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Cooling Optimization of a Pelletizer Extrusion Line

Senior Design Report

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ME 491 Mechanical Engineering Design

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Abstract

DSM Engineering Materials, a large plastics company, has three new extrusion lines of different sizes at their Evansville facility. The extrusion lines utilize closed-loop, jet stream granulation cooling systems that cool the hot extruded plastic down to roughly 300 degrees Fahrenheit before entering the cutter head to be cut into uniform pellets. The cooling systems rely on plate and frame heat exchangers that each consist of a loop of process cooling water, and a loop of cooling tower water. The heat exchanger on the largest line (line 2) currently operates with suboptimal performance to the point of causing the line to be rate limited when running products with higher specific heat capacities. The heat exchangers used for the cooling system experience frequent fouling due to build up of various sediment and cannot be changed out easily due to poor connection designs.

This report presents a preliminary set of design changes to the cooling system that corrects the problems of suboptimal cooling, fouling, and rate limitation. The authors began by creating three different sets of design changes capable of increasing the cooling capacity of the system based on research of previously completed projects. After analysis, the final preliminary design was chosen. The final design chosen by the authors consists of increasing the number of plates on the existing plate and frame heat exchanger from 88 to 117. We concluded that adding an additional 29 plates and gaskets to the heat exchanger will resolve the issue of rate limitation, allowing the extruder to run at its maximum capability. Also, the project will have a return on investment of 8,600%.

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1 Introduction

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Closed-loop cooling systems utilizing water as both fluids that pass through the heat exchanger are very commonly used for industrial plastic plants due to high effectiveness and low relative cost. DSM Engineering Materials has implemented this cooling strategy for their 3 newest production lines for plastic extrusion. The extruder on largest line (line 2) is rated to produce a maximum of 6,000 kilograms of plastic material per hour but the plastic it extrudes must be cooled to at least 150 degrees Fahrenheit before being pelletized to ensure a uniformly cut product. Due to the under sizing of line 2’s plate and frame heat exchanger, DSM is unable to run the extruder at its maximum rate without damaging the quality of the product, resulting in a notable decrease in the line’s profitability. The piece of equipment responsible for the loss in production and the focus of this project is the Funky brand plate and frame heat exchanger pictured below in Figure 1

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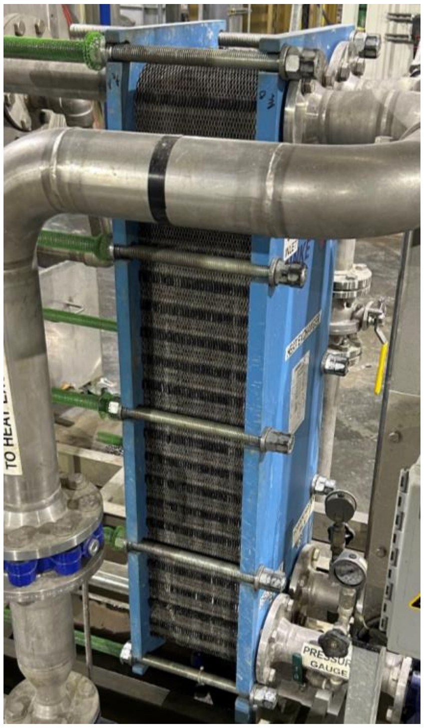

Figure 1: Funky Plate and Frame Heat Exchanger

1.1 Objective

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The objective of this project is:

Modify and optimize a closed-loop cooling system to enhance the efficiency of a plastic extrusion line, addressing challenges related to rate limitation.

1.2 Deliverables

The deliverables for the project are as follows:

- A preliminary set of design changes to the cooling system
- Complete engineering calculations that validate the merit of the new design
- Cost savings analysis of the design
- 3-D AUTOCAD model of the design changes

1.3 Stakeholders

The sponsor for the project is DSM Engineering Materials. DSM Engineering Materials is a global supplier of high-performance plastics that expanded and upgraded their Evansville facility in September of 2022. The new 40,000-square-foot facility was an investment by the company to meet the increasing demand for high-performance polymers in the area with roughly 50% of their product being distributed among the automotive industry [1].

2 Background

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As mentioned in the introduction, DSM Engineering Materials does plastic extrusion. For their process, the solid material begins in a large vessel called a feeder on the second floor. From there, the material is fed into the extruder where it becomes very warm and is mixed with additives. The material is then extruded through the die into multiple stands onto the slit and belt. The slit and belt make up and conveyor belt like system that sucks the plastic down onto it via the use of a vacuum pump and transports the material forward. Next, the materials travels through the cutter where the stands are cut into uniform 1/8th inch by 1/8th inch pellets. Finally, the material is dropped onto a vibratory sorter where the pellets are air cooled and vibrated back upto the second floor to be packaged. As mentioned above, the material becomes very warm inside of the extruder. A key aspect of this process is that the plastic must get cooled down to a temperature of 150 degrees Celsius before reaching the cutter, or else the material will be too ductile to be cut into uniform pellets, rendering the product unacceptable to sell. A diagram simplifying the extrusion process for DSM’s production line can be seen below in Figure 2.

