Spring Midterm Report

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Team 2

Purina Dryer Efficiency

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Contents

Problem Statement

Introduction

Nestlé Purina is one of the top manufactures of pet food in the United States. The Flagstaff, AZ plant produces about 1,000 tons of pet food each day. When the food is done cooking it contains 35% moisture content. Therefore, all of the food produced needs to be properly dried to meet the 11.5% moisture content requirement. This requirement was set forth to reduce the risk of mold growth due to the build-up of condensation in the bags while cooling. To dry the food, the Flagstaff plant has five steam powered dryers, each responsible for about 20%. However, dryer three is not running as efficient as the other dryers. Dryer 3, shown in Figure 1, should be capable of producing 200 tons per day, but has recently been producing only 150 tons per day, while still using the same amount of energy as the other four dryers.

Figure 1 – Dryer 3

After the product enters the dryer, it is passed through four sections. The first three sections are responsible for removing moisture from the product, and the fourth section is responsible for cooling the product. Each section has its own dedicated air flow, temperature control, and steam coils. The steam coils are used to heat up the air that moves through each section, as hot air can contain much more moisture than cool air. The lack of productivity is largely due to the condensation in the steam used for drying the pet food. Because of the large scale of production, this degree of inefficiency costs our client a large amount of money in terms of unmade product. Our goal is to increase the efficiency and throughput of dryer 3 for Nestlé Purina.

Engineering Analysis

Current System

Before we can analyze our design solutions, we must test our numerical modeling software using the existing system. We used a software package called Interactive Thermodynamics which acts as a simultaneous equation solver. By using a thermodynamic model, we are able to easily change properties at different points in our system model to analyze changes. Our thermodynamic model and analysis is presented by Figure 2.

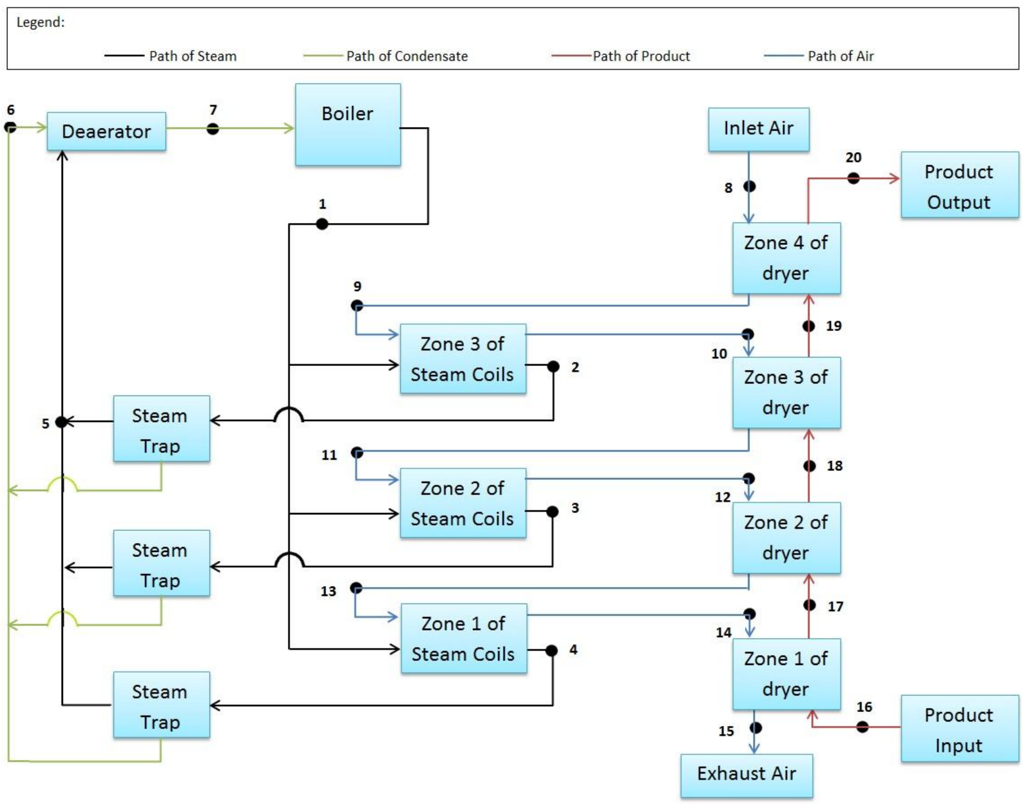

Figure 2 – Overall schematic of how the dryer works with points of interests for thermodynamic analysis.

