions

- Where could the heat be extracted from?
- What machines in the factory would require heat?
- What other ways could heat be used to create energy?

2.3.1 Conceptual Design - Preheating Water Boiler

The team's initial idea was to take the line of the boiler and run it through the RTO in order to transfer heat. This idea had to be reworked in order to account for the RTO being outside and the potential for water freezing in the pipes during winter. This design was reworked and it was decided that a mix of propylene glycol and water would be used as a heat transfer medium. A 50% water-glycol mix has an approximate freezing point of -30 degrees Fahrenheit, which is suitable for winters in Indiana. [6] The rest of the design consists of this water-glycol mix running through a heat exchanger in the RTO where it gains heat from the RTO’s exhaust at a temperature of 171°F to 250°F. The water-glycol mix then runs back through the pipes to the boiler where it dumps heat into the boiler inlet. This heats the boiler water from 162°F to as close as possible to 176°F required in the boiler.

$$Savings\ Calculations$$

$$(1.1 * 350gpm * 1F * 500) = 192,500 \frac{BTU}{hr}$$

$$192{,}500\frac{BTU}{hr} / 1{,}015{,}000 \frac{BTU}{ct} = .189655\frac{1000cf}{hr}$$

$$.189655\frac{1000cf}{hr} * \$9.52 \text{ per } 1000cf = \$1.89655 \text{per hour}$$

$$\$1.89655 \text{ per hour} * 16\frac{hr}{day} = \$28.88828 \text{ per day}$$

$$\$28.88828 \text{ per day} * 255 \frac{working\ days}{year} = \$7366.51 \text{ per year}$$

2.3.2 Conceptual Design - Preheating RTO

One way to save energy is to preheat the air coming into the RTO itself. This proposed idea would take little equipment to implement and not require a lot of maintenance. The first concept for this design was to re-route the inlet air to pass through an air to air heat exchanger inside the exhaust, or run some exhaust air through a heat exchanger before the air enters the RTO. These ideas didn't work very well because if the system failed it may shut down production for a long time. So a safer design was the final conceptual design the team came up with was preheating the RTO with two heat exchangers, one in the exhaust and one in the inlet of the RTO, captures waste heat from the exhaust and then heats up the air coming into the RTO. This is a much safer design from a production standpoint because if it fails it can just be shut off and not stop production. It will not be improving efficiency or saving money, but it will not cause the whole plant to shut down. In the final design it was not decided if the heat exchangers were to be air to water, or air to air. Water as a heat transfer medium can hold and transfer heat much better than air. This would raise the inlet air temperature more. Since this is such a short distance, the air would not lose heat by the time it reached the inlet of the RTO. The air temperature coming from the paint booth is 71°F and the exhaust temperature is 180°F to 250°F. There is a big heat difference so it is possible to raise the inlet temps by a relatively large amount. From the team's calculations, every °F of the inlet raised would save about $2,700 a year on only natural gas costs. This was calculated from$1.1 * Flow\ Rate * \Delta t$ and this would give BTU per hour. In Indiana the average rate of natural gas is about $9.52 for 1,000 cf of natural gas and 1,000 cf of natural gas is 1,015,000 BTUs. [7]

$$Saving\ Calculations$$

$$Assuming\ 16hr\ for\ 2\ *\ 8hr\ shifts\ and\ 255\ for\ the\ number\ of\ working\ days\ a\ year,$$

$$(1.1\ *\ 65,000cfm\ *\ 1F)\ =\ 71,500\ \frac{BTU}{hr}$$

$$71{,}500\frac{BTU}{hr} / \ 1{,}015{,}000\ \frac{BTU}{ct} = .0104433\frac{1000cf}{hr}$$

$$.0104433\frac{1000cf}{hr} * \$9.52 \text{ per 1000cf} = \$.6706207 \text{ per hour}$$

$$\$.6706207 \text{ per hour} * 16\frac{hr}{day} = \$10.72993 \text{ per day}$$

$$\$10.72993 \text{ per day} * 255\ \frac{working\ days}{year} = \$2{,}736.13 \text{ per year}$$

2.3.3 Conceptual Design - Turbine Generator

A turbine generator could be installed on the roof. This would have a simple setup as the turbine could be built/installed close to the RTO. An air to water heat exchanger would capture heat from the exhaust of the RTO and the steam generated would be used to turn a turbine. This generates electricity and could be easily used at the factory. However, after getting more information, the RTO exhaust wasn't as hot as previously thought at 300°F to 350°F but instead at 170°F to 250°F. With the heat this low it takes the feasibility out of the design. There may not be enough heat to consistently boil the water, making the design worthless.

2.3.4 Design Selection Process

To determine the best design plan to implement on this project, several factors were considered and evaluated each design based on the factors.

The following factors were considered:

- **Cost Saving (0.25):** The potential cost savings from a design. Calculated in $/per degree raised. This includes natural gas savings and CO_2 emissions.
- **Payback Period (0.25):** Years taken to payback the original project cost.

- **Efficiency (0.2)**: Improving efficiency of existing systems
- **Maintenance (0.15):** Repairing and service costs of the design.
- **Ease of Implementation (0.1):** Installing time and processes of the design.
- **Cost of Application (0.05):** Costs to install the design including: Design Costs, Installation and Equipment costs.

Table 2 Design Selection Process

Factors	Boiler Preheat	RTO Preheat	Turbine Generator
Cost Saving (0.25)	0.25	0.15	0.05
Payback Period (0.25)	0.2	0.17	0.05
Efficiency (0.2)	0.15	0.18	0
Maintenance (0.15)	0.08	0.12	0.05
Ease of Implementation (0.1)	0.05	0.08	0.05
Cost of Application (0.05)	0.03	0.05	0.01
Total (1)	0.76	0.75	0.21

2.3.5 Final Design Description

The boiler preheat is the preliminary choice for the final design. As seen above in the design selection process table, it was given the highest total value out of one. The largest reason this design was chosen was the quick payback period, and the cost savings per year. These two categories are the most important to HMIN because it affects their bottom line. The other aspects of the design were relatively similar to the RTO preheat, but because of the cost savings for the boiler preheat, the RTO preheat came up short. However, the two designs are so close in value that any small change could result in the

RTO preheat being the best option for this project. The boiler has some unknowns associated with it such as the distances from the RTO to the boilers, as well as the current function of the boilers. Alan discussed with the group that he was unsure when the boilers run and if whether or not their operation is consistent. If the distance from the RTO to the boilers is large enough to cause major losses, or if the boilers are not consistently run, it could cause loss in savings. This has the potential to make the RTO preheat a superior design option.

2.4 Critical Issue(s) Identification

- **Heat Exchange Expertise:** While members of the team have basic experience in thermodynamics and heat exchange problems, none are experts and need to do more research and/or talk to experts on the subject.

- **Simulation Software:** The decision of which simulation software to use. MATLAB (Thermolib), Pro-E, Ansys, AutoCAD, and using McMaster Carr for part downloads. Matlab (Thermolib), Pro-E, and Ansys all have toolkits for measuring and simulating heat transfer.

- **Unknown Variables:** There are some measurements that need to be made to design a system such as distance from the RTO to boiler to know how much piping is needed. The thermal conductivity and the specifics of the heat exchanger which would be used in the simulation software. This would be the boundary conditions that are needed to accurately record, predict, and simulate the system.