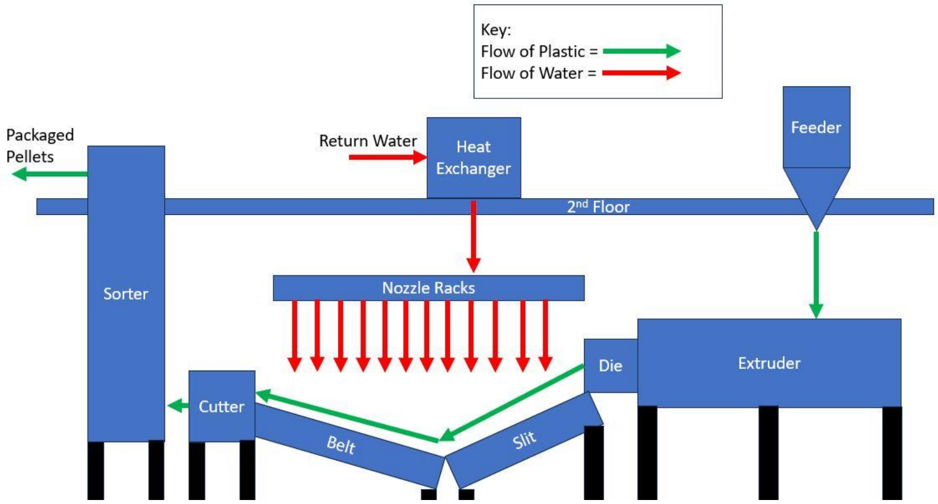

Figure 2: Big Picture of DSM Plastic Extrusion

The way that DSM handles cooling the plastic is by spraying the plastic stands with cooled process water via sets of multiple nozzle racks that set on the assembly between the die and cutter. The water that is used to do so is then pumped back up to the second floor to the plate and frame heat exchanger to transfer a portion of its thermal energy to the cooling tower water so that it can be recycled through the loop again to continue cooling the plastic. With the current cooling capacity, DSM is only able to cool the plastic down to 150 degrees Celsius when the extruder runs at a rate of 5,200 kilograms per hour for some products, despite being capable of running at 6,000 kilograms per hour. This rate limitation costs the sponsor company a considerable amount of money and time each day and would be of measurable benefit to the company for the issue to be resolved. The primary aim of this project is to solve the problem of rate limitation by increasing the cooling capacity of the utilized closed-loop cooling system by increasing the number of heat exchanger plates on the heat exchanger rack to allow for the extruder to operate and its maximum rate of 6,000 kilograms of plastic per hour.

2.1 Motivation

Within DSM's Evansville facility, three different sized plastics extrusions lines utilize a closed loop cooling system for the extruded product. The cooling systems' plate and frame heat exchangers experience significant fouling (buildup of solid material within the heat exchanger that negatively effects cooling capacity) with no convenient way to swap the heat exchangers, due to their construction. Additionally, the largest extrusion line is rate limited due to the amount of cooling achieved from its exchanger, which in turn costs the company a considerable amount of time and money. The lack of cooling for the largest line causes the product to be too hot and ductile as it passes through the rotary cutter, which results in the product being cut incorrectly into nonuniform shapes that are unacceptable to send to a customer. The three lines are nearly identical systems and use the same heat exchangers, but the extruders are at different scales. This means each heat exchanger has a different number of plates. This issue, in combination with having welded connections instead of flex connections, prevents DSM from being able to keep a spare heat exchanger with the capacity to do a quick change when an active exchanger requires service.

2.2 Statement of the Problem

For a facility that runs 24 hours a day to fulfil its orders, experiencing rate limitation on the largest production line is an unwanted financial liability. Line 2 (the largest line) is capable of running at 6,000 kilograms per hour but is currently limited to as little as 5,200 kilograms per hour for some products, which cuts back the line's production by 13 percent. With one of DSM's largest priorities being profit maximization, fulfilling orders at a suboptimal rate and experiencing a cut in profitability is an issue that merits immediate attention. Solving this problem has the potential to result in an attractive return on investment and increase the satisfaction of the employees who run the line by allowing them to operate their extruder at its rated capacity. It will also serve the purpose of decreasing the effort required for monitoring the temperature and quality of the cut pellets.

2.3 Statement of Engineering Problem

In this case, the three extrusion systems have already been designed and have been operational for over a year. The problem is that the systems have supporting components that were poorly designed and force the larger, more expensive components to underperform. The main engineering problem of concern for this project is the cooling capacity of the largest line. To ensure that the finished product has the desired material properties and shape, the line currently must run at 87 percent of its capacity. The secondary engineering problem for this project is that the welded connections to the heat exchanger make the shutdown period unnecessarily long and need to be redesigned with the utilization of flexible connections.

2.4 Literature Review

This is far from the first time that a heat exchanger has needed to be sized correctly. A team of students at Central Washington University completed a similar project involving cooling water for a machine [2]. In their case, a water jet cutter was having to use water that is 150 degrees when the water was desired to be 100 degrees. They did not use the exact same type of heat exchanger but had to do very similar calculations and testing. Their design fell slightly short of solving the problem with a water to air heat exchanger but showed it could work correctly and was just sized too small.

A group from the University of Illinois have come up with a more modern type of heat exchanger that showed a lot of potential in being the most viable solution for our project [3]. Their design incorporated complex, 3D printed geometries that allow for more efficient cooling. They used a tube-in-tube heat exchanger that results in very high heat exchange capacity but was not feasible for the load required for this project.

A paper in the International Journal of Heat and Mass Transfer had plenty of useful information about heat exchanger fouling [4]. This article explains fouling from insoluble salts and minerals from within the tubes, which is the type of fouling that DSM’s heat exchangers are experiencing. It then goes on to demonstrate a prediction algorithm for fouling as well as ways to mitigate the fouling that will be useful during our design process in ensuring the least amount of fouling that we can.

2.5 Knowledge Gained from Literature Review

In the exploration of sizing plate and frame heat exchangers, our primary findings reveal the critical interplay between thermal efficiency and fluid dynamics. Our investigation underscores the significance of accurately determining heat transfer coefficients, flow rates, and pressure drops to optimize the sizing process. The intricacies of plate arrangement, material selection, and overall design configuration significantly impact the performance of these heat exchangers. We emphasize the need for a holistic approach that balances thermal performance with practical engineering constraints, ensuring not only efficient heat transfer but also long-term reliability and cost-effectiveness for industrial applications. Through a systematic analysis of these factors, our research contributes valuable insights for this project.

2.6 Requirements

Based on the constraints given by the sponsor company, the requirements listed below were determined.

The closed-loop jet stream cooling system shall:

- Operate with a cooled water volumetric flowrate of 0.74 cubic meters of water per minute or less.
- Cool the plastic to a temperature at or below 150 degrees Celsius before entering the cutter.
- Allow for line 2 (the largest line) to operate at a rate of 6,000 kilograms of material per hour.
- Consist of heat exchanger plates that are from the manufacturer of the existing plates and fit on the rack currently in use.

3 Concept Selection

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Based on our research, the authors chose 3 designs described below. After analysis, the authors selected the highest quality of the 3 to be the final design.

