MnTAP Intern Project Report
Cortec Advanced Films
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ABSTRACT

Cortec Advanced Films produces blown plastic film. Currently, the scrap rate for this process is approximately 10% of the total film production. This corresponds to 250,000 pounds of scrap per year. The raw material costs associated with scrap production are $125,000 per year. Reducing this scrap production was the main goal of this project. Reductions in water and electricity usage were also studied.

In order to reduce the scrap production at Cortec, the sources of scrap were first identified. There are three main sources of scrap production, including startup, operator error and equipment failure. The percent of scrap in each of these categories is 73%, 24%, and 3% for startup, equipment failure and operator error, respectively. Equipment failure and startup are the main causes of scrap, so a few different reduction options were studied for both of these categories.

To reduce the amount of equipment-related scrap, a preventive maintenance and record keeping system was developed. A preventive maintenance system is a schedule that is set up to ensure regular inspections of the equipment take place. This will allow maintenance staff to diagnose any problems before they cause a breakdown of the machine. It will help maintain the equipment and keep it running efficiently. By reducing the number of breakdowns that occur, scrap production will decrease. This will result in raw material and labor savings. The time requirement for implementing this program for all of the extruders at Cortec is four hours per day. However, 70% of the breakdowns should be eliminated, so eventually fewer total hours of maintenance will be required. The savings for this option are shown in table A.

In order to implement a record keeping system at Cortec, machine books for each blown-film extruder were created to store all information relating to that extruder. Information regarding all maintenance procedures and process conditions are stored in these books. These books can help reduce scrap by identifying any recurring problems that need to be addressed. They can also identify any preventive maintenance procedures that may need to be added to the current list. The final way that that these machine books can reduce the amount of scrap is by creating a database of process conditions that should be used for each recipe on each extruder. This will be a good reference for the extrusion operators and help reduce their startup time.

Two other options were explored for reducing the startup scrap from the extrusion process at Cortec. The first option that was researched was an automatic gauge control system that would automatically make adjustments to obtain the correct film width and thickness. Currently, manual adjustments to the extruders are made. An automatic gauge control system would automatically make these adjustments, so it would reduce the amount of time required to obtain the correct dimensions. It was decided that the cost associated with this system ($27,000) and the risk involved was too great, so this option will not be implemented. The second option for reducing startup scrap was to update an extrusion operator training manual. This training manual contains the theory behind the extrusion process, so operators will be able to learn more quickly how the different parameters affect the film properties. It contains written procedures for extruder operation and other related processes. It also contains trouble-shooting tips, so that any corrections that are needed during film production can be made quicker.

A few different water reduction options at Cortec were found. This first option consists of reporting actual water meter readings, so estimates from the water company are not being used. Previously, the usage was being overestimated by about 200,000 gallons per month. A credit of $3,500 was added to Cortec's account due to these overestimates. The second water reduction option is to install an on/off valve on an air compressor that supplies air for cooling the film. Water is currently being circulated through this air compressor seven days per week when it is only in operation for 3 ½ days per week. Installing this valve would reduce the water usage by 14,000 gallons per month with savings of $1,000 per year. The final water reduction option studied was to install a water-cooling tower to cool a glycol/water mixture that is currently being cooled using a heat exchanger. The water being used in this heat exchanger ends up as waste. This would reduce the water usage by 68,000 gallons per month with savings of $3,300 per year. All of the results stated above are summarized in table A.

Electricity usage was also briefly looked into. Cortec is billed for three separate charges including monthly usage, peak demand usage, and maximum demand usage. Peak demand usage is the maximum kilowatt usage in a one-hour period for that month during the hours of 5-10 p.m. The maximum demand usage is the maximum kilowatt usage in a one-hour period during any time for the month of the bill. The peak demand and maximum demand charges constitute 2/3 of the total energy costs. Changing startup practices may help reduce the peak demand and maximum demand charges if the energy consumption during the startup of each extruder can be determined. An energy audit will be performed at Cortec to quantify this energy consumption, with East Central Energy paying 70% of the cost for this audit.

Waste Reduction Option	Waste Reduced	Raw Material Saved	Cost Savings	Status
Preventive Maintenance	-------	51,800 lbs./year	$25,000/year	Recommended
Record Monthly Water Readings	-------	-------	One-time savings of $3,500	Implemented
Control valve for air compressor	14,000 gallons/month	-------	$1,000/year	Recommended
Water-cooling tower	68,000 gallons/month	--------	$3,300/year	Recommended

Table A

This table gives a summary of all the waste reduction options that had quantifiable savings associated with them. Although other options were researched, the savings that will result cannot be directly quantified.

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BACKGROUND

Company Information

This report focuses on waste reduction options explored for Cortec Advanced Films. The company is located in Cambridge, Minnesota. Their contact information is as follows:

Cortec Corporation, Advanced Film Division
410 East First Avenue
Cambridge, MN 55008
Phone: 763-689-4100, 800-686-2986
Fax: 763-689-5822
E-mail: info@springlakepackaging.com
www.cortecvci.com

Cortec Advanced Films is a division of Cortec Corporation, whose headquarters are located in St. Paul, Minnesota. Their contact information is as follows:

Cortec Corporation
4119 White Bear Parkway
St. Paul, MN 55110
Phone: 651-429-1100, 800-4-CORTEC
Fax: 651-429-1122

Cortec Advanced Films produces blown plastic film. It is a relatively small division of Cortec Corporation with only 27 employees. They produce 2.5 million pounds of film annually with a profit of just over $5 million.

Plastic film is custom manufactured at Cortec Advanced Films, so bags or rolls of film of virtually any size can be ordered. There are over 30 different blends of polyethylene plastic manufactured at Cortec. LDPE (low density polyethylene), LLDPE (linear low density polyethylene), HDPE (high density polyethylene) and biodegradable bags and film are all produced. Their specialty product is a plastic film containing vapor corrosion inhibitor, which prevents the corrosion of metals. Film containing vapor corrosion inhibitor is available in a variety of colors and sizes. Cortec also manufactures film containing static dissipatives, flame retardant and ultraviolet inhibitors.

Once the plastic film is produced, it is sold on rolls or further converted into bags. Bags can be custom made in a wide variety of sizes, shapes and styles. Features such as perforations, bag-on-a-roll, or Ziploc® can be added. There is also a printing department that can print on film ranging from 10-112 cm wide. Up to four colors can be used, and shading is also available.

Project Motivation

Ten percent of the total film production at Cortec Advanced Films is scrap. This corresponds to 250,000 pounds of scrap per year. Of this scrap, 90 percent is being sent away for reprocessing at a cost of 10 cents per pound. The reprocessed material is then being reused.

The costs associated with reprocessing scrap material are large when labor and energy costs are also taken into consideration. Raw material costs associated with scrap production is $125,000 per year. Finding a way to reduce this scrap production was the main motivation for undertaking this project. Reductions in water and electricity consumption were also explored.

Process Description

Cortec Advanced Films operates 10 different blown film extruders for plastic film production. Each extruder operates in the same manner but is specialized to produce a certain range of film sizes. A diagram of an extruder is shown in figure 1. Small polymer pellets are stored in a hopper and fed to the extruder at a fixed rate. They enter a barrel containing a large screw, which rotates to pump the polymer along the length of the barrel. Heating and cooling coils are located on the outside of the barrel to melt the polymer and keep it at the desired temperature. There is also a large amount of friction due to the motion of the screw that supplies heat to the polymer melt. At the end of the barrel, the polymer melt is pushed through a screen to remove any contamination. The melt is then extruded through a circular ring, called a die ring. Once the polymer is extruded, it forms a circular bubble as shown in figure 1. Air circulates through the center of the bubble at a constant pressure. Air is also circulated around the outside of the bubble. As the bubble rises, the polymer melt cools to form a plastic film.