SECTION 3: Process/Project Design Stage

3.1 Project Mechanical Description

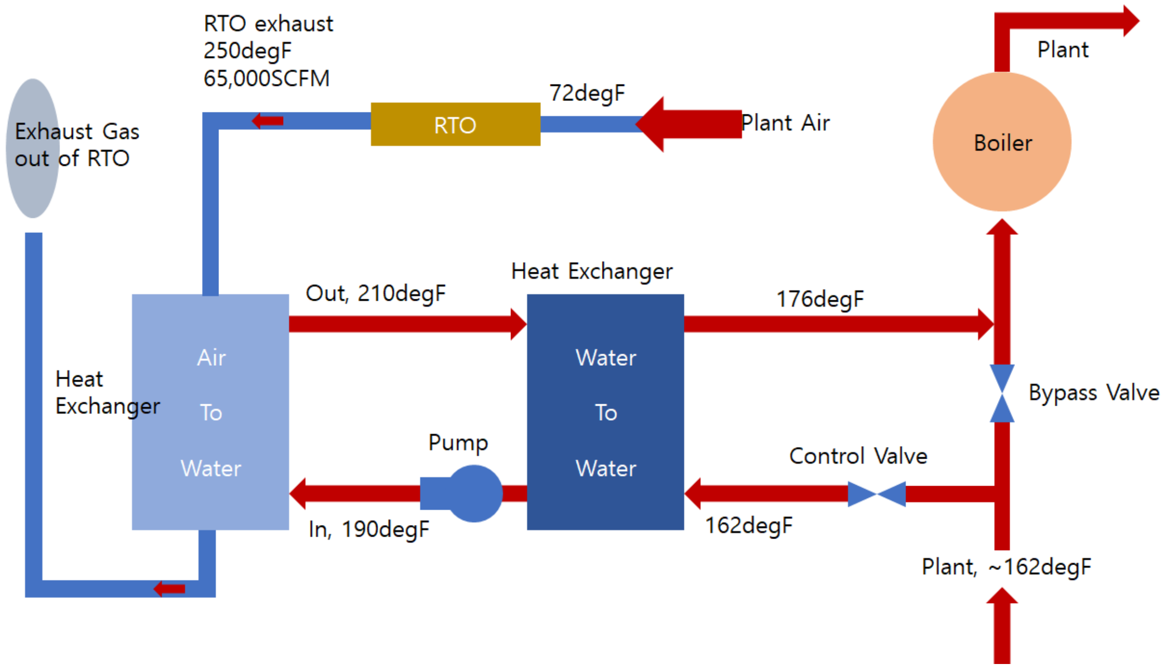


Figure 4 Boiler Heat Recovery System Schematic

Figure 4 is a schematic representation of group 18's ideal design as of Gate 3. The system includes two heat exchangers, one air-to-water and one water-to-water. The system functions as follows: The plant air contaminated with VOCs from the paint booths are taken through the air ducts to the inlet of the RTO. Here they are preheated by a ceramic medium, then heated to approximately 1400-1500 °F. Then they are passed over another ceramic medium, heating it so when the airflows switch it will be able to preheat the plant air. After the air is exhausted from the RTO it is at a temperature of approximately 170-250 °F. This air is currently just exhausted to the atmosphere, however in the design, it goes to the first of the heat exchangers. This heat exchanger is the air-to-water heat exchanger. It will be a fin coiled heat exchanger that extracts heat from the exhaust air to heat a 50% water/propylene glycol mix. This heated mix will be circulated between this heat exchanger and another heat exchanger that is water-to-water. This second heat exchanger will be used to heat up the treated water in the boiler system.

The goal of this design is to reduce the amount of natural gas needed by the boiler to heat the treated water to the proper temperature.

3.1.1 Tolerances and Initial measurements

- RTO Inlet Temperature = 71°F
- RTO Outlet Temperature= 171°F to 250°F
- Boiler Outlet Temperature= 161°F to 163°F
- Boiler Inlet Temperature = 176°F
- Boiler Flow Rate: 350gpm

3.1.2 Parts Required

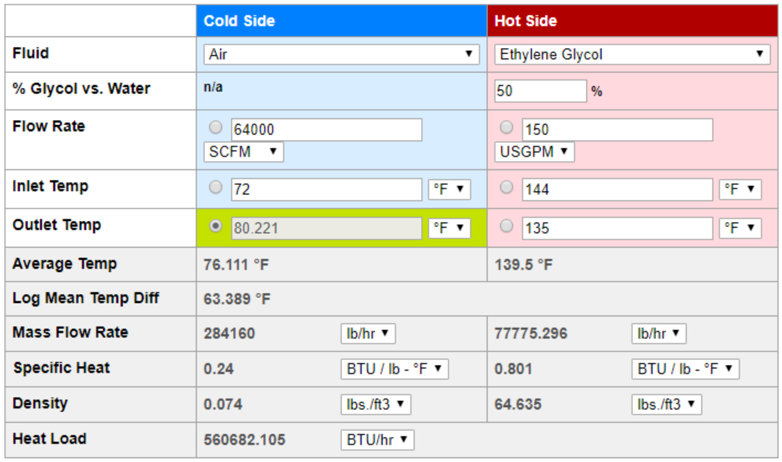
The parts required to build the system are not chosen by the team. The team decides the design and carry out the team's calculations using simulation software provided by the contractors to decide which of the team's designs is efficient. Once the team finalizes a design, the parts are chosen by the contractors and built. Due to the magnitude of the project the team does not have the labor capacity to build the system.

3.1.3 Calculations

The detailed calculations are on **Section 5.2**.

3.2 Project Software Description

During this project it is important that the group uses some software to get calculations to verify the system fits requirements and to get an accurate representation of the cost and savings gained by installing the group's design. Throughout the project multiple softwares have and will be used to verify these things. The first of these is the heat calculator used to give the group an initial idea of the amount of energy that can be attained by a perfect heat recovery system. A picture of this calculator can be seen in **Figure 5** below.



	Cold Side	Hot Side
Fluid	Air	Ethylene Glycol
% Glycol vs. Water	n/a	50 %
Flow Rate	64000 SCFM	150 USGPM
Inlet Temp	72 °F	144 °F
Outlet Temp	80.221 °F	135 °F
Average Temp	76.111 °F	139.5 °F
Log Mean Temp Diff	63.389 °F	
Mass Flow Rate	284160 lb/hr	77775.296 lb/hr
Specific Heat	0.24 BTU / lb - °F	0.801 BTU / lb - °F
Density	0.074 lbs./ft3	64.635 lbs./ft3
Heat Load	560682.105 BTU/hr	

Figure 5. Heat Transfer Calculator [8]

After using this to find reasonable values to input in the group's schematic and future calculations, the group had a meeting with Brian Adika, a sales engineer from BBC Pump and Equipment Company. In order to start choosing equipment for the system Brian directed us to a software provided by Taco Comfort. This calculator is similar to the heat transfer calculator above however their system uses that information and applies it to their database to help choose heat exchangers that are appropriate. In **Figure 6**, below, an image of this calculator and equipment output can be seen.