3.1 Chiller

A chiller emerges as the optimal solution if cost and space were not factors, due to its unparalleled efficiency and adaptability. The intricate manufacturing processes within a plastics plant often necessitate precise temperature control to ensure product quality and process stability. A chiller excels in this context by offering a versatile and reliable means of maintaining the desired water temperature, irrespective of fluctuating external conditions. Its ability to deliver consistent cooling capacity over a wide range of operating conditions, coupled with the flexibility to handle varying load demands, positions the chiller as an indispensable component in the plastics production environment. Furthermore, the chiller's modular design allows for scalability, enabling it to seamlessly integrate into existing systems or accommodate future expansions [5].

In essence, the chiller not only meets the stringent cooling requirements of a plastics plant but also presents an energy-efficient and cost-effective solution, aligning with the industry's demand for sustainable and high-performance thermal management solutions. The issue with this solution is that it would be far more costly than the other possible solutions due to it being such a large piece of equipment and requiring additional piping. A system diagram showing how the chiller would be integrated into the design is shown below in Figure 3.

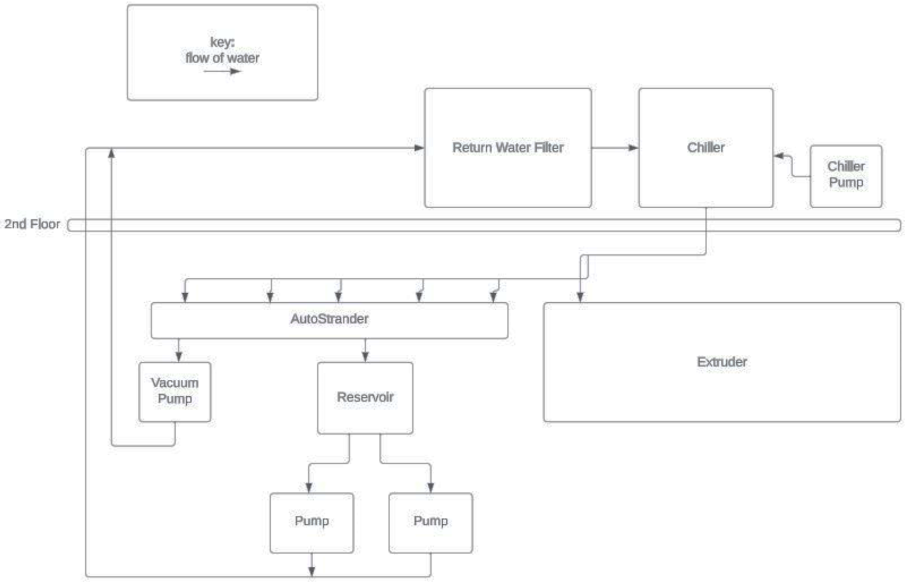


Figure 3: Chiller Design System Diagram

3.2 Tube and Shell

A tube and shell heat exchanger offers several advantages for a closed-loop cooling system in an industrial plastics plant. Its robust and versatile design allows for efficient heat transfer across a broad range of temperatures and flow rates, making it suitable for diverse cooling applications within the plant. The design's simplicity facilitates ease of maintenance and cleaning, contributing to enhanced reliability and longevity. Additionally, tube and shell heat exchangers are well-suited for handling high-pressure and high-temperature fluids commonly encountered in industrial processes. The initial capital cost and footprint of tube and shell heat exchangers can be higher compared to some alternative designs, and their performance might be compromised in situations where space constraints are critical. Careful consideration of specific operational requirements and regular maintenance can help mitigate these challenges and maximize the benefits of employing tube and shell heat exchangers in an industrial plastics plant [6]. A system diagram showing how the tube and shell heat exchanger would be integrated into the design is shown below in Figure 4.

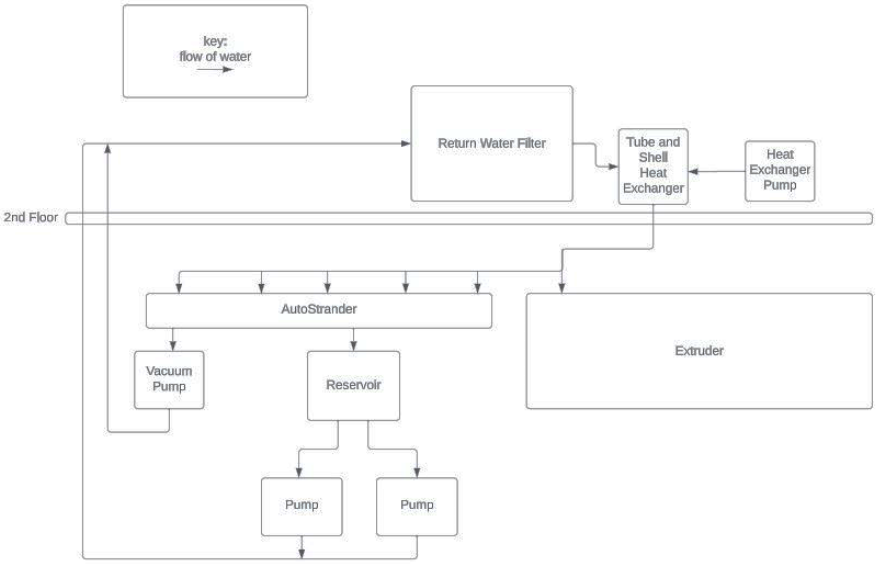


Figure 4: Tube and Shell Heat Exchanger Design System Diagram

3.3 Plate and Frame Heat Exchanger

A plate and frame heat exchanger presents distinct advantages in the context of a closed-loop cooling system for an industrial plastics plant such as DSM. A plate and frame heat exchanger operates on the principle of transferring heat between two fluid streams by maximizing surface area contact through a series of closely spaced metal plates [7]. The device consists of alternating layers of corrugated plates with fluid passages in between. One fluid, known as the hot fluid, flows through one set of passages, while the cold fluid flows through the adjacent passages. The corrugation of the plates serves to enhance turbulence and disrupt laminar flow, promoting efficient heat transfer. As the hot fluid passes through its designated channels, it transfers heat to the adjacent cold fluid through the thin metal plates. The large surface area and turbulent flow characteristics optimize the thermal exchange between the two fluids. Its compact design, characterized by a high surface area-to-volume ratio, facilitates efficient heat transfer in a relatively small footprint. This space efficiency is particularly beneficial in industrial settings where floor space is at a premium.