After the product enters the dryer, it is passed through 4 sections of the dryer. Figure 2 shows a schematic of how the dryer operates. The first 3 sections are responsible for removing moisture from the product, and the fourth section is responsible for cooling the product. Each section has its own dedicated air flow, temperature control, and steam coils. The steam coils are used to heat up the air that moves through each section, as hot air can contain much more moisture than cool air.

Natural Gas Heat Exchanger Design

The progress up to this point has led the team to split into two design groups. Similar to the work that was completed last semester, we brainstormed and refined our ideas down to two natural gas fueled designs.

The first design includes replacing the steam coils in the dryer with a natural gas fire heat exchanger. The team received specifications for this heat exchanger from a heat exchanger that is in use in a Purina facility in Clinton, IA. It was determined from the manufacturer specifications that the heat exchanger would transfer heat at a rate of 1,028 BTU per cubic foot of natural gas used.

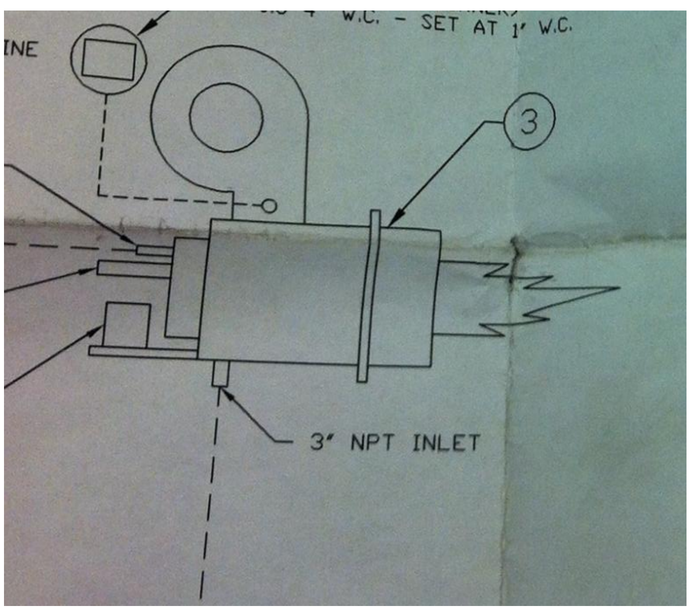

Figure 3 - Natural Gas Burner

Figure 3 shows a drawing of this existing design. The flange denoted by section 3 in the figure is the wall between the fire chamber and the outside of the device.

Table 1: Natural Gas Heat Exchanger Calculations

Natural Gas

Plant Usage (cf) 2/27/13	
Top Meter	927,400.00
Bottom Meter	165,400.00
West Meter	3,000.00
Dryer 5	98,076.00
Total:	**1,193,876.00**

Calculations		
Energy per cf (btu)	1,028.00	
Total Energy in a day (btu)	1,227,304,528.00	
Total Energy in kbtu's	1,227,304.53	
Cost January 2013:	$155,547	
Plant Usage January 2013 (cf)	29,356,000.00	
cf/dollar	188.73	
Price / Mcf:	$5.30	NOTE: 1 Mcf = 1000 cf
Price / MBTU	$5.16	BTU x 10^6
Clinton Nat. Gas Dryer Uses	98.076	Mcf per day
Price / mcf	$5.30	
Price / Day	$519.80	

Table 1 shows a summary of the calculations for the analysis of this design. We used the energy per cubic foot of natural gas and the cost of energy to determine the price of running a natural gas dryer for a day. A day for the plant is denoted as a 24 hour period, as the plant operates over three shifts. Table 1 shows that the total cost of operation per day is $519.80. We can compare this design to design option 2 by using this price. The price of operation for the existing steam dryer is $775.20 per day. We have shown that this new design will save our client $104.20 a day, or approximately $93,221 a year.

Exhaust Gas Design

To gather an estimate on how much energy it uses to run the dryer, a thermodynamic analysis was ran on Dryer 3 by using the Interactive Thermodynamics software (see code and full results in Appendix). To make analysis a little easier, it was decided to only do the analysis on a single simplified heat exchanger, Figure 4, in the first section of the dryer. The first section was analyzed because the air temperatures are the hottest there and therefore use the most energy.