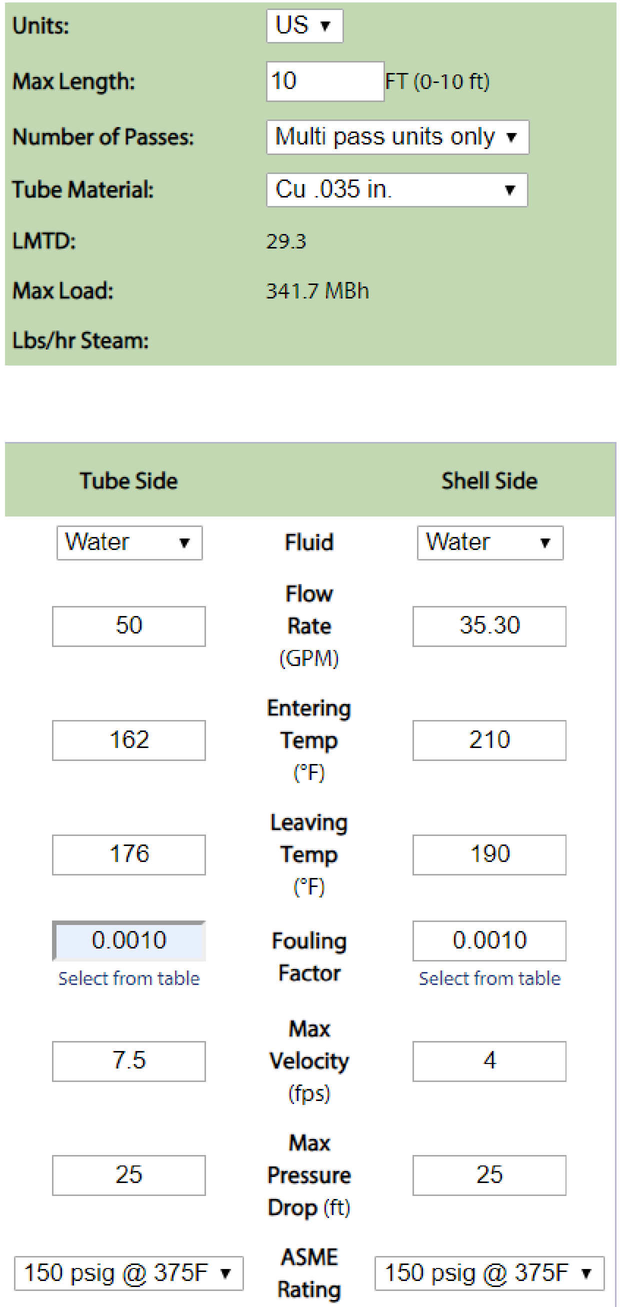


Figure 6. Taco Comfort Heat Exchanger Calculator

When meeting with Brian, he also gave the group a calculator that can help later in the project with the Return of Investment (ROI) calculations and cost comparisons. This calculator will give us the ability to compare the system's cost with the current system, as well as allow us to compare two separate pieces of equipment. **Figure 7**, below, shows an image of this software and its inputs.

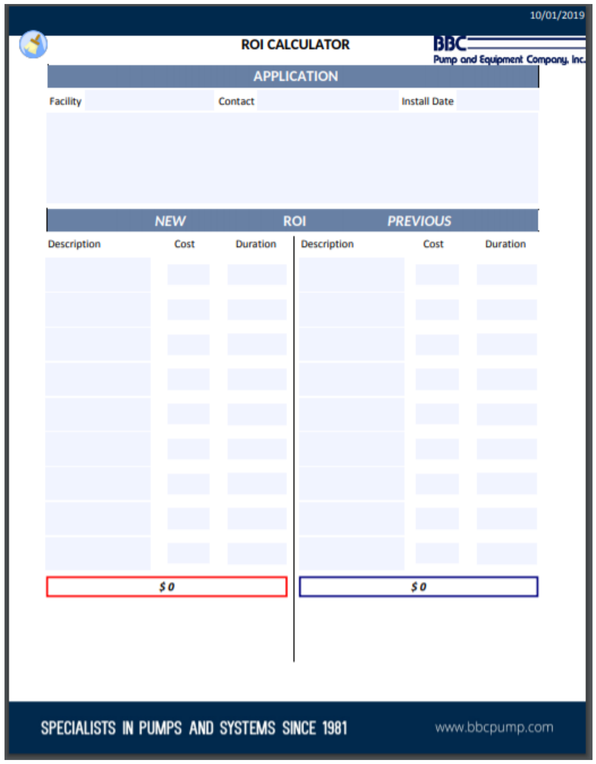


Figure 7. BBC Pump and Equipment Company ROI Calculator

3.3 Bills of Materials

The project cannot be scaled down very well and would not be very accurate as a small scale model. The only thing the team might have needed to purchase is heat transfer software.This was later replaced by an Excel program the team created. This program finds the losses in the pipe, given a variety of circumstances: temperature, insulation, ambient temperature, flow rates, etc. Furthermore, during the first meeting with the contractors, it was found that the team does not need to purchase any simulation software. This is because the contractors are going to use simulation software that they have available to them at BBC Pump and Equipment Company. At this point the team does not have access to the software, however the contractors said they were willing to explain their inputs in the software. They also stated that they could describe the process they went through so the team better understands the process and the equipment chosen for the project.

The team plans to meet contractors at the Honda plant to get quotes for the system in future. Meeting with the contractor and the client may be spread over multiple visits for scheduling purposes. After these meetings, if the system would be seen efficient, an equipment list would be finalized and all the pieces of equipment needed will be ordered and put in by July. This is when the plant shuts down for a week for maintenance. This would be done to not interrupt the factory production line. Adding these costs to the installation labor costs the total cost for the system will be found.

3.4 Budget for the Fabrication Phase

As discussed above, there is no bill of materials for the team since Honda makes all the parts purchases through the contractor. Therefore, following are the required supplies needed to carry out the project.

- **Simulation Software Cost:** $0, online calculators, excel sheet and the contractor softwares were used.
- **Honda Cost:** Piping cost, pump, heat exchanger, labor cost, insulation, water-water mix and boiler.
- **Heat Exchanger (Water-to-Water):** Option 1: $26,400
Option 2: $33,608.00
- **Heat Exchanger (Steam-to-Water):** Option 1(standard): $15,000
Option 2(stainless): $26,500

The rest of the equipment costs such as pump, piping, and insulation costs were not able to be reached due to the closure of the HMIN plant and the inability to reach Alan and Brian during the time the group participated in online courses.

The cost for these will be handled by Honda through contractors. Once a final cost estimation is given to the team, the team will run saving calculations on various alternatives to the materials listed above. The combined quote will be the budget for the whole project for Honda with an expected return policy within 5 years and preferred 2 years.

3.5 Materials Required

The materials for the piping and heat exchangers have not yet been decided. It is unknown what materials are required inside the RTO, as the chemicals in the exhaust have not been clearly stated. The client Alan suggested that the group can start with 316 stainless steel, but the group plans on making the design with 316 stainless steel and with regular galvanized steel. The second heat exchanger will likely be made out of galvanized steel as it is the less expensive option and is industry standard. The pump will also be made out of industry standard materials as it will be transporting water. The exact sizes of piping, insulation, and pumps are not known at this time, and the group is working on heat exchanger sizing with Brian at this time.

The current plan calls for either a Taco G06418-4L or a Taco E06218-3L shell and tube heat exchanger on the boiler side, and a Taco E06212-S heat exchanger made of either stainless steel 316 or regular galvanized steel. These will be needed as they are the devices used to transfer the heat from the RTO to the Boiler. After the heat exchangers are found, the sizing of the pump will be determined and finally the piping and insulation sizes will be found.

The specification sheets for the Taco G06418-4L and Taco E06218-3L shell and tube heat exchangers for the boiler Water-to-Water heat exchanger can be seen below. Their prices will also be stated in the budget section.

Submittal Data Information

Double Wall Heat Exchangers

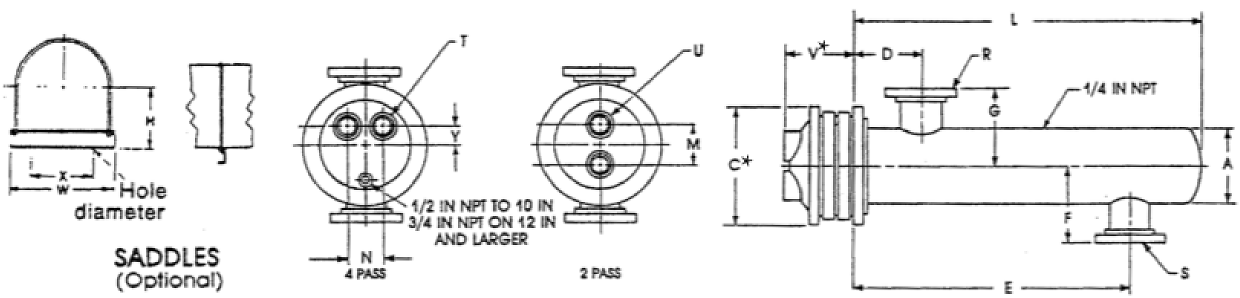
201-075

6" Diameter Liquid **SUPERSEDES: January 2, 1991** **EFFECTIVE: April 30, 2018**

JOB: ENGINEER: CONTRACTOR: REP:

Item No	Model No	Pass	GPM Tubes	Temp. In	Temp. Out	P.D. Tubes	Vel. Tubes	GPM Shell	Temp. In	Temp. Out	P.D. Shell	Vel. Shell
	G06418-4L	**4**	**50**	**162**	**176**	**9.79**	**7.36**	**35.30**	**210**	**190**	**5.92**	**1.97**

Tube Fluid **Water** Shell Fluid **Water**



DIMENSIONS: 6 Inch Diameter

Model Number		Cast Iron Heads						Dimensions (inches)									Heating Surface (sq. ft.)	Shipping Weight (lbs.)
2 Pass	4 Pass	2 Pass		4 Pass				2 and 4 Pass										
		M	U	N	T	Y	V*	A	C*	D	E	F	G	L	R	S		
G6204L	G6404L	4	2T	3¾	1½T	1¼	3¾	6⅝	11	5	18	5⅞	5⅞	25	2½T	2½T	18.2	138
G6206L	G6406L	4	2T	3¾	1½T	1¼	3¾	6⅝	11	5	30	5⅞	5⅞	37	2½T	2½T	27.6	166
G6208L	G6408L	4	2T	3¾	1½T	1¼	3¾	6⅝	11	5	42	5⅞	5⅞	49	2½T	2½T	37.0	200
G6210L	G6410L	4	2T	3¾	1½T	1¼	3¾	6⅝	11	5	54	5⅞	5⅞	61	2½T	2½T	46.4	225
G6212L	G6412L	4	2T	3¾	1½T	1¼	3¾	6⅝	11	5	66	5⅞	5⅞	73	2½T	2½T	55.8	253
G6214L	G6414L	4	2T	3¾	1½T	1¼	3¾	6⅝	11	5	78	5⅞	5⅞	85	2½T	2½T	65.2	280
G6216L	G6416L	4	2T	3¾	1½T	1¼	3¾	6⅝	11	5	90	5⅞	5⅞	97	2½T	2½T	74.6	308
G6218L	G6418L	4	2T	3¾	1½T	1¼	3¾	6⅝	11	5	102	5⅞	5⅞	109	2½T	2½T	84.2	336
G6220L	G6420L	4	2T	3¾	1½T	1¼	3¾	6⅝	11	5	114	5⅞	5⅞	121	2½T	2½T	93.6	364

SADDLE DIMENSIONS: H-6 15/16; W-9¼; X-7½; Hole Dia.-⅝

Figure 8. Taco G06418-4L Specifications

G06418-4L

Tag:

Pass	Diameter	Length	Pitch
4	6	9	4

TUBE SIDE

Fluid Type	Flow	Temp In	Temp Out	Fouling Factor	Pressure Drop	Velocity
Water	50	162	176	.001	9.79	7.36

SHELL SIDE

Fluid Type	Flow	Temp In	Temp Out	Fouling Factor	Pressure Drop	Velocity
Water	35.30	210	190	.001	5.92	1.97

Tube Material	LMTD	Max Load
Cu .035 in.	29.3	341.7 MBh

Figure 9. Taco G06418-4L - Liquid Flow Details

201-082

Submittal Data Information

Enhanced Surface U Tube Heat Exchangers

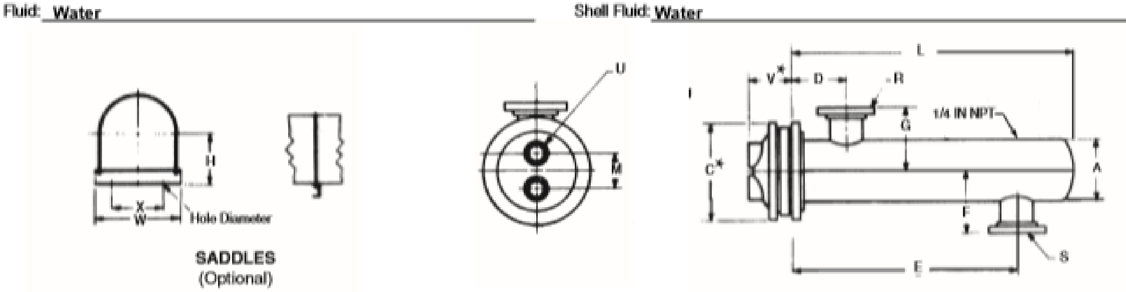
6" DIAMETER LIQUID | SUPERSEDES: May 16, 2014 | EFFECTIVE: April 30, 2018

JOB: | ENGINEER: | CONTRACTOR: | REP:

Item No.	Model No.	Pass	GPM Tubes	Temp. In	Temp. Out	Pressure Drop Tubes	Velocity Tubes	GPM Shell	Temp. In	Temp. Out	Pressure Drop Shell	Velocity Shell
	E06218-3L	2	50	162	176	1.41	3.68	35.30	210	190	10.08	2.63

Tube Fluid: Water

Shell Fluid: Water



DIMENSIONS: 6 Inch Diameter

Model Number	Cast Iron Heads		Dimensions (Inches)										Heating Surface (sq. ft.)	Shipping Weight (lbs)
	M	U	A	C*	D	E	F	G	L	R	S	V*		
E06204L	4	2T	6⅝	11	5	18	5¾	5¾	25	2½T	2½T	2¼	9.1	120
E06206L	4	2T	6⅝	11	5	30	5¾	5¾	37	2½T	2½T	2¼	14.2	148
E06208L	4	2T	6⅝	11	5	42	5¾	5¾	49	2½T	2½T	2¼	19.3	182
E06210L	4	2T	6⅝	11	5	54	5¾	5¾	61	2½T	2½T	2¼	24.4	207
E06212L	4	2T	6⅝	11	5	66	5¾	5¾	73	2½T	2½T	2¼	29.5	235
E06214L	4	2T	6⅝	11	5	78	5¾	5¾	85	2½T	2½T	2¼	34.6	262
E06216L	4	2T	6⅝	11	5	90	5¾	5¾	97	2½T	2½T	2¼	39.7	290
E06218L	4	2T	6⅝	11	5	102	5¾	5¾	109	2½T	2½T	2¼	44.8	318
E06220L	4	2T	6⅝	11	5	114	5¾	5¾	121	2½T	2½T	2¼	50.0	346

Figure 10. Taco E06218-3L Specifications

E06218-3L

Tag:

Pass	Diameter	Length	Pitch
2	6	9	3

TUBE SIDE

Fluid Type	Flow	Temp In	Temp Out	Fouling Factor	Pressure Drop	Velocity
Water	50	162	176	.001	1.41	3.68

SHELL SIDE

Fluid Type	Flow	Temp In	Temp Out	Fouling Factor	Pressure Drop	Velocity
Water	35.30	210	190	.001	10.08	2.63

Tube Material	LMTD	Max Load
Cu .035 in.	29.3	341.7 MBh

Figure 11. Taco E06218-3L - Liquid Flow Details

For the Steam-to-Water heat exchanger it was decided that the proper heat exchanger would be the Taco E06212-S. Based on the information given by Alan, it was decided that the group would give Honda the option of either a standard material heat exchanger or one made with stainless steel to ensure it could withstand the exhaust of the RTO. The specification sheets for this exchanger can be seen below

Taco Comfort Solutions
A Taco Family Company

Submittal Data Information

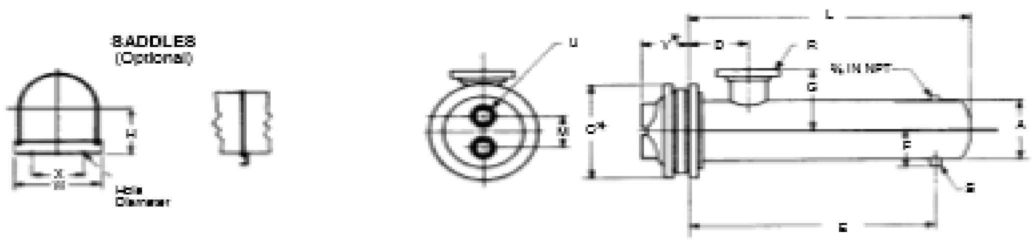
201-082

Enhanced Surface U Tube Heat Exchangers

6" DIAMETER STEAM SUPERSEDES: August 1, 2006 EFFECTIVE: April 30, 2018

JOB: Honda Capstone ENGINEER: CONTRACTOR: REP:

Item No.	Model No.	Pass	GPM Tubes	Temp. In	Temp. Out	Steam Pressure Shell	Pressure Drop Tubes	Velocity Tubes
Steam to Water	E06212-S	2	60.00	180.00	210.00	10	1.10	4.00



DIMENSIONS: 6 Inch Diameter

Model Number	Cast Iron Heads		Dimensions (inches)									Heating Surface (sq. ft.)	Shipping Weight (lbs)
	M	U	A	C*	D	E	F	G	L	R	S		
E6204S	4	2T	6⅝	11	5	18½	4⅝	4⅝	25	1½T	1T	9.1	120
E6206S	4	2T	6⅝	11	5	30½	4⅝	4⅝	37	2T	1T	14.2	148
E6208S	4	2T	6⅝	11	5	42½	4⅝	5¾	49	2½T	1T	19.3	182
E6210S	4	2T	6⅝	11	5	54½	4⅝	5¾	61	2½T	1T	24.4	207
E6212S	4	2T	6⅝	11	5	66½	4⅝	$5\frac{13}{16}$	73	3T	1T	29.5	235
E6214S	4	2T	6⅝	11	5	78½	4⅝	$5\frac{13}{16}$	85	3T	1T	34.6	262
E6216S	4	2T	6⅝	11	5	90½	4⅝	$5\frac{13}{16}$	97	3T	1T	39.7	290
E6218S	4	2T	6⅝	11	5	102½	4⅝	$5\frac{13}{16}$	109	3T	1T	44.8	318
E6220S	4	2T	6⅝	11	5	114½	4⅝	$5\frac{13}{16}$	121	3T	1T	49.9	346

SADDLE DIMENSIONS: H-$6\frac{13}{16}$; W-9¾; X-7½; Hole Dia.-⅝.

Figure 12. Taco E06212-S Specifications

E06212-S

Tag: Steam to Water

Pass	Diameter	Length	Pitch
2	6	6	

TUBE SIDE

Fluid Type	Flow	Temp In	Temp Out	Pressure Drop	Velocity
Water	50.00	190.00	210.00	1.10	4.00

SHELL SIDE

Fluid Type	LBS Per Hour	Sat Steam Temp	Steam Pressure
Steam	504.1	239.40	10

Tube Material	LMTD	Max Load
Cu .049 in.	38.5	483.9 MBh

Figure 13. Taco E06212-S - Liquid Flow Details

After the group's movement to online courses for the duration of the semester, the Honda Manufacturing Plant of Indiana furloughed all employees and the group was unable to reach Alan. At the beginning of online classes, there was contact with Brian Adika, however after the beginning of April there were no more responses leading the team to believe he also was unable to work during this time. Due to these factors, the group was unable to obtain information on the correct pump information to utilize as well as the pipe length, size, and correct insulation.

3.6 Failure Modes and Effects Analysis (FMEA)

The Failure modes were chosen by the team by first figuring out each process required to be completed in order to make the final product and then going over each process in detail and figuring out what could go wrong with this. These processes included simulation, research and testing. After determining the failures that could be caused in these processes, the team then tried to understand its consequences, causes, recommendations for prevention and actions required if this failure were to happen.

The following FMEA were what the group has found and resulted:

- **Simulation Software Cases**

  The group tried with several simulation softwares and was able to do some calculations/simulations of the design. The software found were: Heat Transfer Calculator, Taco Comfort Heat Exchanger Calculator, BBC Pump and Equipment Company ROI Calculator. Microsoft Excel was also used for doing the calculations of size of the material, pipe's radius and distance, and the expected payback period of the system.

- **Condensation Issue, Heat Exchanger Leak, Pipe System Leakage and Air pocket in Heat Recovery Loop**

  The team has not yet encountered this problem. Since the system will be built by the contractors and the team cannot encounter these problems until the system is built.

The detailed information about each FMEA are written below.

Simulation Software Case 1

Part	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes
Simulation Software	Cannot get any simulation software to use	Slower the process of doing the project in terms of calculation	3	Purdue did not have the appropriate software to use yet.

Current Controls	DET	RPN	Actions Recommended	Actions Taken
Try to find the simulation software that could be implemented to the project.	1	3	Try to find other methods of alternating the software the group needs.	The group chose to do the hand calculations, which is a slow process but simpler method that the group can do.

Simulation Software Case 2

Part	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes
Simulation Software	No one is able to use the simulation software that related to the project	Slower the process of doing the project in terms of calculation.	3	The software is hard to learn.

Current Controls	DET	RPN	Actions Recommended	Actions Taken
Try to find the simulation software that could be implemented to the project.	1	3	Try to find other methods of alternating the software the group needs.	The group tried to search the alternate simulation software to use for the project and check if the group could use it. The group in the end chose the hand calculations.

Condensation Issue

Part	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes
Condensation Issue	Exhaust temperature of the HMIN's RTO decreases to condensation point	Lead to problems exhaust ducts creating inefficiencies, so HMIN would have replace the exhaust air ducts	7	The situation caused by the lower temperature of the RTO exhaust

Current Controls	DET	RPN	Actions Recommended	Actions Taken
Currently there is no heat recovery system in HMIN for this situation	1	7	Install a temperature sensor inside of the exhaust system; if the temperature in the exhaust decreases below the condensation point, the heat recovery system will shut off to protect the RTO.	This has not happened yet. The group should be aware the situation could happen and make sure to think about the output temperature.

Heat Exchanger Leak

Part	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes
Heat Exchanger Leak	Leaks in the Heat Exchanger into the exhaust of the RTO	A buildup of water/glycol mix could mix into the RTO exhaust and cause issues	7	Incorrect installation of pipes. Wear of pipe-heat exchanger connection or heat exchanger itself

Current Controls	DET	RPN	Actions Recommended	Actions Taken
There is not a system currently installed at HMIN. Once installed, proper installation and maintenance are necessary	1	7	Install a pressure sensor into the system. Any leaks in the system will result in a drop in pressure, leading to an alarm that requires maintenance to be performed on the system	There is no system currently in place so no action has been taken to prevent this failure mode. Preventative measures must be put in place when installing the system.

Pipe System Leakage

Part	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes
Pipe/System Leakage	Water/Glycol mix leak from the pipes connecting the two heat exchangers	Water/Glycol mix could leak onto the roof of Honda or into the factory causing a hazard	4	Incorrect installation of pipes. Wear of pipes/system

Current Controls	DET	RPN	Actions Recommended	Actions Taken
There is not a system currently installed at HMIN. Once installed, proper installation and maintenance are necessary	1	4	Install a pressure sensor into the system. Any leaks in the system will result in a drop in pressure, leading to an alarm that requires maintenance to be performed on the system	There is no system currently in place so no action has been taken to prevent this failure mode. Preventative measures must be put in place when installing the system.

Incorrect Simulation Inputs/Missing Information

Part	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes
Incorrect Simulation Inputs/Missing Information	There could be a potential for the information obtained by Alan to be incorrect, or necessary information for the simulations that Alan does not have	The simulations would result in incorrect information and the final design would not be an accurate reflection of the problem	6	Missing information or incorrect input of data into simulation software

Current Controls	DET	RPN	Actions Recommended	Actions Taken
Double check information with Alan, and have some sort of validation check for the software results	3	18	Find a validation check for the simulation to make sure that the results found are accurate	No actions have been taken currently because the group has no positive values for the system. The group will need to brainstorm with Alan and Ralph to come up with a validation check for the simulation

Air Pocket in Heat Recovery Loop

Part	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes
Air Pockets in Heat Recovery Loop	Air pockets could enter the heat recovery loop if there is a leak in the system	Air pockets could cause cavitation of the pump	7	Air pockets in the system due to leakage

Current Controls	DET	RPN	Actions Recommended	Actions Taken
There is not a pump or a heat recovery system at Honda so there are no current controls	5	35	Put a temperature sensor in the system. Cavitation can cause abnormally high fluid temperatures. Listen for abnormal noises coming from the pump. Look for slow operation of the system	No actions have currently been taken because there is heat recovery at HMIN. This issue is more difficult to detect, and the system will need somewhat constant monitoring to be sure this does not occur.