The modular nature of plate and frame exchangers allows for scalability, accommodating changes in cooling requirements or system expansions with relative ease. Additionally, the ease of disassembly and accessibility between plates simplifies cleaning and maintenance procedures, contributing to the overall reliability and longevity of the system. The design's flexibility makes it well-suited for handling variations in flow rates and temperatures, providing versatility in adapting to the dynamic cooling demands of an industrial plastics production environment. However, plate and frame heat exchangers are not without their challenges. They are susceptible to fouling, especially on the plate surface, which can reduce heat transfer efficiency over time [8]. Regular maintenance is essential to prevent such issues. The initial cost of a plate and frame heat exchanger can be higher compared to some traditional shell-and-tube designs, although the operational benefits and space savings often offset this upfront expense. Careful consideration of the specific requirements of the plastics manufacturing process, along with a proactive maintenance strategy, is crucial for harnessing the advantages of plate and frame heat exchangers in an industrial setting.

Just like the first two designs, this system sends the cooled water from the heat exchanger to the AutoStrander and the end of the extruder to cool the extruded plastic. From there, most of the water collects in a reservoir below the AutoStrander until it has reached a certain volume and then is pumped back up to the return water filter to be sent back through the loop. The remainder of the water is pulled through the AutoStander via a vacuum pump and is continuously sending water back through the loop to be cooled. A system diagram showing how the plate and frame exchanger would be integrated into the design is shown below in Figure 5. Note that because this design utilizes the heat exchanger presently in use, the system diagram below is also representative of the current cooling system.

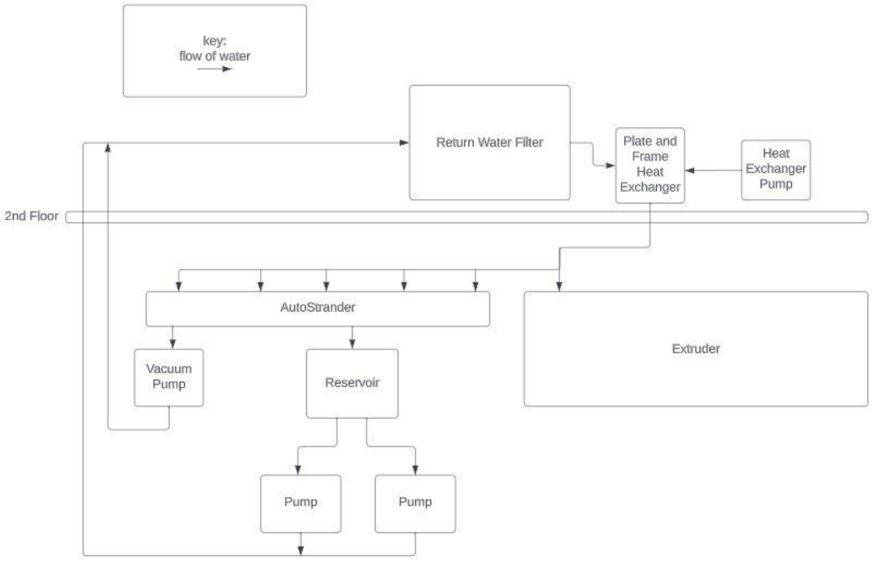


Figure 5: Plate and Frame Heat Exchanger Design System

3.4 Justification of Chosen Design

The plate and frame heat exchanger design were chosen by the authors to be the final design despite not being the most efficient in terms of effectiveness due to there already being a plate and frame heat exchanger in place that currently has room on the rack for additional plates. In other words, it will be much cheaper to purchase components to the existing system than to purchase and integrate an entirely new system. It was also the design most preferred by the sponsor company whose wishes are top priority for this project.

4 Preliminary Engineering Design

As discussed previously, the plate and frame heat exchanger design were selected due to that design being the cheapest and easiest to implement. The heat exchanger currently consists of 88 plates and the goal was to determine how many more need to be added.

4.1 Testing

Once the authors had determined that the chosen design would be to add additional heat exchanger plates to the existing frame, the problem was figuring out exactly how many plates would be needed. It was decided that the most efficient way to do so would be to conduct a test with the goal of collecting data on the heat exchangers' current performance capabilities. The test consisted of running the extruder on line 2 at increasing intervals from 4,080 kg/hr up to 5,445 kg/hr while changing the flowrate of cooled water at each interval to maintain a consistent temperature of 150 degrees Celsius for the extruded pellets. The reason the testing stopped at 5,445 kg/hr is because that was the maximum rate the extruder could run without the pellets being above 150 degrees Celsius and damaging the product. For each trial, the extruder rate, the temperature at each inlet and outlet of the heat exchanger, and the flowrate of cooled water were recorded. With this information, the authors were able to extrapolate the data to get a theoretical value for what the cooling capacity of the heat exchanger would need to be to perform at its maximum rate of 6,000 kg/hr

4.2 Data Collection

On November 3, 2023, the authors went to the plant to run the test on a rate limited product.

The data collected from the testing can be seen below in Table 1. Note that the rightmost collum in the table was extrapolated and not recorded from testing.

Table 1: Data Collected 9/3/2023

Extruder Rate (kgs/hr)	4080	4535	4990	5445	6000
Temp Process inlet (degC)	39	41.5	45	48	49.5
Temp Process outlet (degC)	30.5	32	35.5	38	39
Temp Tower inlet (degC)	19.5	19.5	19.5	19.5	19.5
Temp Tower outlet (degC)	25	26	27	28	28.5
Delta Temp Process (degC)	8.5	9.5	9.5	10	10.5
Volumertic Flowrate (kg/sec)	7.79	8.94	10.42	11.21	12.32
Cooling Capacity (kw)	276.88	355.27	414.27	468.85	541.13

The test was conducted for a second time on November 22, 2023, but for a different rate limited product. Due to an error in collection, the data from the second trial was unable to be used for extrapolation. A table and graph of the data, as well as a discussion of the trial's inadequacy can be found in Appendix K.