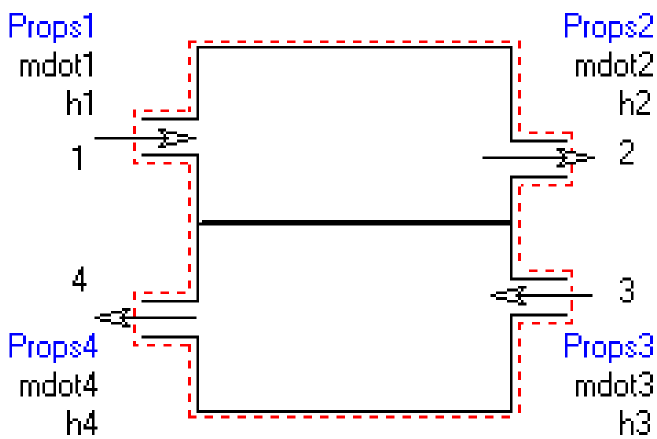

Figure 4: Simplified heat exchanger

For the purpose of our calculations, the analysis was run under steady state conditions (no mass accumulations, so inlet mass flow rate equals the mass flow rate at the outlet). It was assumed that the pressure does not drop over the length of the heat exchanger. Because the exhaust of the natural gas fire is completely theoretical, a starting temperature of 500F was used and an ending temperature of 345F to provide enough energy to heat the air to the 280F temperature. Steam has a much higher capability of transferring heat due to an enthalpy 1212 BTU/lb at 350 degrees Fahrenheit, while air at 500 degrees Fahrenheit has an enthalpy value of 231 BTU/lb (Table 2 and Table 3). Calculations showed that the energy the steam loses is 21740 BTU/lb. At a cost of \$6.19/MBTU, the total cost per day comes out to be \$193.80. Calculations showed that the energy the air loses is 21290 BTU/lb. At a cost of \$5.16/MBTU the total cost per day comes out to be \$158.12. The major difference in the cost is due to a 20% transmission loss from transferring the steam from the natural gas boiler to the heat exchanger across the plant. Also we could tell that the heat exchangers are not that efficient because they are losing quite a bit of energy. Between the steam and air, a total of 458.7 BTU are being lost during the heat transfer. This would equate to a cost of $4.09 per day.

Since each dryer has 3 heat exchangers, the approximate cost per day to run the dryer on steam would be $581.40 per day and on exhaust would cost $474.36. However, due to the lack of production of these dryers as compared to the natural gas dryers, the total cost is actually quite a bit more.

Table 2: Results of analysis on the heat exchanger for steam

Measurement	Value
Temperature of steam at inlet	350 F
Pressure of steam at inlet	40 psi
Enthalpy of steam at inlet	1212 BTU/lb
Mass flow rate of steam	22.27 lb/min
Temperature of steam at outlet	267 F
Enthalpy of steam at outlet	235.8 BTU/lb
Temperature of air at inlet	120 F
Pressure of air at inlet	10 psi
Mass flow rate of air	552 lb/min
Enthalpy of air at inlet	138.6 BTU/lb
Temperature of air at outlet	280 F
Enthalpy of air at outlet	177.2 BTU/lb
Energy extracted from steam	21740 BTU
Energy from steam into air	21280 BTU

Energy lost between steam and air	458.7 BTU
Cost	193.80 $/day

Table 3: Results of analysis on the heat exchanger for natural gas fire exhaust

Measurement	Value
Temperature of exhaust at inlet	500 F
Pressure of exhaust at inlet	10 psi
Enthalpy of exhaust at inlet	231 BTU/lb
Mass flow rate of exhaust	560 lb/min
Temperature of exhaust at outlet	345 F
Enthalpy of exhaust at outlet	193 BTU/lb
Temperature of air at inlet	120 F
Pressure of air at inlet	10 psi
Mass flow rate of air	552 lb/min
Enthalpy of air at inlet	138.6 BTU/lb
Temperature of air at outlet	280 F
Enthalpy of air at outlet	177.2 BTU/lb
Energy extracted from exhaust	21290 BTU
Energy from exhaust into air	21280 BTU
Energy lost between exhaust and air	9.337 BTU
Cost	158.12 $/day

Future Tasks

Because our prototype plan is flawed, we decided to model simplified full scale dryer (seen in Figure 5) using numerical modeling software. To accomplish our goal of showing the benefit of switching to a natural gas system, we will fully define the steam and natural gas dryers at the Nestle Purina plant using our software. This will serve as a bench test for our numerical modeling program, and we will be able to utilize real time data to verify our model. Once we have tested and verified our numerical model, we will use the design process to design a conversion plan for dryer 3 at the Nestle Purina plant.