When the bubble reaches the top of the apparatus, guide rollers collapse the bubble. The flattened film is then pulled through a set of rollers called nips, which remove all the air to give a completely flattened film. The width of the flattened film is termed the lay-flat width. (see figure 2) When the film is collapsed, gussets can be added. Gussets are foldings in the side of the film as shown in figure 3. The film is fed through a series of rollers after it leaves the nip rollers that stretch the film and remove any wrinkles. The film can undergo surface treating, perforating, or printing as it runs through this set of rollers. At the end of the process, the film is rolled up using variable drive rollers to prevent any inconsistencies or defects in the rolls.

The rolls of film produced by the extruders can be sold as is or further converted into bags. Conversion of the film into bags also takes place in this plant. Specialized equipment is used that seals and separates the film into bags using heat. Many different bag sizes can be produced using the same machinery. Also, perforations or Ziploc® features can be added.

A layout of the plant is shown in figure 4. Each extruder is numbered on the diagram. Extruder 1 has a die ring with a diameter of 10" and can produce films with a lay-flat width in the range of 40-60" at a rate of approximately 300 lbs/hr. Extruder 3 has a die size of 5" that produces film with a lay-flat width of 20-24" at a rate of 110 lbs/hr. Extruder 4 has a die size of 6" that can produce film with a lay-flat width in the range of 24-30" at a rate of 125 lbs/hr. Extruder 5 has a die size of 2.5" with a lay-flat width of 10-11" and operates at a rate of 45 lbs/hr. Extruder 6 has a die size of 3 or 4" with lay-flat widths of 15-20" and 12-15", respectively. This machine operates at a rate of 75 lbs/hr. Extruder 7 has a die size of 7", a lay-flat width of 12-15", and a rate of 45 lbs/hr. Extruder 8 has a die size of 2", a lay-flat width of 9-10" and a rate of 40 lbs/hr. Extruder 13 has a die size of 1.75", a lay-flat width of 7-8" and a rate of 25 lbs/hr. Extruder 14 has a die sizeof 1.25", a lay-flat width of 5-6" and a rate of 16 lbs/hr. Extruder 18 has a die size of 8", a lay-flat width of 30-40" and a rate of 180 lbs/hr. Extruder 19 has die sizes of 20 and 28" with lay-flat widths of 55-100" and 80"+, respectively. It operates at a rate of 550 lbs/hr. This extruder is the largest producer with 60% of the total production.

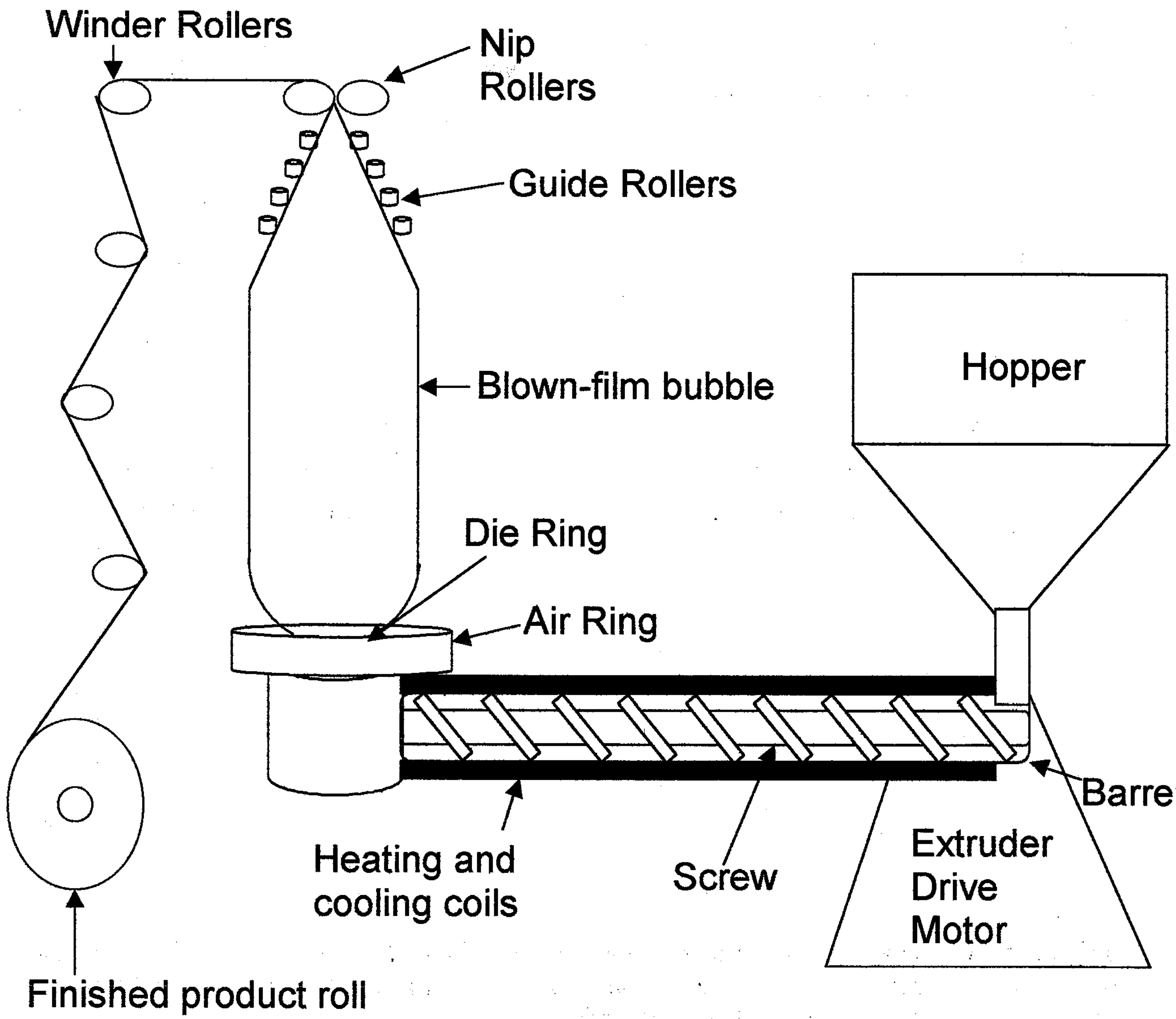

Figure 1
This figure is a schematic diagram of the blown-film extrusion process.