4.3 Calculations

$$(T_{HXin} - T_{HXout})\dot{v}(4184 \times 3.79/(1000 \times 60)) = Cooling\ Rate(kw) \qquad (1)$$

Where:
T_{HXin} = temperature of the process water at the inlet of the heat exchanger
T_{HXout} = temperature of the process water at the outlet of the heat exchanger
T_{HXin} = temperature of the process water at the inlet of the heat exchanger
$\dot{v}$ = Volumetric flowrate of process water.
all constants = conversion factors

Equation 1 is an attempt to predict the cooling rate needed to run the line at its full capacity. This was used to yield the cooling capacity for each trial which is highlighted in yellow in Table 1. We collected data with the extruder set to 9,000, 10,000, 11,000, and 12,000 lbs/hr, then recorded the temperature at the inlet and outlet of the heat exchanger, and the volumetric flow rate of the cooling water through the system. We then multiplied the change in temperature by the volumetric flowrate by 4184 because that is the number of Joules required to heat or cool a kg of water 1 degC. That number is then multiplied by 3.79 to convert gallons to kgs and then divided by 60,000 to get the cooling capacity in terms of kilowatts. As seen below in Figure 6, this data was then put onto a graph. From there, we were able to build a curve and extrapolate to figure out what cooling capacity would be needed. It was concluded that the system would require about 541 kw to get the proper cooling capacity. The extrapolated point on the graph in Figure 6 is indicated by a red square.

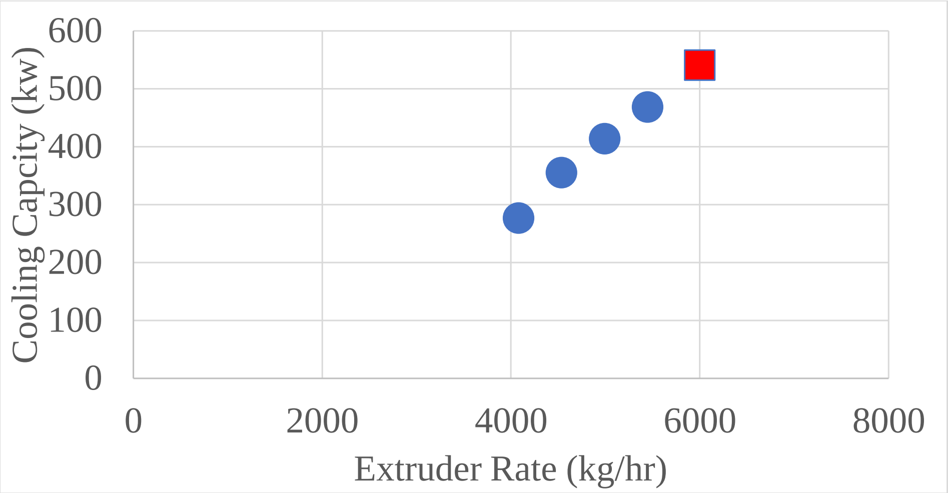


Figure 6: Graph of Data Collected 9/3/2023

$$\frac{Desired\ Cooling\ Rate(kw)}{Maximum\ Cooling\ Rate(kw)}(x)(88) = Total\ Number\ of\ Plates\ Needed$$

(2)

The maximum output by the extruder during the testing was 468.85 kw, and the desired output was found to be 513.38 kw. 88 is the number of plates currently on the heat exchanger and “x” represents the factor of oversizing and serves the purpose of preventing the sponsor company from having to increase cooling capacity in the future if they begin producing a new material with a higher polymer content (increased specific heat capacity). It also helps mitigate fouling because as minerals build up within the plates and decrease the cooling capacity, the heat exchanger will still be capable of allowing the extruder to run at its maximum rate. Assuming the final oversizing factor will be 1.15, Equation 2 yields the number of 117 plates, meaning 29 plates need to be added to the heat exchanger.

4.4 Simulation

To conduct a virtual simulation, the authors used SolidWorks, a versatile program tailored for engineering endeavors, to construct and assess a heat exchanger mirroring the dimensions of our envisioned design. This segment dives into the intricacies of the three-dimensional (3D) model construction process, elucidates the methodology employed in conducting simulations, and overviews the outcomes obtained from these simulations. While simulations serve as invaluable tools for predictive analysis, it's essential to acknowledge their inherent limitations. Imperfections in simulation algorithms or assumptions can potentially yield misleading or inaccurate results. Hence, to mitigate such risks, the authors rigorously cross-referenced the simulation outcomes with both empirical data obtained through experimental trials and extrapolated data derived from theoretical calculations. This comprehensive approach not only enhances the reliability of our findings but also ensures a more robust validation of our simulation methodology.

Obtaining precise dimensions for the heat exchanger proved to be a challenging endeavor for the authors. Despite our proactive approach in contacting the manufacturer, direct answers regarding the dimensions remained elusive. However, DSM did provide us with several manuals and order forms, allowing us to gather general dimensions. This necessitated a careful process of piecing together fragmented information to derive an approximation of the heat exchanger's dimensions. The extrusion line continuously running throughout the duration of the project hindered the author’s ability to access detailed specifications. Despite this setback, leveraging the available manuals and order forms, the authors started the process to formulate an approximation of the internal structure of the heat exchanger plates. This involved synthesizing fragmented data to infer the composition and layout of the interior components. In light of the limitations posed by the author’s knowledge of SolidWorks and the intricate nature of the heat exchanger plates, integrating an effective extruded design directly onto the plates proved to be a daunting task. The thinness of the plates compounded the challenge, further restricting our ability to implement intricate designs. As depicted in Figure 7, the simplicity of the heat exchanger plates that were used in the simulation is evident. The authors could not build a more accurate and complex model and had to use a simpler version.