SECTION 4: Project Fabrication Stage (N/A)

4.1 As Built / Implemented Documentation (N/A)

Currently, the Implementation Documentation is not available. The project will be implemented by the contractors in June/July 2020 (Might be delayed due to COVID) when the factory shuts down. Also, all the required materials and detailed building designs would be done by the contractors since the team does not have the required labor to build to a scale of a factory. Unfortunately, the project cannot be scaled down due to increase in errors and unsteady efficiency results in a smaller scale model. Originally, once the contractors have a final building design the team planned to ask the contractors for a copy of the design and if allowed, the team would have used that. However, due to

COVID, there was a hold put on this and the team was unable to receive a copy of the plan.

SECTION 5: Project Testing and Evaluation Stage

5.1 Test Plans

The requirements given to the team would verify if the system proposed would work or not. If the requirements are met, more detailed examination of the system to account for every loss in the system, and verify if the proposition would still be effective. By testing how much fuel can be saved by raising the starting temperature the team can calculate the energy savings. The pricing of all the parts will determine if it is an avenue to search down.

	Cold Side		Hot Side	
Fluid	Air		Ethylene Glycol	
% Glycol vs. Water	n/a		50 %	
Flow Rate	64000 SCFM		150 USGPM	
Inlet Temp	72	°F	144	°F
Outlet Temp	80.221	°F	135	°F
Average Temp	76.111 °F		139.5 °F	
Log Mean Temp Diff	63.389 °F			
Mass Flow Rate	284160	lb/hr	77775.296	lb/hr
Specific Heat	0.24	BTU / lb - °F	0.801	BTU / lb - °F
Density	0.074	lbs./ft3	64.635	lbs./ft3
Heat Load	560682.105	BTU/hr		

Figure 14 RTO exhaust to Recapture loop **[8]**

	Cold Side		Hot Side	
Fluid	Ethylene Glycol		Air	
% Glycol vs. Water	50 %		n/a	
Flow Rate	150 USGPM		64000 SCFM	
Inlet Temp	135	°F	195	°F
Outlet Temp	144.062	°F	185	°F
Average Temp	139.531 °F		190 °F	
Log Mean Temp Diff	50.468 °F			
Mass Flow Rate	77775.296	lb/hr	234240	lb/hr
Specific Heat	0.801	BTU / lb - °F	0.241	BTU / lb - °F
Density	64.635	lbs./ft3	0.061	lbs./ft3
Heat Load	564518.4	BTU/hr		

Figure 15 Recapture Loop To RTO preheat **[8]**

Shown in **Figure 8 and Figure 9** is an online heat transfer calculator that the team found and it simplifies the heat calculations necessary to get an accurate model.
This is an example of the calculations for preheating the RTO. At very optimistic temperatures the system could only recover 80% of heat taken from the exhaust. This does not include the losses in the piping and other inefficiencies. With the low heat recovery potential and the low cost savings it appears that this may not be the best course of action. Other heat recovery options would give better recoveries and less losses.

The first and second requirements in the Requirements Matrix are interlinked. The team tested the team's solutions for the second requirement (Payback Period) for each solution by running savings calculations.

$$Savings\ Calculations$$

$$(1.1 * 350gpm * 1F * 500) = 192,500 \frac{BTU}{hr}$$

$$192{,}500\frac{BTU}{hr} / 1{,}015{,}000 \frac{BTU}{ct} = .189655\frac{1000cf}{hr}$$

$$.189655\frac{1000cf}{hr} * \$9.52 \text{ per 1000cf} = \$1.89655 \text{ per hour}$$

$$\$1.89655 \text{ per hour} * 16\frac{hr}{day} = \$28.88828 \text{ per day}$$

$$\$28.88828 \text{ per day} * 255 \frac{working\ days}{year} = \mathbf{\$7366.51\ per\ year}$$

The team is still waiting on the budget requirements from the contractor to implement the idea. Once the price of implementation is given to the team, the team will run calculations using this price and the savings calculations to calculate the payback period.

While deciding equipment with the contractor, the contractor is given the weight limit and therefore cannot purchase equipment that would result in a higher weight capacity than required.

5.2 Design Calculations and Results

The calculations seen below are the necessary values to find the amount of savings Honda would have given a one degree difference in temperature gained from the RTO recovery system. These calculations also show an energy balance between the boiler and the RTO heat exchanger. The amount of total energy as well as temperature change between both the boiler and the RTO are also shown

Energy Equations Upstairs Boiler:

Boiler:

$Q = 500 * gpm * \Delta T$

$Q = 500 * 350 gpm * (176 - 162)°F$

$Q = 2.45\ MBtu/hr$

Glycol:

$Q = 425 * gpm * \Delta T$

$Q = 425 * x\ gpm * (210 - 190)°F$

$Q = 425 * gpm * 20°F$

RTO:

$Q = 1.1 * cfm * \Delta T$

$Q = 1.1 * 65000\ cfm * \Delta T$

Boiler-Glycol HX:

$Q_B = Q_G$

$2.45\ MBtu/hr = 425 * gpm * 20°F$

$V_G = 288.2\ gpm$

Glycol-RTO HX:

$Q_G = Q_{RTO}$

$425 * 288.2\ gpm * 20°F = 1.1 * 65000\ cfm * \Delta T$

$\Delta T_{RTO} = 34.3$ °F

Downstairs Boiler:

Boiler (total energy):

$Q = 500 * gpm * \Delta T$

$Q = 500 * 1100 gpm * (194 - 181)$°F

$Q = 7.150\ MBtu/hr$

Boiler (usable energy):

$Q = 500 * gpm * \Delta T$

$Q = 500 * 1100 gpm * (185 - 181)$°F

$Q = 2.20\ MBtu/hr$

Glycol:

$Q = 425 * gpm * \Delta T$

$Q = 425 * x\ gpm * (214 - 194)$°F

$Q = 425 * gpm * 20$°F

RTO:

$Q = 1.1 * cfm * \Delta T$

$Q = 1.1 * 65000\ cfm * \Delta T$

Boiler-Glycol HX:

$Q_B = Q_G$

$2.20\ MBtu/hr = 425 * gpm * 20$°F

$V_G = 258.8\ gpm$

Glycol-RTO HX:

$$Q_G = Q_{RTO}$$

$$425 * 258.8\, gpm * 20°F = 1.1 * 65000\, cfm * \Delta T$$

$$\Delta T_{RTO} = 30.8\ °F$$

Based on a variety of inputs such as temperature and dimensions of an air to water heat exchangers can give a variety of important details that are crucial to finding the financial possibility of the project. This will be expanded upon as information is known and will be needed to complete the project. This may be rearranged in order to have all the inputs in one area and all the outputs in another. Once the cost of the parts required all the options could be weighed against one another. With the profitable options being selected.*

Temps

Heat exchanger (air to water)		
Hot Temp in	205	F
Hot Temp out	195	F
Cold Temp in	181	F
Cold Temp out	183	F
Heat Transfer (desired)	575000	BTU/hr
Temp Inside Factory	72	F
Temp Outside	0	F
Heat Exchanger Dimentions		
Length	24.75	in
Width	17.325	in
Depth	3.5	in
Plates per in	12	

Losses

Pipe		
Sch 40		
Wall thickness	0.258	in
Thermal resistance (conversion)		W/(m*K)
	0	BTU/(hr*ft*F)
Thernal Resistance (conversion)	26.1	BTU/(hr*ft^2*F)
	45.14196507	W/(m*K)
Length of pipe (one way factory)	150	ft
Length of Pipe (one way outside)		ft
Insulation		
Wall thickness	1	in
Thermal resistance		W/(m*K)
	0	BTU/(hr*ft^2*F)
Thermal resistance (this)	0.03	BTU/(hr*ft^2*F)
	0.051887316	W/(m*K)

Flow

Pipe		
Flow rate	150	gpm
	34650	in^3/min
Pipe dia	1.5	in

Figure 16 Flow, Temps and Losses

*NOTE : Due to COVID pandemic, we were unable to get a value of the parts required. Therefore, this put our research and effective contact with Brian on Hold.