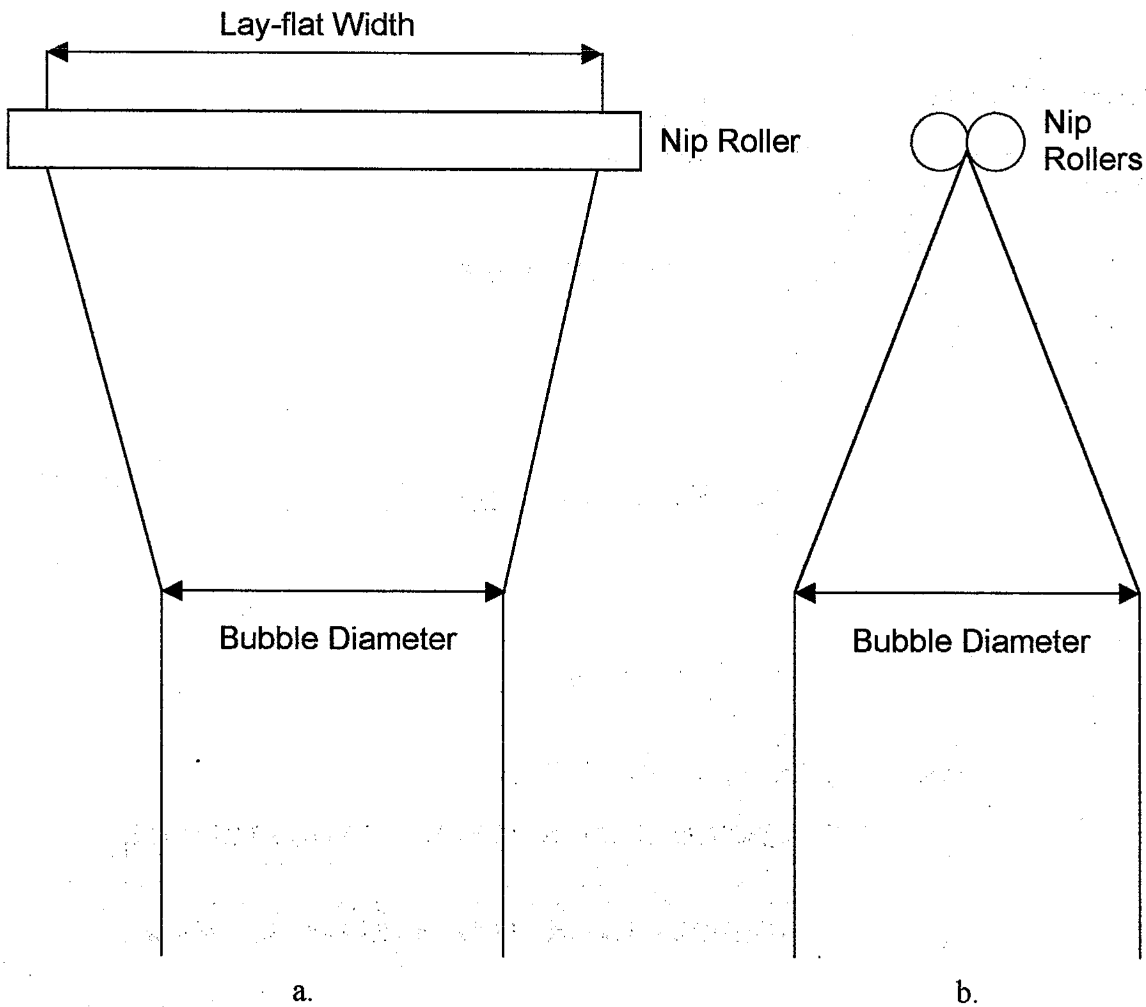

Figure 2
This figure shows the lay-flat width of the plastic film. The first figure (a) shows the front view of the film, including the lay-flat width. The second figure (b) show the side view of the bubble and how it is collapsed to obtain the lay-flat width.

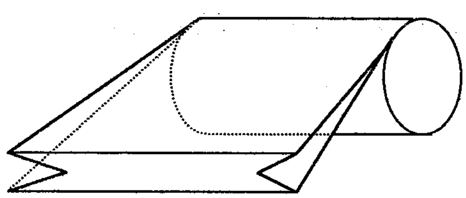

Figure 3
This figure shows gussets in a finished roll of plastic film. These gussets are introduced by collapsing the sides of the blown film bubble

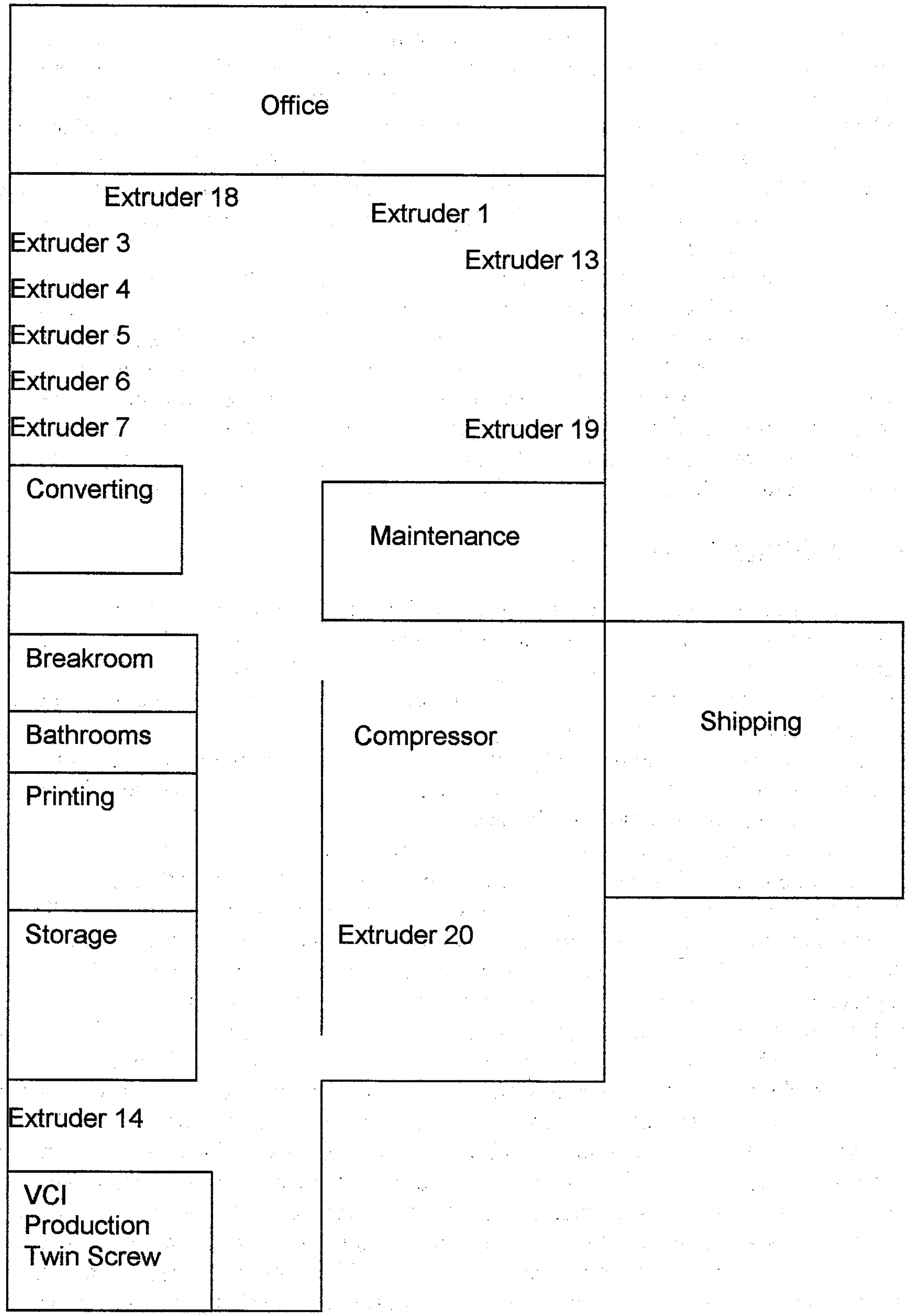

Figure 4
This figure shows the layout of the plant at Cortec Advanced Films.

The final extruder is number 20. This extruder is different from all the others, because it is a co-extruder. It contains three screws that melt three different resins. All three polymer melts are combined at the die and extruded. The remaining equipment is the same as all the other extruders, as described earlier. The co-extruder forms a plastic film with three distinct layers. The middle layer provides strength for the film. The inner layer contains vapor corrosion inhibitor, and the outer layer possesses special properties that give it cling. The film being produced by this machine is still in the developmental stages and is just beginning to be produced for consumers.

There are a few other areas of the plant shown in figure 4 that should be noted. The converting area, which was described earlier, is shown. Also, there is a compressor towards the back of the plant that produces all the compressed air to be used for cooling the blown film. The final piece of equipment that is shown on the floor plan is the twin screw. This machine makes the polymer pellets containing vapor corrosion inhibitor. It combines polyethylene pellets and the vapor corrosion inhibitor, which are fed into an extruder and melted. The melt is then fed into a pelletizer, which cools the polymer and forms pellets that contain polyethylene and vapor corrosion inhibitor. These pellets are used in blown film production, as described earlier.