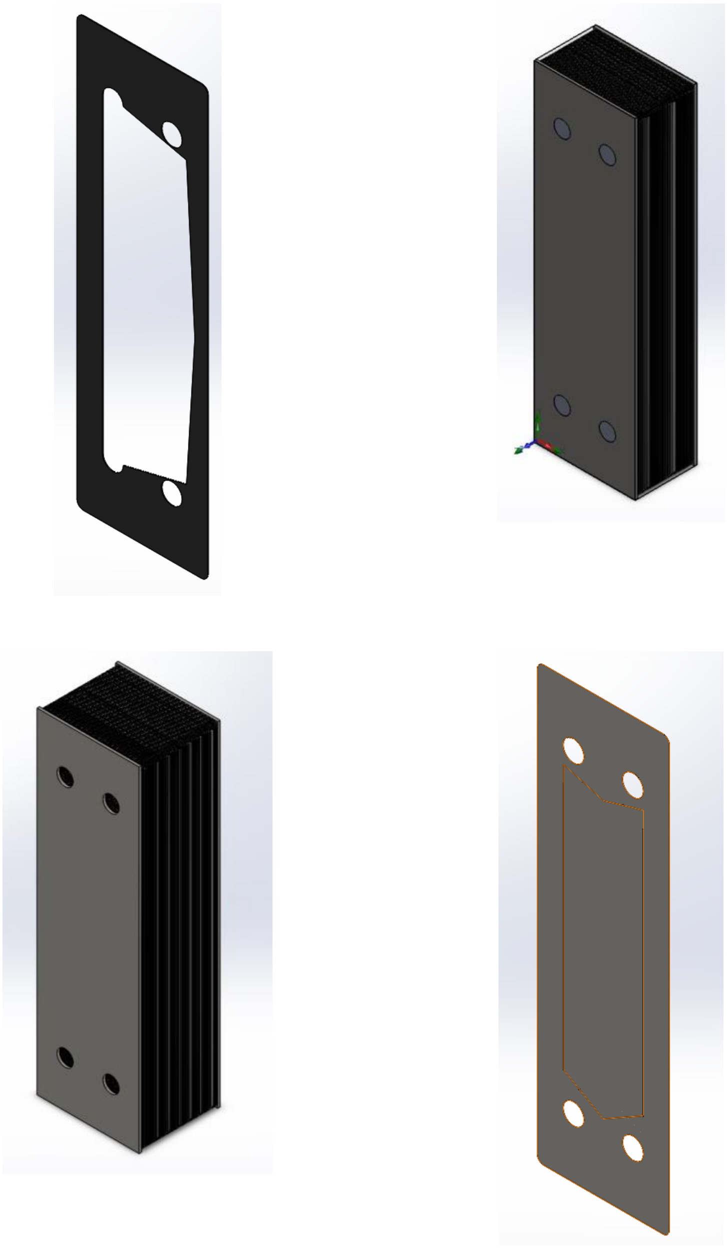
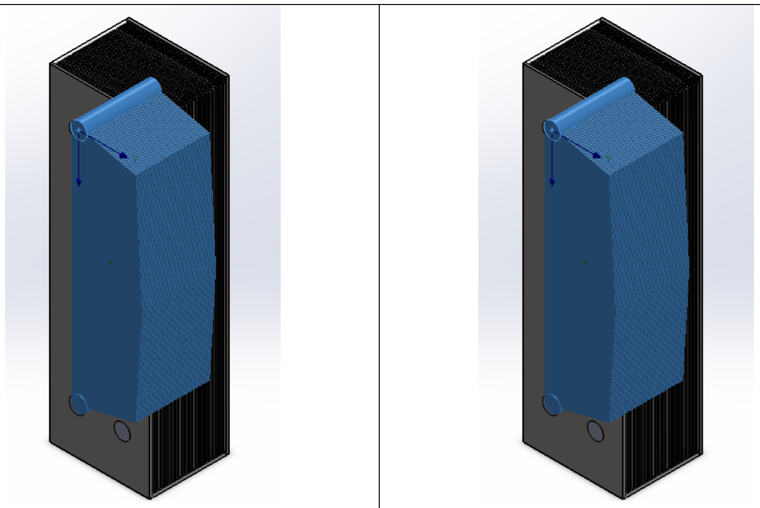


Figure 7: 3D Models

The stainless-steel heat exchanger plates, measuring 0.4mm in thickness, feature a symmetrical cut, 0.15mm deep, on each side, ensuring uniformity and structural integrity. These plates, with dimensions of 400mm width and 1312mm height, are punctuated by 63.5mm diameter cut-out circles to optimize fluid flow. Figure 7 showcases the integral gasket, designed for a secure seal between plates, meeting rigorous industrial demands.

A cut-out area in the gasket of 0.256m^2 and a thickness of 2.125mm was used for the configuration. Armed with the finalized dimensions for both the plates and gaskets, the authors proceeded to craft two distinct 3D models. The first model, comprising 88 plates, served as a baseline for comparison, while the second model boasted an expanded array of 117 plates. Despite the difference in plate count, both models were meticulously constructed using identical methods, with the addition of plates and gaskets distinguishing the larger configuration. This standardized approach ensured consistency and comparability between the two models, allowing for a comprehensive evaluation of their respective performances. By maintaining uniformity in methodology while varying the number of plates and gaskets, the authors sought to elucidate the impact of scale on heat exchange efficiency, paving the way for informed decision-making in the optimization process.

Once the 3D models were built, the authors had to verify that the model did not leak. This is depicted in Figure 8 and 9



A: Process Water Volume

B: Cooling Tower Water Volume

Figure 8: Volume of Process and Cooling Tower Water

Figure 9: Combined Volume

After the authors validated that the heat exchanger models did not leak, they then added in the material properties of stainless-steel plates and the rubber gaskets by using SolidWorks Wizard. The SolidWorks Wizard also assisted in the creation of the mesh used for both models.

Using the parameters of the process water flow rate and temperature, as well as the cooling tower water temperature of the 4535 kgs/hr extrusion rate in Table 1. Because the authors did not have the accurate geometry of the plates and gaskets, the authors ran multiple flow simulations through the 88-plate model and slightly altered the geometry until the results were within 15% on the process outlet temp when compared to the experimental data.

Once the 3D model for the current heat exchanger was solved, the authors then used the 3D model for the proposed design to validate their hand calculations. The authors used the extrapolated process water temperature, process water volumetric flow rate, as well as assuming that the cooling tower water volumetric flow rate was at its maximum rate during the on-site experiment for the parameters for the 117-plate model.

4.6 Results

When looking at the results from the simulation, the authors were only focused on the process outlet temp. This is because this is a representation of the effectiveness of the heat exchanger. The simulation process outlet temperature of the 88-plate model was $36°C$. During the experiment, the process outlet temperature was $32°C$. This results in a 12.5% error, which is within the respectable percentage of error. The simulation process outlet temperature of the 117-plate model was $42°C$ and the extrapolated data was $39°C$. This resulted in a 7.69% error. Also, within the respectable limit of percent error. With both results within our parameter for percent error, the authors concludes that the simulation was a success. Figure 10 shows the temperature gradient as the water flows through the process water inlet to the process water outlet.