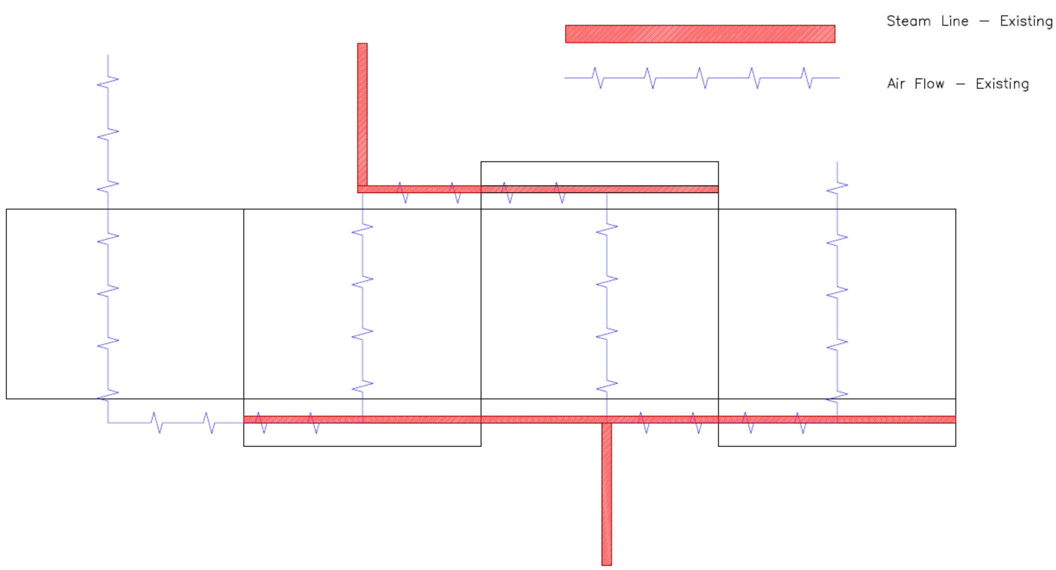

Figure 5 - Steam Dryer Model

Figure 5 shows a simplified steam dryer model. This model shows the existing steam lines, as well as the air flow through the dryer. The air inlet is on the far right side, and travels in a serpentine pattern through the dryer until it is exhausted on the left. The product will travel in the opposite direction of the airflow, from left to right. There are currently three steam coils in the steam dryers at the plant, each shown above as a box above or below the main dryer volume. These steam coils act as a closed heat exchanger, with no mixing of the two fluids involved, steam and air. Our current design goal involves replacing these heat exchangers with furnaces powered by natural gas. We plan to keep the product and air flow through the system the same, and make changes to only one component.

Figure 6 is an example heat exchanger model made in Solidworks. The heat transfer simulation is generated based on this model. The inlet temperature and pressure and the outlet temperature are inputted as boundary conditions. The Figure 7 shows the heat distribution inside of the heat exchanger. Solidworks can also give the average outlet temperature, which can be used to analyze the efficiency of the heat exchanger. The same methodology will be used to make a heat exchanger model close to the current heat exchanger. Solidworks is a good tool to design a new heat exchanger. It can also help us to simulate the current heat exchanger and the new design. Once we have the data, we need to verify the model with the existing data. So we can modify the model to a natural gas heat exchanger. Then we will analyze on the modified design to see if there is any improvement.