WASTE REDUCTION OPTIONS

I investigated three main areas of waste reduction while at Cortec. Reductions in water and electricity usage were studied, but the main focus was to reduce scrap production. The first step in reducing the amount of scrap being produced was to identify and quantify all the contributing sources. Scrap is produced during both the extrusion and converting processes. Rejected product is another source of scrap. Company records showed that less than one percent of the total scrap comes from rejected product, and only two percent of the total film being converted ended up as scrap. The extrusion process was responsible for nearly all of the scrap being produced, so this was the main focus area.

In order to identify scrap reduction options for the extrusion process, I further categorized scrap production. First, I determined the total amount and total percent of scrap that was being produced by each extruder by going through shop orders from the last five months. Table 1 summarizes the total production rates and scrap rates for each extruder. It should be noted that the film production for some of the extruders are added together, because the orders could have been produced by each of these extruders and were not specified on company records. It can be seen that extruder 19 is the largest producer by far with 60% of the total production, so most of my efforts were focused on this particular extruder. The scrap produced from extruder 19 was then quantified by its source. This information was also obtained from company shop orders. There were three main sources of scrap during the extrusion process. They include startup/shutdown/transition, equipment failure, and operator error. The percent of scrap in each of these categories is summarized in table 2. The scrap produced during startup, shutdown and the transition between orders is lumped together as one category. At the end of an order, the extruder is either shutdown or the parameters are changed for the following order (transition). If the extruder is shutdown, the plastic remains in the machine until it is started up again. It is then counted as startup scrap for the next order. If the parameters are changed and a transition takes place, the scrap produced between orders is categorized as startup scrap for the new order. Because scrap is recorded in this manner, the scrap for startup, shutdown and transition is lumped together.

Extruder	Total Yearly Film Production (lb)	Total Yearly Scrap Producton (lb)	Percent Scrap
1	528,000	50,000	8.8
3,4,6	321,000	27,000	7.8
5,7,8	146,000	7,700	5.0
13,14	52,600	1,900	3.4
18	321,000	34,000	7.6
19	1,480,000	189,000	12.6

Table 1
This table shows the total yearly film production, total scrap production and percent scrap for all of the extruders at Cortec. The total yearly film production includes only product and does not include scrap. It should be noted that the film production for some of the extruders are added together, because the orders could have been produced by each of these extruders and were not specified on company records.

Source of Scrap	% of Scrap
Startup / Shutdown / Transition	73.1
Equipment Failure	23.6
Operator Error	3.3

Table 2
This table shows the percent of scrap that is produced by startup/shutdown/transition, equipment failure and operator error for extruder 19.

From table 2 it can be seen that the majority of scrap is produced during the startup of an order. Two different options to reduce the startup waste were investigated. Measures for operator training were introduced to help improve the efficiency of the startup process. An automated control system was also researched. This would automatically control the gauge and width of the film, which would reduce startup time.

Equipment failure was responsible for the majority of the remaining scrap production. A couple of options for reducing equipment related scrap production were explored. A system of record keeping was introduced to track the performance of the machines. A preventive maintenance system was also developed. This measure will help identify problems before they cause a complete shutdown of the equipment.

Record Keeping

Currently, there are very few records being kept at Cortec regarding process information. For each order, a form tracking roll weight, scrap production, and production rate is filled out. This form is the extent of the current record keeping system. There are no records regarding process conditions such as temperature, pressure, nip speed or screw RPM. Also, there is no record of any major events related to the extruder such as breakdowns, setup changes, new equipment, cleaning or repairs. In order to introduce a more extensive record keeping system at Cortec, I created machine books that contain several forms to keep track of the above information.

Recording process conditions is important for several reasons. One reason for recording process conditions is to establish a temperature profile for all the different recipes that are used. There are over 30 different recipes used at Cortec, and each recipe has an optimal temperature profile along each extruder. The operators cannot be expected to know all the different temperature profiles, so having a record of them is an important reference. Achieving the correct temperature profile is critical, because it affects the film properties. (see appendix p. 25) The overall quality of the film can be increased by ensuring that the temperature profile gives the desired film properties. Film that does not give the desired properties ends up as scrap, so establishing temperature profiles can help in reducing scrap production.

Recording other process conditions besides the temperature profile, such as the blow-up ratio, nip speed, nip pressure and screw RPM, is also important. (see Appendix p. 25 for a complete description of these parameters) From these parameters, it can be seen if optimum process conditions are being used. It can also track the performance of the machine and identify problems that may occur. For example, a temperature reading that is significantly different from the setpoint may identify a problem with the temperature controller. An increase in die pressure may signify that a screen change is needed. Also, a decrease in output over time can signal extruder screw and barrel wear.

Frequent changes of the screen located at the end of the extruder barrel are very important, so a separate sheet to record this procedure was included in the machine books. Screen changes are important for a couple of different reasons. When the screen becomes clogged, the polymer melt surges unevenly out of the extruder and can lead to variations in film thickness. This, in turn, can affect many other aspects of the process as described in the Theory section of this report in the appendix on page 25. Clogged screens can also cause a large increase in pressure in the extruder barrel, which can cause equipment damage and force a shutdown of production. This can be very costly in terms of the scrap produced when this occurs.

Checking the extruder screws and barrels for wear is also an important procedure, so a form was included in the machine books to keep track of this. Extruder screws and barrels wear over time for several different reasons. Bent screws or barrels can cause metal-to-metal contact that chips away at the screw and barrel surface. Pressure increases inside the barrel can also cause the screw to bend and cause wear. Abrasive resins are another source that can cause wear of the screw and barrel. Worn screws and barrels result in a decrease in the output rate and an increase in energy consumption. A 30% increase in the clearance between the screw and barrel due to wear can cause a 60% increase in energy consumption. For this reason, it is important to annually measure the clearance between the screw and barrel to check for wear. Both screws and barrels can be rebuilt at half the cost of new equipment.

A few sections regarding maintenance records were also included in the machine books. The first section regarding maintenance is a record of all of the repairs that take place on a specific extruder. This form allows for the maintenance staff to record the description, hours spent, and parts used on the repair. This is important for tracking the condition of the equipment. Repairs that take place frequently may signal a larger problem or show that new equipment may be needed. Also, it can identify pieces of equipment that should be added to the preventive maintenance program. The second section of the machine book related to maintenance keeps track of the preventive maintenance procedures, which are described later. The third section of the machine book devoted to maintenance concerns is a form that allows the maintenance personnel to leave messages for the extruder operators. This is important for signifying if repairs are complete. It can also be used to let the operators know if certain parameters need to be monitored to make sure the equipment was correctly repaired.

The final section of the machine book is devoted to a journal that will signify when any major events take place on that extruder. This form records of any major events related to the extruder such as breakdowns, setup changes, new equipment, cleaning or repairs. This form was added to prevent the loss of any information related to the extruders. It can prevent the same mistakes from happening more than once. It can also signify any recurring problems so that a solution can be developed.

Preventive Maintenance Program

A preventive maintenance program is a system that is set up to organize maintenance procedures for inspecting and maintaining the equipment. Each piece of equipment included in the preventive maintenance program has a schedule for routine inspection and servicing, which includes lubrication, cleaning, changing filters and oil, and replacing parts. The maintenance procedures in this program include only minor adjustments and repairs. While performing inspections, any deficiencies discovered that require more than the allotted time to repair should be entered into the normal planning of the maintenance group. This ensures that the preventive maintenance schedule is followed, and the maintenance staff does not fall further and further behind. The whole idea behind a preventive maintenance program is to diagnose an equipment deficiency as early as possible to allow more time to plan, acquire materials and schedule repairs. This is in contrast to normal breakdown maintenance where repairs are done on an immediate or emergency basis. In order to achieve early diagnosis of equipment deficiencies, it is important that experienced staff members be assigned to preventive maintenance procedures.

Preventive maintenance of the extruders at Cortec is extremely important for keeping the machines running efficiently. It allows you to identify a problem before it becomes a major issue that can shutdown production or create large quantities of scrap due to equipment failure. Records show that equipment failure was responsible for about 25% of the total scrap produced from the largest producer, extruder 19. (see Table 2) Equipment failure also has labor costs associated with scrap production and downtime of the equipment, which can be very costly as well.