Answer			
Heat Exchanger Info			
Heat transfer Coefficient required (u)		129.8783487	BTU/(ft^2*h*F)
Surface Area (A)		250.1296875	ft^2
Log mean difference of temp (LMTD)		17.69969758	
Inefficiences			
Heat loss Rate (factory)		9021.401153	BTU/hr
Heat loss rate towards (factory)		30.34471297	BTU/(hr*ft)
Heat loss rate return (factory)		29.79796138	BTU/(hr*ft)
Pipe			
Pipe Area	1.767094	in^2	
Velocity	27.23398	ft/sec	

Figure 17 Heat Exchanger Information

SECTION 6: Project Management including Schedules

6.1 Work Breakdown Structure (WBS)

The following charts demonstrate Work Breakdown Structure, which recorded what each team member did for the project.

Day	**Date**	**Meeting**	**Members**	**Tasks**
Tuesday	**1/14/20**	**Lab**	Arshpreet Singh	Researching and Coordinating with the Client Mentors
			Charles Lee	Manages schedule and tasks
			Luke Winteregg	Calculations/Simulations
			Matthew Fogarty	Looked into potential simulation software and alternatives

Day	Date	Meeting	Members	Tasks
Thursday	**1/16/20**	**Lab**	Arshpreet Singh	Updating the WBS and Gantt Chart for the Team
			Charles Lee	Manages schedule and tasks
			Luke Winteregg	Fixed bugs in program
			Matthew Fogarty	Contacted client mentor about contractor meetings

Day	Date	Meeting	Members	Tasks
Tuesday	**1/21/20**	**Lab**	Arshpreet Singh	Distributing Works and starting on the Gate 4 Report
			Charles Lee	Manages schedule and tasks
			Luke Winteregg	Organized data entry slots
			Matthew Fogarty	Looked into air-to-water heat exchanger manufacturers and distributors

Day	Date	Meeting	Members	Tasks
Thursday	**1/23/20**	**Lab**	Arshpreet Singh	Updating Gate 4 Report
			Charles Lee	Manages schedule and tasks
			Luke Winteregg	Found missing information in program
			Matthew Fogarty	Analyzed picture and video from Honda and found temperature of RTO over one cycle

Day	Date	Meeting	Members	Tasks
Tuesday	**1/28/20**	**Lab**	Arshpreet Singh	Updating Gate 4 Report
			Charles Lee	Manages schedule and tasks
			Luke Winteregg	Tidied up program
			Matthew Fogarty	Used a heat transfer calculator to find relative values for temperatures and needed pump size

Day	Date	Meeting	Members	Tasks
Thursday	**1/30/20**	**Lab**	Arshpreet Singh	Finalizing Gate 4 Report with the Team
			Charles Lee	Manages schedule and tasks
			Luke Winteregg	Showed off demo of program
			Matthew Fogarty	Lab Demo and Gate 4 Report

Day	Date	Meeting	Members	Tasks
Tuesday	**2/04/20**	**Lab**	Arshpreet Singh	Updating the WBS and Gantt Chart for the Team
			Charles Lee	Manages schedule and tasks, coordinating a meeting with the client.
			Luke Winteregg	Help Matt with questions for Allen
			Matthew Fogarty	Email Alan about meeting with contractors and future of project

Day	Date	Meeting	Members	Tasks
Thursday	**2/06/20**	**Lab**	Arshpreet Singh	Distributing Works and starting on the Gate 4.5 Report
			Charles Lee	Manages schedule and tasks, coordinating a meeting with the client.
			Luke Winteregg	Gathers questions for contractor
			Matthew Fogarty	Contact Honda contractors about equipment sizing

Day	Date	Meeting	Members	Tasks
Tuesday	**2/11/20**	**Lab**	Arshpreet Singh	Updating Gate 4.5 Report
			Charles Lee	Manages schedule and tasks, coordinating a meeting with the client.
			Luke Winteregg	Coordinate meeting with BBC Pump
			Matthew Fogarty	Coordinate meeting with BBC Pump

Day	Date	Meeting	Members	Tasks
Thursday	**2/13/20**	**Lab**	Arshpreet Singh	Updating Gate 4.5 Report
			Charles Lee	Manages schedule and tasks, contacting the client and the contractor for scheduling meetings
			Luke Winteregg	Initial communications with Brian and Alan about meetings
			Matthew Fogarty	Initial communications with Brian and Alan about meetings

Day	Date	Meeting	Members	Tasks
Tuesday	**2/18/20**	**Lab**	Arshpreet Singh	Updating Gate 4.5 Report
			Charles Lee	Manages schedule and tasks
			Luke Winteregg	Organized data for meeting
			Matthew Fogarty	Coordinate meeting with Brian from BBC Pump and Equipment

Day	Date	Meeting	Members	Tasks
Thursday	**2/20/20**	**Lab**	Arshpreet Singh	Updating Gate 4.5 Report
			Charles Lee	Manages schedule and tasks, collecting updated data.
			Luke Winteregg	Meeting with Brian from BBC Pump and Equipment Company
			Matthew Fogarty	Meeting with Brian from BBC Pump and Equipment Company

Day	Date	Meeting	Members	Tasks
Tuesday	**2/27/20**	**Lab**	Arshpreet Singh	Updating Gate 4.5 Report
			Charles Lee	Manages schedule and tasks, collecting updated data.
			Luke Winteregg	Organized data for Demo
			Matthew Fogarty	Email Alan questions from BBC Pump meeting

Day	Date	Meeting	Members	Tasks
Thursday	**2/27/20**	**Lab**	Arshpreet Singh	Finalizing Gate 4.5 Report with the Team.
			Charles Lee	Manages schedule and tasks, collecting updated data, Gate 4.5 presentation.
			Luke Winteregg	Lab Demo and Gate 4.5 report
			Matthew Fogarty	Lab Demo and Gate 4.5 report

Day	Date	Meeting	Members	Tasks
Tuesday	**3/03/20**	**Lab**	Arshpreet Singh	Updating the WBS and Gantt Chart for the Team
			Charles Lee	Manage schedules and tasks
			Luke Winteregg	Organized data for meeting
			Matthew Fogarty	Forward Alan answers to Brian Adika and discuss

Day	Date	Meeting	Members	Tasks
Thursday	**3/05/20**	**Lab**	Arshpreet Singh	Distributing Works and starting on the Gate 5 Report. Coordinate meetings with the Contractor.
			Charles Lee	Manage schedules and tasks
			Luke Winteregg	Organized data for Demo
			Matthew Fogarty	Coordinate meeting with Brian Adika form BBC Pump and Equipment Company

Day	Date	Meeting	Members	Tasks
Tuesday	**3/10/20**	**Lab**	Arshpreet Singh	Updating Gate 5 Report. Presentation Preparation.
			Charles Lee	Manage schedules and tasks, collecting updated data
			Luke Winteregg	Lab Demo and Gate 5 report
			Matthew Fogarty	Meeting with Brian Adika from BBC Pump and Equipment Comp.