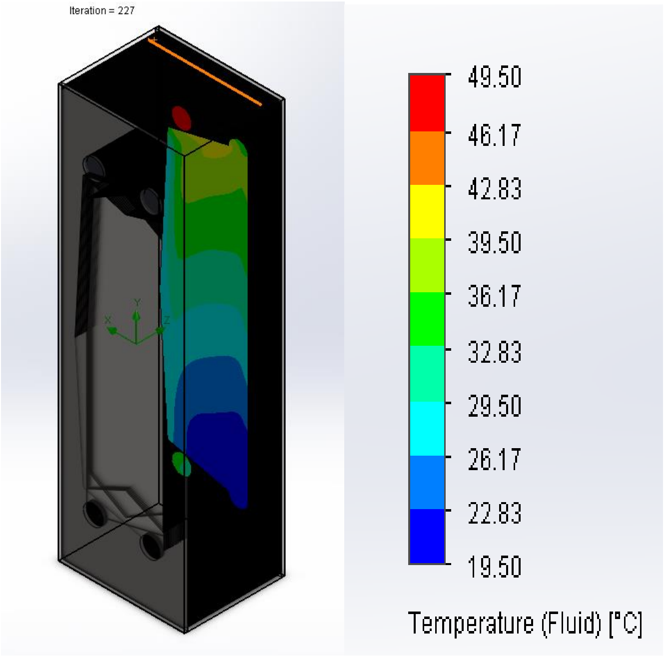


Figure 90: Simulation Results

5 Conclusions

5.1 Financial Analysis

To allow for the execution of a financial analysis, a DSM representative provided financial information for one of their many rate-limited products. This product has an order amount of 320,000 kilograms of plastic per month. Due to the underperformance of the heat exchanger, the extruder is only able to run this product at 5,200 kilograms per hour, resulting in 61 hours of monthly run time to fulfill the order. At this rate, the extrusion line yields a profit per hour of 1,700 dollars. After implementing the proposed design changes that allow for the extruder to run at its maximum rate of 6,000 kilograms per hour, the required run time goes down to 53 hours per month and generates 1,952 dollars per hour.

To calculate the profitability for the implementation of this design, the 8 hours of saved run time per month was multiplied by the extrusion line’s new hourly profit rate of 1,952 dollars to yield a monthly increase of potential profit of 15,616 dollars. This number was then multiplied by the 12 months in a year which resulted in a 187,000 dollar increase of potential yearly profit.

The design changes would cost 2,175 dollars to implement not including the labor cost because it would be constructed by a DSM employee during a scheduled cleaning of the exchanger. This cost was calculated by multiplying the cost of each plate and gasket assembly (75 dollars each) by the 29 additional plates that the design calls for. Dividing 187,000 by 2,175 yields a return on investment of 8,598%, which corresponds to a return-on-investment period of 4.2 days. This analysis does not account for the additional products that are currently rate limited, meaning that the true return on investment is much higher. This degree of profitability greatly exceeds the sponsor company’s requirements for the implementation of a project and is far greater than the authors anticipated when beginning the project.

5.2 Lessons Learned

Navigating through this project has been an enlightening journey, filled with valuable insights that have deepened both my partner's and my understanding of engineering design and project management. Among the most significant lessons gleaned from this experience is the paramount importance of effective communication and collaboration. We quickly realized that maintaining open channels of communication, not only between ourselves but also with external stakeholders, was pivotal in overcoming hurdles and steering our efforts towards common goals. Whether brainstorming ideas or troubleshooting issues, our ability to articulate thoughts, concerns, and solutions fostered a sense of cohesion that propelled us forward.

One of the largest lessons learned from this project was the indispensable value of on-site problem-solving, as opposed to solely relying on theoretical calculations. While theoretical frameworks provide essential groundwork, they often fall short in capturing the intricacies and nuances inherent in practical applications. It became evident that direct engagement with the project site, supplemented by empirical data and measurements, yielded a more comprehensive understanding of the underlying issues, and facilitated more effective problem-solving strategies.

5.3 Project Analysis

Following careful consideration, the authors made the decision to enhance the performance of the existing plate and frame heat exchanger by increasing the number of plates. Through analysis and experimentation, it was determined that a total of 117 plates would be necessary to meet the required cooling capacity, enabling the extrusion line to operate at its maximum output of 6,000 kg/hr. This strategic modification proved to be incredibly lucrative, boasting a remarkable return on investment of 8,598% and a mere 4.2-day return on investment period. Additionally, the authors successfully presented the findings of their report to the sponsor company, securing their full endorsement. Based on the factors of enhanced performance, substantial return on investment, and sponsor approval, the authors confidently assert the success of the project and advocate for its immediate implementation.