Upon starting this project, a system to keep track of preventative maintenance of the extruders had been created. It was not being used, however, because of the time commitment required to keep up with it. For this reason, a new system was desired that was more user-friendly and less time consuming.

The first step in developing a new preventive maintenance system was to create a list of preventive maintenance procedures for each piece of equipment. I created a list for each extruder by going through the old preventive maintenance procedures and by receiving input from the chief operating officer, maintenance supervisor, plant manager, and operators. The frequency and duration of each procedure was determined by the maintenance supervisor. I also created preventive maintenance checklists for the converting equipment and twin screw. (see appendix p. 27 for all of the lists created)

From the list of preventive maintenance procedures, the total amount of time required for implementing this system was found. Table 3 shows the amount of time that would be required for the extruders, converting equipment and twin screw. With all of this equipment included, 16 hours of maintenance per day is required. Because the maintenance department is not able to devote this much time to preventive maintenance, it was decided that the converting equipment and twin screw be left out of the program at this time. This decision was based on the fact that the extrusion equipment produces a much larger amount of scrap, so implementing the preventive maintenance program on the extruders will have a bigger economical impact. Table 4 shows a breakdown of the time required for each extruder.

Equipment	Repair Time (hours per day)
Extruders	4.0
Converting	4.5
Twin Screw	3.5

Table 3
This table shows the repair hours that would be needed for the three main types of equipment at Cortec.

Extruder	Repair Time (hours per day)
1	0.4
3, 4 and 6	0.9
5, 7 and 8	0.8
18	0.4
19	0.5
20	1.0
Total hours per day	4.0

Table 4
This table summarizes the hours per day that are required for implementing a preventive maintenance program. The total amount of hours for all of the extruders is also shown.

The savings that would result from implementing this program were calculated next and are summarized in table 5. The calculations for all of the extruders were based on the findings from extruder 19. This was done because the records for the other extruders did not give details on the cause of the scrap being produced. Also, the results for some of the extruders are combined due to the fact that their individual production rates were unknown, as described earlier. The total amount of scrap due to equipment failure was taken as 25% of the total scrap production. Of this scrap, it was assumed that adding a preventive maintenance program would prevent 70% of the breakdowns and related scrap. For a successful preventive maintenance program, this is what can be expected. (see reference 7) Once the amount of scrap that would be reduced by implementing this program was found, the raw material savings that would result were calculated. (see table 5) The savings that would result from reduced labor costs were also calculated and are shown in table 5. The number of labor hours that would be reduced was found by dividing the amount of scrap reduced by the hourly production rate of the extruder. The number of labor hours reduced were then multiplied by the hourly machine rate to obtain the labor cost savings. The details of these calculations, including raw material and labor costs, are shown in the appendix starting on page 49. Since the co-extruder (extruder 20) is not yet in regular operation, the savings from this extruder are not yet known.

Initially, the preventive maintenance program will require additional hours from the maintenance staff. As the program is implemented, the amount of time spent on breakdowns should significantly decrease (by 70%). Eventually, the total maintenance time spent on each extruder should be less than it was before implementing this program. This will result in labor savings. Because there are no records thus far regarding the time spent on repairs, this figure could not be calculated. This will not be a significant factor when compared to the scrap savings that result, though.

From this economic analysis, it can be seen that implementing this program for the extruders is advantageous. Once it was determine that the program would be beneficial, the system for organizing the program was developed. Forms were created for each extruder and placed in the machine books described earlier in the Record Keeping section of this report. Each procedure was put on a monthly, quarterly or annual schedule. Once the procedures were categorized, a form to keep track of each of these three categories was created. A description of each procedure and its approximate length are given on the form. Spaces for recording the date the procedure was performed and its next due date were also included. Although the next due date for each procedure is automatically set, this column was added to allow more flexibility. While performing checks on the equipment, it may be concluded that certain parts will need to be replaced sometime in the near future. To make sure that this happens, the next due date can be changed to include this.

Extruder	Scrap Reduced (lbs/year)	Scrap Cost Savings ($/year)	Labor Cost Savings ($/year)
1	8,800	4,200	500
3, 4 and 6	4,700	2,300	500
5, 7 and 8	1,300	600	300
18	6,000	2,900	600
19	31,000	15,000	1,200
Total	51,800	25,000	3,100

Table 5
This table shows the amount of scrap that will be reduced and the savings that will result by implementing a preventive maintenance program at Cortec. Both scrap and labor savings are shown.

Operator Training

By observing and conversing with the extrusion operators, I noticed that there was a great deal of inconsistency between them. Each operator sets up the extruders in a different way. In order to obtain the correct film dimensions, parameters are continuously changed until the correct dimensions are found. The experienced operators can quickly correct any problems, but the more inexperienced operators take longer to achieve the desired dimensions. This difference in operator setup time can increase the scrap production during startup by a significant amount. A difference of only ten minutes on the largest line can cause 100 extra pounds of scrap.

In order to help the operators reduce their startup time, I updated an old training manual that would be made available in the plant. The first section of the manual is an overview of the theory behind the extrusion process. This will give the operators a chance to learn more quickly how the different parameters affect the film properties and dimensions. The information contained in this section of the manual is similar to that contained in the Theory section of this report in the appendix, starting on page 25. I also included updated procedures in the manual that will help the new operators learn the steps more quickly. A procedure for measuring the film thickness and the film dyne were included in the training manual. Procedures for screen changes and for cutting the cores for the rolls of film were also included in the training manual. The extrusion startup, shutdown, and gusset formation procedures were included too. The final two procedures that were included were air ring and die ring adjustments.

Besides the procedures described above, there were a few other items that were included in the training manual. Tips on troubleshooting were included, so that corrections during operation can be made quicker. It also shows samples of all the forms that need to be filled out during an order and directions for doing so. The film specification tolerances for thickness, width, and roll weight are all given. The quality control areas that need to be monitored are also included.

Automatic Gauge Control

The final option explored for reducing scrap was to install automatic gauge control on the largest producer, extruder 19. Currently, the dimensions of the film are measured manually. The width of the film can be measured as it is produced using a ruler. The thickness must be measured by taking a sample and passing it through a measurement device. If the dimensions are incorrect, adjustments are made manually by the operators. The width is adjusted by increasing or decreasing the volume of air in the bubble. The thickness is adjusted by changing the speed of the nip rolls. Increasing the nip roll speed stretches the film more and decreases the film thickness. Decreasing the nip roll speed has the opposite affect. These adjustments can be time consuming, especially for inexperienced operators. All of the film produced while final adjustments are being made ends up as scrap. Automatic gauge control can reduce the amount of time necessary for adjustments, and therefore reduce the amount of scrap that is produced.

Automatic gauge control systems consist of a measuring unit and a process control system. The measuring unit is a laser sensor that measures either the thickness or width. This information is sent to a computer control system, which automatically makes any equipment adjustments to achieve the desired dimensions. This information is stored in the computer and displayed on the control screen. Reports and trend graphs can be produced using a control system. The top of the line control systems let you monitor and control any of the important process variables. They also allow you to store recipes.

The cost of automatic gauge control systems is fairly large. I received a quote from Kundig Control Systems for a system similar to that described above. This system would cost about $27,000. The detailed quote of this system is shown in the appendix on page 52. Cortec is not willing to make this large of an investment for a control system, so this option was not explored further. There are a couple of reasons why Cortec has made this decision. First, a thickness gauge was bought a few years ago that did not give the expected results and broke shortly after it was installed. The cost for fixing this thickness gauge is $10,000, and Cortec is not willing to pay this. Secondly, there is no concrete way to determine the savings that would result from installing an automatic gauge control system. Because of this, there is a lot of risk in purchasing this equipment.