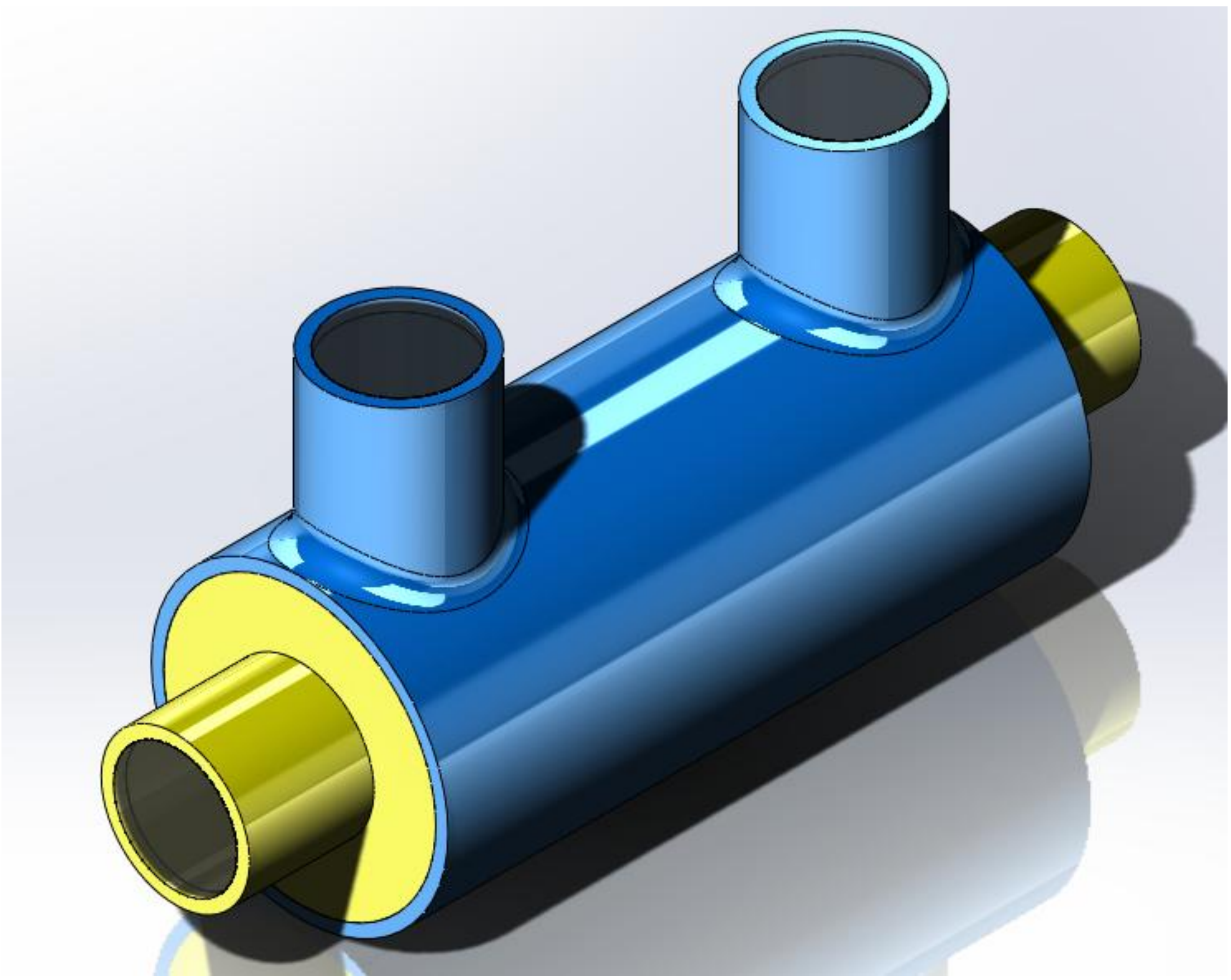

Figure 6: Heat exchanger in Solidworks

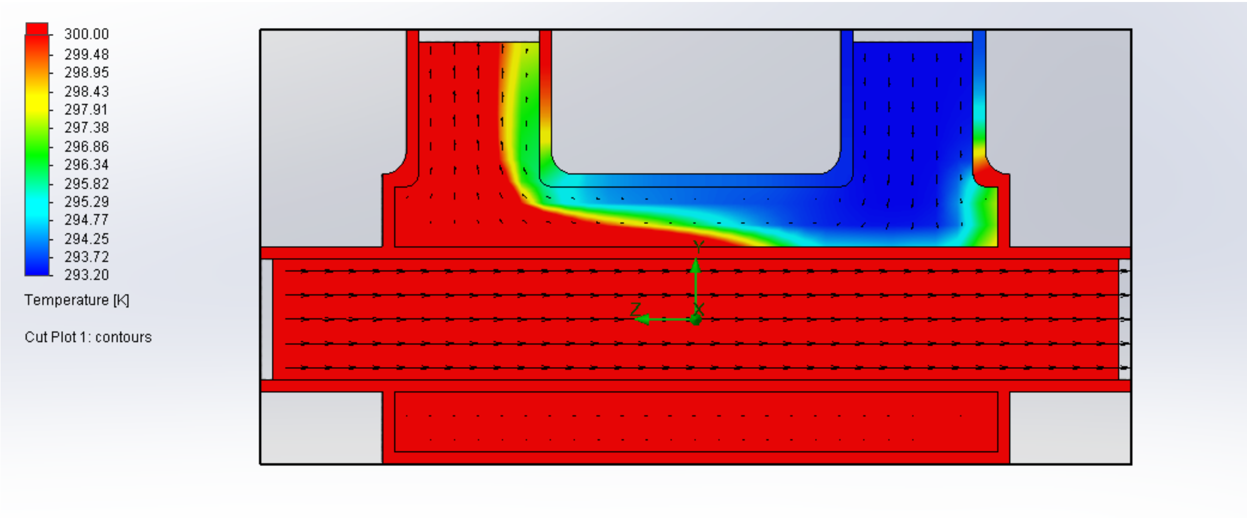

Figure 7: Temperature distribution in heat exchanger

Project Plan

Figure 8 shows an updated Gantt chart for the Spring