Day	Date	Meeting	Members	Tasks
Thursday	**3/12/20**	**Lab**	Arshpreet Singh	Presentation. Going over the outcomes of the meetings. And Finalizing Gate 5 Report with the team.
			Charles Lee	Manage schedules and tasks, collecting updated data
			Luke Winteregg	Lab Demo and Gate 5 report
			Matthew Fogarty	Lab Demo Gate 5

Day	Date	Meeting	Members	Tasks
Tuesday	**3/24/20**	**Lab**	Arshpreet Singh	Updating the WBS and Gantt Chart for the Team
			Charles Lee	Manage schedules/meetings and tasks for the project.
			Luke Winteregg	Working on calculations
			Matthew Fogarty	Contact Alan and Brian about rest of semester

Day	**Date**	**Meeting**	**Members**	**Tasks**
Thursday	**3/26/20**	**Lab**	Arshpreet Singh	Distributing Works and starting on the Gate 6 Report. Coordinate meetings with the Contractor.
			Charles Lee	Manage schedules/meetings and tasks for the project.
			Luke Winteregg	Organize data
			Matthew Fogarty	Brian equipment meeting #1

Day	Date	Meeting	Members	Tasks
Tuesday	**4/21/20**	**Lab**	Arshpreet Singh	Updating Gate 6 Report.
			Charles Lee	Managed tasks for the project in terms of COVID pandemic.
			Luke Winteregg	Organize data
			Matthew Fogarty	Use equipment calculator to find Steam-to-Water Heat EX

Day	Date	Meeting	Members	Tasks
Thursday	**4/23/20**	**Lab**	Arshpreet Singh	Updating Gate 6 Report.
			Charles Lee	Managed tasks for the project in terms of COVID pandemic.
			Luke Winteregg	Organize data
			Matthew Fogarty	Use equipment calculator to find Water-to-Water Heat EX

Day	Date	Meeting	Members	Tasks
Tuesday	**4/28/20**	**Lab**	Arshpreet Singh	Updating Gate 6 Report.
			Charles Lee	Managed tasks for the project in terms of COVID pandemic.
			Luke Winteregg	Finalizing Calculations
			Matthew Fogarty	Start Gate 6 Report

Day	Date	Meeting	Members	Tasks
Thursday	**4/30/20**	**Lab**	Arshpreet Singh	Finalizing Gate 6 Report with the team.
			Charles Lee	Managed tasks for the project in terms of COVID pandemic.
			Luke Winteregg	Finalizing Calculations
			Matthew Fogarty	Gate 6 report finalization

6.2 Schedule

6.2.1 Milestone chart for task completion

Table 3 Milestone Chart for Task Completion

Milestone	Description	Due Date
Research	Research on current systems used by HMIN	October 14, 2019
Research	Research on higher efficiency RTO Systems	October 28, 2019
Brainstorming	Come up with ideas to improve the HMIN RTO	October 28, 2019
Simulation/calculation	Conduct calculations of ideas	December 9,2019
Analysis	Analyze the calculations of each idea and narrow down to three conceptual designs	February, 2020
Down Selection Process	Use pros and cons to select the final design concept	March, 2020
Final Design	Product Demonstration to client	May, 2020

APPENDIX

Meeting Minutes

- **September 9th 6:30PM ~ 7PM, 2019**

  Location: Knoy 199C, Purdue University

- **September 16th 6:30PM ~ 7PM, 2019**

  Location: RHPH 172, Purdue University

- **September 20th 3PM ~ 5:30PM, 2019**

  Location: Honda Manufacturing of Indiana (HMIN), 2755 North Michigan Avenue, Greensburg, IN 47240.

- **September 23rd 6:30PM ~ 7PM, 2019**

  Location: RHPH 172, Purdue University

- **September 30th 3PM ~ 5:30PM, 2019**

  Location: Heavilon Hall B023, Purdue University

- **October 14th 6:30PM ~ 7PM, 2019**

  Location: Heavilon Hall B023, Purdue University

- **October 17th 3:30PM ~ 6PM, 2019**

  Location: MGL 1234, Purdue University

- **October 21st 6:30PM ~ 7:30PM, 2019**

  Location: Heavilon Hall B023, Purdue University

- **October 24th 3:30PM ~ 10PM, 2019**
  Location: MGL 1234, Purdue University

- **October 25th 11:30AM ~ 1PM, 2019**
  Location: MGL 1234, Purdue University

- **October 28th 6:30PM ~ 7:30PM, 2019**
  Location: Heavilon Hall B023, Purdue University

- **November 4th 6:30PM ~ 7:30PM, 2019**
  Location: Heavilon Hall B023, Purdue University

- **November 7th 3:30PM ~ 5:30M, 2019**
  Location: MGL 1234, Purdue University

- **November 11th 6:30PM ~ 7:30PM, 2019**
  Location: Heavilon Hall B023, Purdue University

- **November 14th 3:30PM ~ 5:30M, 2019**
  Location: MGL 1234, Purdue University

- **November 21st 3:30PM ~ 5:30M, 2019**
  Location: MGL 1234, Purdue University

- **December 5th 3:30PM ~ 10M, 2019**
  Location: Knoy Lounge, Purdue University

- **January 16th 3:30PM ~ 5:20PM, 2020**
  Location: Potter Engineering Center, Purdue University

- **January 21st 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **January 23rd 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **January 28th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **January 30th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **February 4th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **February 6th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **February 11th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **February 13th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **February 18th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **February 20th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **February 27th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **March 3rd 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **March 5th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **March 10th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

- **March 12th 3:30PM ~ 5:20PM, 2020**

  Location: Potter Engineering Center, Purdue University

* COVID pandemic situation had affected the further meetings, one of the group members went outside of the United States.

Trip Reports

- **September 20th 1PM ~ 6:30PM, 2019**

  Location: Honda Manufacturing of Indiana (HMIN), 2755 North Michigan Avenue, Greensburg, IN 47240.

  Purpose: To view and get more information of the HMIN paint department, and discuss about doing this project. One of the clients, Alan Chacon, guided HMIN.

- **February 19th 2PM ~ 4PM , 2020**

  Location: BBC Pump and Equipment Company, Inc., 777 N Tibbs Ave, Indianapolis, IN 46222

  Purpose: To meet with Brian Adika, a sales engineer from BBC Pump and Equipment Company, for discussing about the group's project and the preliminary design

- **March 11th 9AM ~ 11AM , 2020**

  Location: BBC Pump and Equipment Company, Inc., 777 N Tibbs Ave, Indianapolis, IN 46222

  Purpose: To meet with Brian Adika, a sales engineer from BBC Pump and Equipment Company, for performing simulation. This was done to test the sizes and the materials the design needed for the project design.

Reference Materials

[1] Berry, F., (2019, Aug 26th), *2019-2020 SENIOR CAPSTONE PROJECT CATALOG*. Retrieved from: Purdue University Blackboard (Accessed 2019, Sep 25th)

[2] Catalytic Products International, Inc., (Date N/A), Regenerative Thermal Oxidizer (RTO), Retrieved from: https://www.cpilink.com/ (Accessed 2019, Sep 26th)

[3] Warahena, A. S. K., & Chuah, Y. K. (0AD). *Energy Recovery Efficiency and Cost Analysis of Voc Thermal Oxidation Pollution Control Technology* (15th ed., Vol. 43). American Chemical Society. (Accessed 2019, Sep 26th)

[4] Barndt, D., Woracheck, C., & Larsen, S. (2009). *Investment of Regenerative Thermal Oxidizer and Process Oven Heat Recovery*. Washington D.C: American Council for an Energy-Efficient Economy. (Accessed 2019, Sep 26th)

[5] Volatile Organic Compounds' Impact on Indoor Air Quality. (2017, November 6). Retrieved September 27, 2019, from https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality.

[6] Bill Hutzel, Capstone Calculations Meeting, October 24th, 2019.

[7] "AVERAGE PRICE OF NATURAL GAS (per 1,000 cubic feet)," Just The Facts - Average Price of Natural Gas - The Public Policy Institute. [Online]. Available: http://www.ppinys.org/reports/jtf2004/naturalgas.htm. [Accessed: 29-Oct-2019].

[8] "Heat Transfer Calculator." *Heat Calculator*, www.heat-balance.com/.

Abbreviations Used

- HMIN: Honda Manufacturing of Indiana
- RTO: Regenerative Thermal Oxidizers
- VOC: Volatile organic compounds
- ROI: Return of Investment