An economic evaluation of an automatic gauge control system is difficult for several reasons. First of all, it is very difficult to get an accurate assessment of how much scrap is produced while the process conditions are being optimized to obtain the correct film dimensions. This value changes with every order, and there are several factors that influence it. The recipe used and the operator starting the extruder both influence the time necessary to obtain correct film dimensions. Even the weather can affect the startup time, because the temperature and humidity affect the cooling rate of the film. If an estimate were made about the time required to obtain the correct film dimension and the scrap produced during this time, it would be difficult to determine how much this could be reduced by adding automatic gauge control. The response of the system is largely dependent on the extrusion equipment, so it would be difficult to estimate the affect it would have until it was installed.

There are a few other factors to consider when evaluating automatic gauge control. During startup, there are a lot of adjustments to the equipment that may be needed. For example, the air ring or die ring may need to be adjusted and cause uneven thickness in the film. An automatic gauge control system will not be able to recognize that there is a problem and will keep trying unsuccessfully to fix the problem. An operator who is manually making adjustments to the equipment will most likely diagnose the problem much quicker and be able to fix it. Another factor to consider about automatic gauge control is that the operators will require training to learn how to operate the system. The entire setup procedure that is currently used will need to be modified to include the automatic gauge control system. The control system will also require maintenance and cleaning to assure that it is working properly. The final thing to consider is the price to fix the equipment if it were to breakdown, which, as described earlier, can be very expensive.

<u>Water Reduction</u>

The first step in finding ways to reduce water usage at Cortec was to identify the water usage throughout the plant. Five pieces of equipment use water for cooling applications. The air compressor uses water to cool the compressed air. Extruder 1 uses water to cool the feed throat of the screw. Extruder 19 uses water to cool a refrigerant, which is used to cool the extruder barrel. The co-extruder also uses water to cool refrigerant used for barrel cooling. The twin screw also uses a small amount of water for cooling. The remainder of the water consumption comes from employee use, lab use, and cleaning. The total monthly water usage and the usage from each of the above sources were ascertained by taking measurements. This information is described below. A diagram showing the water flow throughout the building is shown in figure 5 in the appendix on page 58.

The total monthly water usage was found by looking at water bills for the previous year and by taking water meter readings over a two month period. When looking at the water bills, I noticed that the current water meter reading was quite a bit lower than the readings given on the bills. After contacting the City of Cambridge, it was found that the water usage was being estimated. Water meter readings were not being reported by Cortec, so an estimate of 500,000 gallons per month was used. This is quite a bit more than the usage shown by taking water meter readings, which was 207,000 gallons per month. (see appendix p.54 for water meter readings and a water bill summary) A credit of $3,500 was added to Cortec's account due to the overestimates, and Cortec will now be reporting monthly readings to avoid overcharging in the future. Because of this discrepancy, water meter readings were used to estimate the monthly usage.

Water usage from the co-extruder was measured manually using a bucket and stopwatch. These measurements are shown in the appendix starting on page 70. The average water flow rate for the co-extruder was 126 gallons per hour. The cooling water for all of the extruders is started on Monday morning and turned off on Thursday afternoon, so water is being used 3 ½ days per week. This gives a total monthly usage of 42,000 gallons per month for the co-extruder. The water flow to and from the co-extruder is shown in figure 6 in the appendix on page 60. Water was fed from a sink to a large holding tank. The water from this holding tank is then pumped through heat exchangers for the three extruders to cool the refrigerant that was used for barrel cooling. The hot water leaving the heat exchangers is then pumped back to the holding tank. Overflow from this tank is dumped in the drain. Water is kept in the holding tank from week to week so that it only needed to be filled once. This setup is a temporary cooling solution for the co-extruder. Cortec is planning on installing a refrigeration unit soon, so eventually no water will be used for the co-extruder at all.

It can be seen from figure 5 that the air compressor, extruder 1 and extruder 19 all drain into a sink. The combined volumetric flow from these three sources was measured manually and found to be 320 gallons per hour. The flow rate from the air compressor was found by disassembling the pipe and manually taking a measurement. A flow rate of 35 gallons per hour was measured. The flow rate from extruder 19 was also measured by disassembling the water pipes and was found to be 200 gallons per hour. (All of these measurements and calculations are shown in the appendix p. 61) The flow rate from extruder 1 was then calculated by subtracting the flow rates from the air compressor and extruder 19 from the combined flow rate. Extruder 1 uses 85 gal/hr. Since water is being used continuously for 3 ½ days per week for the extruders, the monthly usage is 28,000 gallons per month and 68,000 gallons per month for extruders 1 and 19, respectively. The air compressor uses water continuously, seven days a week. This gives a monthly usage for the air compressor of 26,000 gallons per month.

The rest of the water usage in the plant was estimated. Employee use was estimated as 20 gallons per day for each employee. (see reference 9) This gave a monthly usage of 19,000 gallons per month for employee use. The lab use, cleaning use and twin screw use was found by taking the total monthly usage and subtracting all other uses. This was approximated as 24,000 gallons per month. A summary of the water use throughout the plant is shown in table 6.

Source	**Usage (gal/month)**
Air compressor	26,000
Extruder 1	28,000
Extruder 19	68,000
Co-extruder	42,000
Employee use	19,000
Lab use, cleaning and twin screw	24,000
Total Monthly Usage	207,000

Table 6
This table summarizes all the sources of water usage at Cortec. The total monthly usage is also given, as measured by the water meter.

Water is being used continuously seven days a week for the air compressor even though it is only in operation for 3 ½ days a week. Currently, the air compressor uses 26,000 gallons per month. By installing an on/off valve that would stop water flow when the air compressor is not in use, the water usage could be reduced to 12,000 gallons per month. This would reduce water usage by 14,000 gal/month and save $1,000 per year in water and sewage charges. This valve would cost about $100, so the payback period would be less than two months.

The next water reduction option that was researched was to find a way to recycle the water being used for cooling extruder 19. Currently, water is being used to cool a water/glycol refrigerant using a heat exchanger. The water/glycol mixture is then used for barrel cooling. A diagram of the water flow to and from extruder 19 is shown in figure 7 in the appendix on page 59.

In order to close the loop on the water flow for this extruder, a water-cooling tower could be installed. This tower would cool the outlet water and send it back to the heat exchanger. In order to determine the specifications that would be needed for this water-cooling tower, measurements of the temperatures and flow rates of the water and water/glycol mixture were made. (actual measurements are shown in the appendix p. 61) From these measurements, the flow rate to the cooling tower and the heat that it would need to remove were calculated. (see appendix p. 73) The cooling tower would need to cool a water stream with a flow rate of 10 gal/min from 95°F to 80°F. This corresponds to removing 1300 kW of heat from the water/glycol mixture, which has a flow rate of 14 gal/min and inlet and outlet temperatures of 115°F and 100°F, respectively.

Once the specifications for this tower were found, I contacted several cooling tower manufacturers to obtain a quote on the cost of this tower. One of the manufacturers, Systems H_2O, suggested using a closed loop evaporative cooling tower. In this cooling tower, the water/glycol mixture could be cooled directly eliminating the need for a heat exchanger. The water/glycol mixture is passed through the cooling tower in coils. Water is sprayed over these coils to provide cooling. Air is fed through the bottom of the tower to evaporatively cool the water, which is then recycled back to the top of the tower. A diagram of this system is shown in figure 8. This system would cost $10-12,000. A 1-2 hp fan motor would be required, and ½ gallon per minute of water would be needed to recoup evaporative losses. The water and electricity would cost $1500 per month. (see appendix p. 77 for details) The current system costs $4,800 per year for water and sewage. The total savings from installing this system would be $3,300 per year and would give a payback period of 3.6 years. For this analysis, I used $12,000 for the cost of the tower. I also used a 2 hp fan for calculating electricity costs. Actual prices may be less than this, so a payback of 3.6 years is the highest that can be expected.