semester. The green bars refer to how many remaining days we plan on spending for each task, while the red bars refer to completed days and milestones.

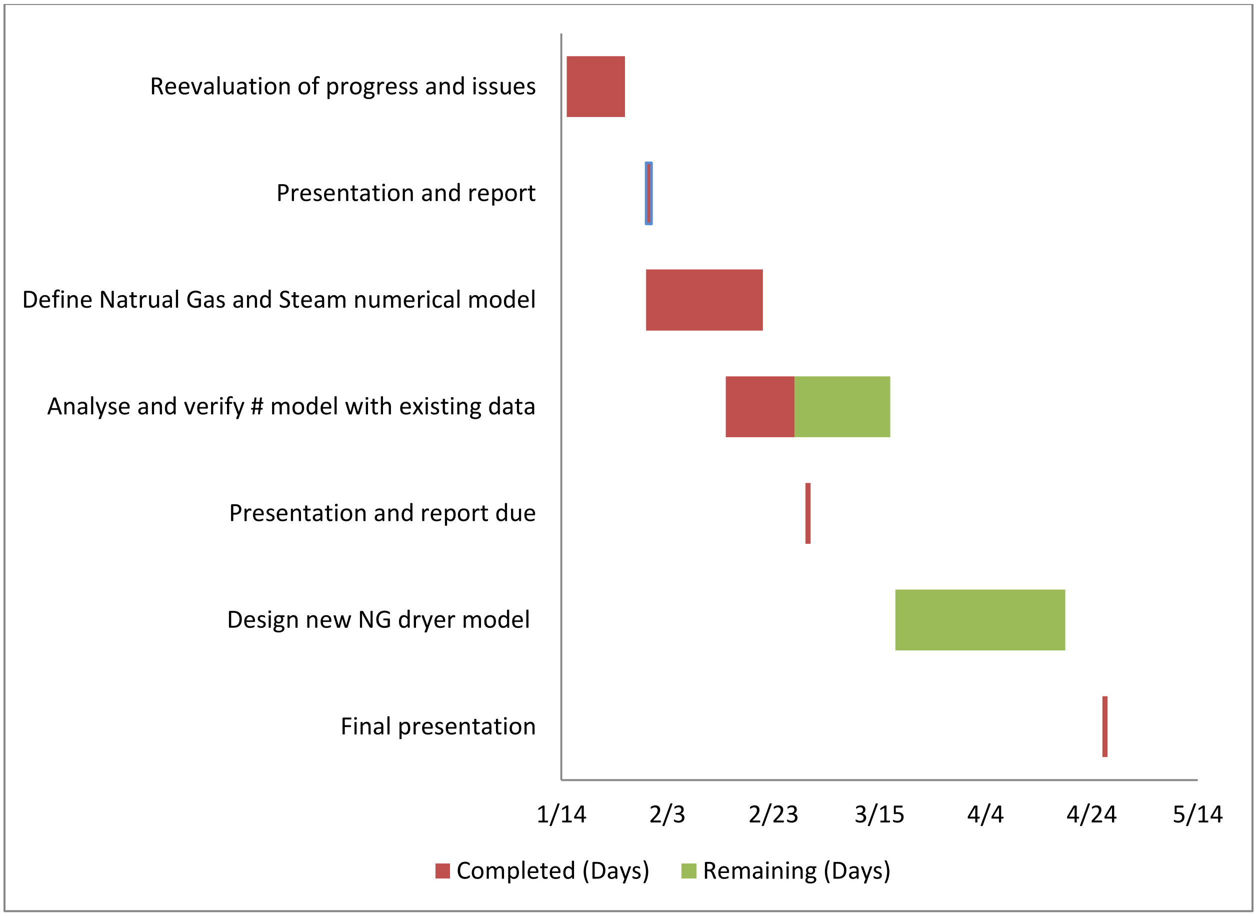

Figure 8 – Gantt chart for the Spring semester.