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Appendix

Appendix A: System Hierarchy

Appendix B: Project Budget

Appendix C: Failure Modes and Effects Analysis

Appendix D: Functional Block Diagram

Appendix A

System Hierarchy

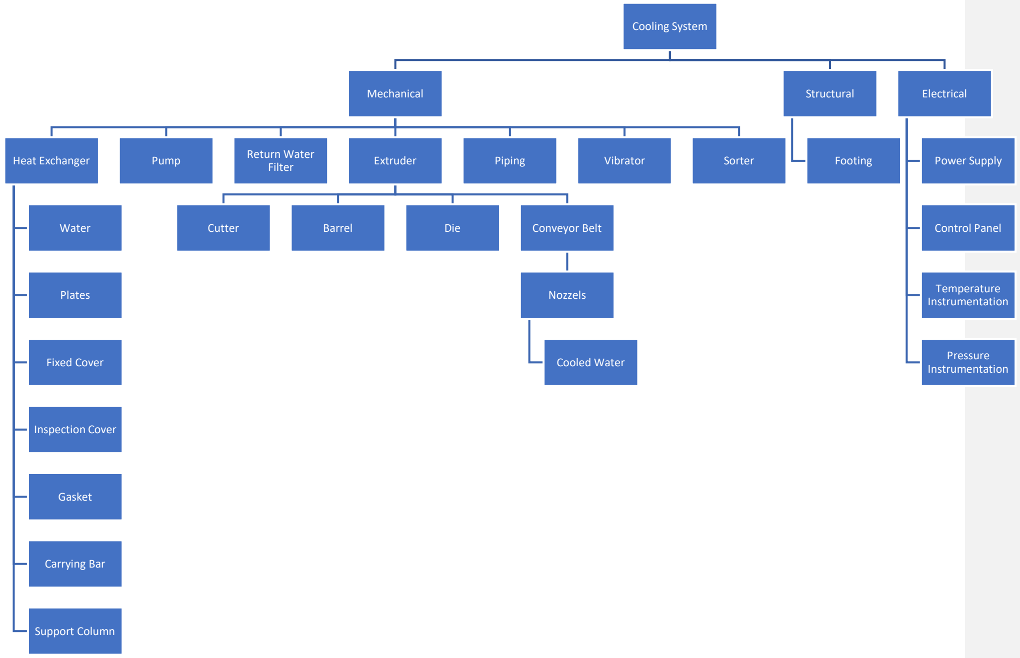


Figure 11: Cooling System Hierarchy

Appendix B

Project Budget

Table 2: Project Budget

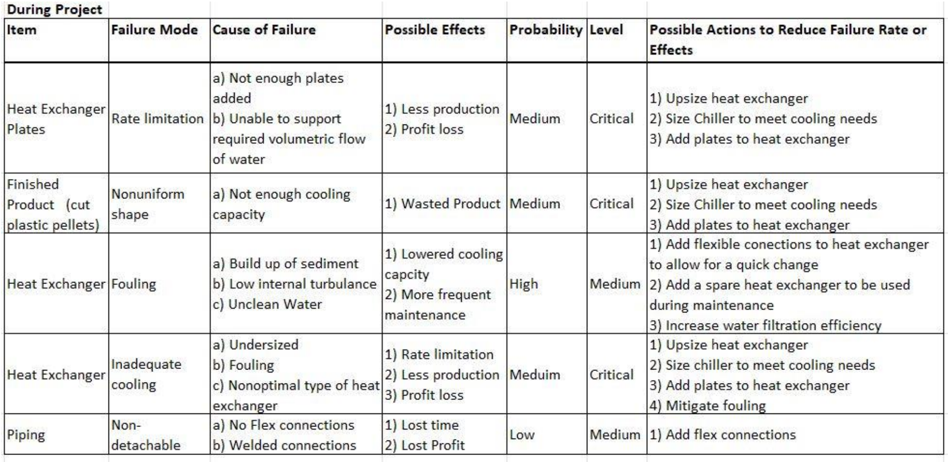
Item	Amount	Price per Item	Total
Plates and Gaskets	29	$75.00	$2,175
Total Budget			$2,175

The end plate covers are removed by disassembling eight nuts and bolts and can be placed on the heat exchanger rack in a matter of hours. Because of this, the authors did not factor in the cost of labor or the cost of transportation to install the additional plates.

Appendix C

Failure Modes and Effects Analysis

Table 3: Failure Modes and Effects Analysis



During Project

Item	**Failure Mode**	**Cause of Failure**	**Possible Effects**	**Probability**	**Level**	**Possible Actions to Reduce Failure Rate or Effects**
Heat Exchanger Plates	Rate limitation	a) Not enough plates added b) Unable to support required volumetric flow of water	1) Less production 2) Profit loss	Medium	Critical	1) Upsize heat exchanger 2) Size Chiller to meet cooling needs 3) Add plates to heat exchanger
Finished Product (cut plastic pellets)	Nonuniform shape	a) Not enough cooling capacity	1) Wasted Product	Medium	Critical	1) Upsize heat exchanger 2) Size Chiller to meet cooling needs 3) Add plates to heat exchanger
Heat Exchanger	Fouling	a) Build up of sediment b) Low internal turbulance c) Unclean Water	1) Lowered cooling capcity 2) More frequent maintenance	High	Medium	1) Add flexible conections to heat exchanger to allow for a quick change 2) Add a spare heat exchanger to be used during maintenance 3) Increase water filtration efficiency
Heat Exchanger	Inadequate cooling	a) Undersized b) Fouling c) Nonoptimal type of heat exchanger	1) Rate limitation 2) Less production 3) Profit loss	Meduim	Critical	1) Upsize heat exchanger 2) Size chiller to meet cooling needs 3) Add plates to heat exchanger 4) Mitigate fouling
Piping	Non-detachable	a) No Flex connections b) Welded connections	1) Lost time 2) Lost Profit	Low	Medium	1) Add flex connections

Appendix D

Functional Block Diagram

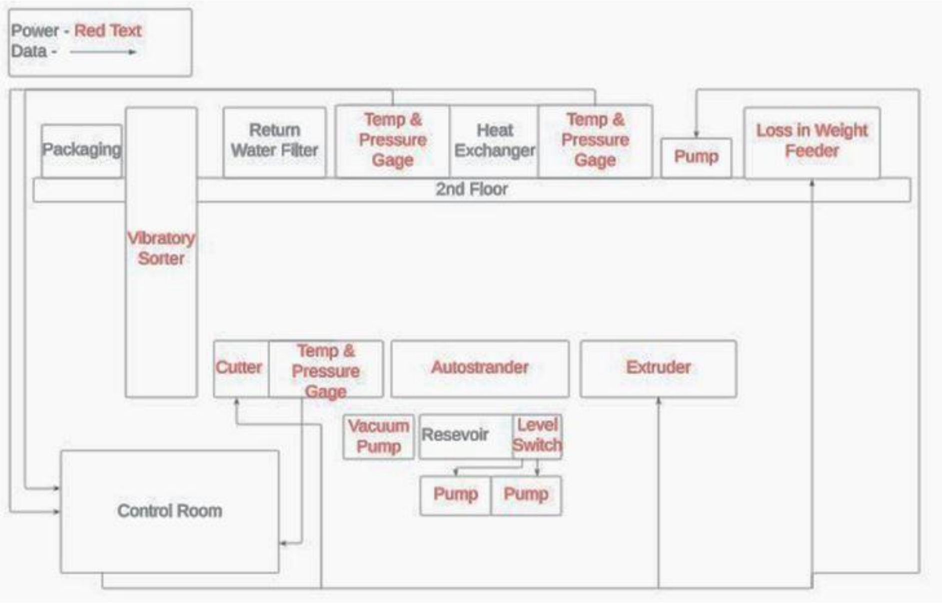


Figure 102: System Functional Block Diagram