If it is determined that the water-cooling tower described above will not be used, another water reduction idea was explored. Currently, extruder 1 uses 28,000 gallons per month for feed throat cooling. This usage could be eliminated by using the outlet water from extruder 19 for cooling. A savings of $2,000 per year would result. Currently, 85 gallons per hour of water is being used with inlet and outlet temperatures of 50°F and 57°F, respectively. (see appendix for measurements) This corresponds to 90 kW of heat removal. By using the outlet water from extruder 19 and keeping the flow rate the same, the inlet and outlet water temperatures would change to 110°F and 117°F, respectively. This should ensure that the feed throat of the extruder stays below the melting point of polyethylene, which is 198°F. All of the water reduction options explored are shown in Table 7. This table gives the reduction in water usage, the savings that result, and the status of each option.

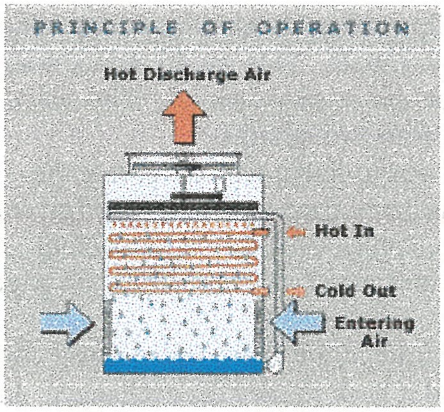

Figure 8
This figure is a schematic of the water-cooling tower from Systems H_2O that was researched. All of the inlet and outlet flows are shown. (reference: www.systemsh2o.com)

Waste Reduction Option	Reduction in water usage	Cost Savings	Status
Report monthly readings	-------	One time savings of $3,500 possible overcharges of $20, 500/year	Implemented
Control valve for air compressor	14,000 gal/month	$1,000/year Payback = 2 months	Recommended
Eliminating extruder 1 usage	28,000 gal/month	$2,000/year	Recommended*
Water cooling tower	68,000 gal/month	$3,300/year Payback = 3.6 years	Recommended

Table 7
This table summarizes the water reduction options explored. The reduction in water usage and the savings that result are shown. The status of each suggestion is also given.
*This option is only recommended if the water-cooling tower on extruder 19 is not installed. Otherwise, it is not feasible.

Electricity Usage

The electricity usage at Cortec was also briefly looked into. There are three different monthly fees that Cortec is charged for. The first is an energy charge, which is 2.7 cents per kWH used in a month. The second fee is a maximum demand charge, which is the maximum kilowatt demand that is used for any one-hour period during the month. The maximum demand charge is $3 per kilowatt used during that one-hour period. The final fee is the peak period demand charge. This is the maximum kilowatt demand that is used during a one-hour period between the hours of 5:00 p.m. and 10:00 p.m. during the month. The rate for this usage is $9.25 per kilowatt.

When inspecting the electricity bills, it was noticed that the maximum demand period and peak period demand charges constituted the majority of the cost. A summary of the electricity usage for the year 2001 is shown in table 8. The costs associated with the usage shown in table 8 are given in table 9. The large amount of electricity used during the maximum demand period may be due to startup practices at Cortec. Currently, the majority of the extruders are all started up for the week at the same time, even if they are not scheduled to start production until much later. This causes a huge surge in the electricity usage, because the extruders use a large quantity of energy during startup. When the extruders are first started up, the electric heater bands use a large quantity of energy to heat the polymer melt to the desired temperature of around 300°C. Once this temperature is reached and the extruders begin production, the energy used by the heater drops significantly.

By changing startup practices, the maximum demand and peak demand charges may be significantly reduced. A schedule could be made in which the extruders are started up one by one to avoid a large peak in electricity usage. In order to evaluate this further, meters that measure the electricity usage of each extruder will be installed by the electric company, East Central Energy. Randy Cook from MnTAP will be assisting Cortec in any evaluations of reducing the peak electricity usage.

Month	Monthly Usage (kWH)	Max Demand (kW)	Peak Demand (kW)
8	85200	302.4	290.4
7	79200	332.4	278.4
6	86880	325.2	292.8
5	75840	316.8	313.2
4	106800	370.8	337.2
3	94800	322.8	295.2
2	105960	314.4	291.6
1	83640	325.2	304.8

Table 8
This table summarizes the monthly electricity usage at Cortec for the year 2001.

Month	Monthly Usage Cost ($)	Max Demand Cost ($)	Peak Demand Cost ($)
8	2300.40	907.20	2686.20
7	2138.40	997.20	2575.20
6	2345.76	975.60	2708.40
5	2047.68	950.40	2897.10
4	2883.60	1112.40	3119.10
3	2559.60	968.40	2730.60
2	2860.92	943.20	2697.30
1	2258.28	975.60	2819.40

Table 9
This table summarizes the costs associated with the electricity usage at Cortec for the year 2001.

Appendix

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THEORY

In the process of extrusion, a polymer resin is fed into the channel of a screw that is rotating within the barrel of an extruder. A funnel-shaped hopper feeds the resin into the barrel. The resin is then melted through the application of heat and pressure. Heat is supplied both by heaters and by friction produced from the rotating screw. The screw also compresses the resin and thoroughly mixes it to produce a homogeneous melt. At the end of the screw, the melt is pushed through a screen that removes any contamination. The melt is then pushed out of the extruder through a circular die ring. The screen generates back-pressure to aid in mixing. These screens must be changed frequently, because they can become clogged and cause uneven extrusion of the melt.

The temperature profile along the extruder barrel and the die are very important in controlling the properties of the film produced. At the inlet to the barrel, the resin must be kept cool so that melted resin does not accumulate and plug the inlet. As the resin moves along the barrel, its temperature is strictly controlled by heating and cooling bands. As it leaves the die, the temperature should be approximately equal to the melt temperature. High temperatures give the best transparency for blown film. If the temperature becomes too high, the viscosity may become too low causing the bubble to become unstable. For each resin, the temperature profile that gives the best film properties should be used.

As the resin melt is extruded, it is expanded to form a bubble of desired diameter. It is important that the die opening through which the melt is extruded be centered correctly, because non-uniform film thickness can result. Air is circulated through the center of the die ring to expand the melt into a bubble. It is closed by the die at the bottom and by a set of rollers (called nips) at the top. The air pressure inside the bubble can be adjusted to obtain the desired bubble diameter. The pressure remains constant once the desired diameter is reached. As the hot film expands to form a bubble, it is cooled by the air inside and outside of the bubble. Controlling the air flow is very important for obtaining uniform thickness. Non-uniform flow of the cooling air can cause uneven film cooling and lead to non-uniform thickness.

The height of the 'frost line' of the extruded film is an important parameter in blown film extrusion. The frost line is the point where the bubble appears frosty because the film temperature has fallen below the softening range of the resin. This point is often difficult to see and is taken as the line around the bubble where the final diameter has been reached. The frost line is important for controlling the molecular orientation of the melt, which affects the tear, tensile and impact strengths of the film. It is critical that the frost line remain level, so that uniform strength can be obtained. The recommended height of the frost line is 2-3 die diameters. Raising the frost line gives the film a smoother surface and higher clarity, because the film has more time to solidify. When the frost line becomes too high, the film may not have sufficient time to cool and can stick to the nip rolls. The frost line can be adjusted by changing the extruder speed or by changing the volume of cooling air inside the bubble.

The blow-up ratio is another important parameter that must be controlled during the blown film extrusion process. The blow-up ratio is the bubble diameter divided by the die diameter. The blow-up ratio is determined by the desired lay-flat width and the extruder die size. The lay-flat width is the width of the completely flattened film. (see figure 2, p. 4) The blow-up ratio is given by the following equation:

Blow-up ratio = 0.637*(lay-flat width / die diameter)

The blow-up ratio affects many of the film properties. As the polyethylene molecules are extruded, they line up in the machine direction as the film is pulled up and stretched by the nip rolls. If the bubble size is not increased and the blow-up ratio remains 1:1, the film is easy to tear in the machine direction. By increasing the blow-up ratio, bi-directional stretching occurs and a more balanced molecular orientation is achieved. The molecular orientation then affects the film's optical and strength properties. The optimum blow-up ratio is about 2-3:1. By maintaining the blow-up ratio in this range, the size range that can be produced from each extruder is set.