Conclusion

Dryer 3 is experiencing efficiency problems; we decided to fix this with two design solutions. The first is to replace the steam coils with a more efficient, natural gas heat exchanger. The cost per day for this option is $519.80. The second design solution involves replacing the fluid in the steam coils with hot exhaust gasses. The cost per day for this design option is $632.48. The client was presented with both of these design options, and decided to pursue design option 1. The team will complete a detailed design with an implementation plan for Purina. This will include a detailed heat transfer analysis of option 1 using the heat transfer software tool in Solidworks. Based on the team's calculations, Purina hopes to save as much as $93,221 a year per dryer by pursuing this design option.

References

Clint Chadwick
Environmental Coordinator
Nestle Purina Pet Care, Flagstaff, AZ

Chad Girvin
Processing Maintenance Team Leader
Nestle Purina Pet Care, Flagstaff, AZ

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Appendix: Interactive Thermodynamics Code

(Steam Analysis Code)

```
//*Neglect Kinetic Energy

//Steam Inlet
T1 = 350
p1 = 40
mdot1 = ((4009.3/3)/60)
h1 = h_PT("Water/Steam", p1, T1)

//Steam Outlet
T2 = 267
p2 = p1
mdot1 = mdot2
h2 = h_PT("Water/Steam", p2, T2)

//Air Inlet
T3 = 120
p3 = 10
density3 = 0.115
//0.115 [lb/ft^3] at 120F and 10psi
mdot3 = 4800*density3
h3 = h_T("Air",T3)

//Air Outlet
T4 = 280
p4 = p3
mdot4 = mdot3
h4 = h_T("Air",T4)

//Balance
Qdot_steam = mdot1*(h1-h2)
Qdot_air = mdot3*(h4-h3)
Qloss = Qdot_steam - Qdot_air

Price = 6.19 //$/BTU
Cost = (Qdot_steam/1000000)*Price*60*24
//Cost = $/day
```

(Natural Gas Fire Exhaust Code)

```
//*Neglect Kinetic Energy

//Exhaust Inlet
T1 = 500
p1 = 10
density1 = 0.070
mdot1 = 8000*density1
h1 = h_T("Air",T1)

//Exhaust Outlet
T2 = 345
p2 = p1
mdot1 = mdot2
h2 = h_T("Air",T2)

//Air Inlet
T3 = 120
p3 = 10
density3 = 0.115
//0.115 [lb/ft^3] at 120F and 10psi
mdot3 = 4800*density3
h3 = h_T("Air",T3)

//Air Outlet
T4 = 280
p4 = p3
mdot4 = mdot3
h4 = h_T("Air",T4)

//Balance
Qdot_exhaust = mdot1*(h1-h2)
Qdot_air = mdot3*(h4-h3)
Qloss = Qdot_exhaust - Qdot_air

Price = 5.16 //$/MBTU
Cost = (Qdot_exhaust/1000)*Price*60*24
//Cost = $/day
```

(Steam Analysis Results from IT Software)

Cost	193.8
h1	1212
h2	235.8
h3	138.6
h4	177.2
mdot2	22.27
mdot3	552
mdot4	552
p2	40
p4	10
Qdot_air	2.128E4
Qdot_steam	2.174E4
Qloss	458.7
density3	0.115
mdot1	22.27
p1	40
p3	10
Price	6.19
T1	350
T2	267
T3	120
T4	280

(Natural Gas Fire Exhaust Results from IT Software)

Cost	158.12
h1	231
h2	193
h3	138.6
h4	177.2
mdot1	560
mdot2	560
mdot3	552
mdot4	552
p2	10
p4	10
Qdot_air	2.128E4
Qdot_exhaust	2.129E4
Qloss	9.337
density1	0.07
density3	0.115
p1	10
p3	10
Price	5.16
T1	500
T2	345
T3	120
T4	280