As the film leaves the nip rolls, it is pulled through a series of rollers before being wound up onto a roll. (see figure 1 on p.3) When the film is pulled through these rollers, blocking can occur. Blocking occurs when film adheres to itself or the surface of the rollers. Smooth, glossy films have a greater tendency to block. Thin-gauge films also block more easily, because they build up static electricity and are run at higher take off speeds and tensions. High temperatures can also cause blocking. Slip additives can be added to the film to reduce the blocking. Lower extrusion temperatures reduce blocking by reducing the film temperatures and preventing the slip additive from evaporating.

Wrinkling is another problem that may be encountered while winding the film. There are many causes for wrinkling of blown-film rolls. Variations in the film gauge (thickness) can cause wrinkling, because it causes uneven pull at the nip rolls. The pressure at the nip rolls must also be uniform to prevent any wrinkling. It may also be caused by a condition called 'bias'. Bias occurs when the two halves of the bubble circumference are unequal and can be caused by air currents or by the die ring being out of adjustment. If the temperature of the film is too cold at the nip rolls, wrinkling can result. The nip rolls can be lowered to prevent this, but care must be taken to ensure that the temperature increase does not cause blocking. Wrinkling can occur when the bubble becomes wobbly due to air currents or surging from the extruder. The surging can be corrected by obtaining even melt temperatures along the extruder barrel. Guide rolls can be used to support the bubble, but they can also cause wrinkles if not properly aligned. The final cause for wrinkling is uneven tension on the winding roll. This can be fixed by installing variable drive rollers that adjust the tension as the film is rolled up.

It can be seen from the discussion above that there are many different design parameters to consider when processing blown-film. Changing one design parameter can have a chain reaction to affect many different aspects of the process. Obtaining the correct film properties and dimensions is very difficult, because there are so many variables that affect them. It can also be seen that there are many problems that can occur during extrusion and even more possible causes of these problems. This makes blown-film extrusion a difficult process to understand and control.

Extruder 1
PM Checklist

Frequency (days)	Repair Time (hours)	Yearly Repair Hours	Description
365	1.75	1.8	change oil in main gear box, change oil in thrust bearing housing
365	1.5	1.5	change oil in winder turret gear boxes
365	2	2.0	change oil in upper and lower nip gear box
365	1.5	1.5	change oil in rotator gearbox
30	0.5	6.1	check oil in rotator gearbox
90	3	12.2	check oil in lower and upper nip gearbox
30	0.25	3.0	check oil in extruder main gearbox
90	0.5	2.0	check oil in winder turret gearboxes
90	1	4.1	check brushes in upper and lower nip drive motor
365	1.5	1.5	check brushes; clean, purge blower screen; blow out motor with compressed air
90	0.25	1.0	grease rotator
30	0.25	3.0	check filter on hopper receiver
365	1	1.0	check belts and pullies on main extruder
365	2	2.0	check winder and belts
365	0.5	0.5	check air ring blower for noise, loose, damaged or missing duct work, pipe, belts, hoses; check filter
90	0.5	2.0	check the collapsing frame and idler rollwer for the tower
30	1	12.2	check the temp controllers and heater bands to make sure they are all working
90	0.25	1.0	check feed throat cooling water loop for leaks
365	2	2.0	check calibration of controllers
90	1	4.1	clean air ring
365	4	4.0	check screw and barrel wear (measure flight diameter, barrel diameter, barrel thickness)
90	1	4.1	clean nip rollers and idler rollers
90	2	8.1	center air ring and pin die gap
90	1	4.1	clean die lip
	Total yearly hours	84.7	
	Hours per working day	0.33	

Extruder 3
PM Checklist

Frequency (days)	Repair Time (hours	Yearly Repair hours	Description
365	2.5	2.5	change oil in main gear box; grease thrust housing
365	3	3.0	change oil in upper and lower nip gear box
365	1.5	1.5	change oil in rotator
365	1.5	1.5	change oil in winder turret gearboxes
90	0.5	2.0	check oil level on the rotator gear box
90	2	8.1	check oil in upper and lower nip gearbox
90	0.25	1.0	check oil level in the extruder main gearbox
90	0.5	2.0	check oil in winder turret gearboxes
90	1	4.1	check brushes in upper and lower nip drive motor
365	0.75	0.8	check brushes in main ext. drive motor, blow out motor
90	2.5	10.1	pull and clean heat pot, check or grease
90	0.25	1.0	grease rotator
30	0.25	3.0	check filter on hopper receiver
365	2	2.0	check air ring blower motor belt and filter
365	1	1.0	check belts on main drive motor
365	2	2.0	check winder and belts
365	2	2.0	check calibration of controllers
90	0.5	2.0	inspect the collapsing frame and idler rollers
365	4	4.0	check screw and barrel wear(measure flight diameter, barrel diameter, barrel thickness)
90	2	8.1	center air ring and pin die gap
90	1	4.1	clean die lips
90	1	4.1	clean nip rollers and idler rollers
	Total yearly hours	69.9	
	Hours per working da	0.27	

Extruder 4
PM Checklist

Frequency (days)	Repair Time (hours	Total Repair hours	Description
365	3	3.0	change oil in upper and lower nip gear box
365	1.5	1.5	change oil in main gear box, grease thrust housing
365	1.5	1.5	change oil in rotator
365	1.5	1.5	change oil in winder turret gearboxes
90	1	4.1	check oil in lower and upper nip gearbox
90	0.5	2.0	check oil in the rotator gearbox
90	0.5	2.0	check oil in main gear box
90	0.5	2.0	check oil in winder turret gearboxes
90	1	4.1	check brushes in upper and lower nip drive motor
90	0.75	3.0	check brushes on the main ext. drive motor
90	2.5	10.1	Pull heat pot, clean, check or grease
30	0.25	3.0	grease pressure gages with silicone grease
90	0.25	1.0	grease rotator
30	0.25	3.0	check filter on hopper loader
365	2	2.0	check air ring blower motor belt and filter
365	1.5	1.5	check main ext. motor belts for cracks
365	2	2.0	check winder and belts
90	0.5	2.0	inspect the collapsing frame and idler rollers
365	2	2.0	check calibration of controllers
365	4	4.0	check screw and barrel wear (measure flight diameter, barrel diameter, barrel thickness)
90	2	8.1	center air ring and pin die gap
90	1	4.1	clean die lips
90	1	4.1	align and clean nip rolls
365	0.25	0.3	Blow out main motor, check brushes
	Total yearly hours	72.0	
	Hours per working da	0.28	

Extruder 5
PM Checklist

Frequency (days)	Repair Time (hours)	Total Repair Hours	Description
365	1	1.0	change oil in upper and lower nip gear box
365	2	2.0	change oil in main gear box and thrust housing
365	1.5	1.5	change oil in rotator
365	1.5	1.5	change oil in winder turret gearboxes
90	0.5	2.0	check oil in winder turret gearboxes
90	0.25	1.0	check oil in the extruder main gearbox
90	0.5	2.0	check the oil in the rotator gearbox
90	3	12.2	check oil in upper and lower nip gear box
90	0.5	2.0	check the brushes in the main ext drive motor
90	1	4.1	check brushes in upper and lower nip drive motor
90	2.5	10.1	pull and clean die pot, check or grease
30	0.25	3.0	grease pressure gages with silicone grease
90	0.25	1.0	grease rotator
30	0.25	3.0	check or replace filter on hopper receiver
365	2	2.0	check air ring blower motor belt and filter
365	0.72	0.7	check the main ext. drive motor belts
365	2	2.0	check winder and belts
90	0.5	2.0	check the collapsing frame assy and idler rollers
365	2	2.0	check calibration of controllers
365	4	4.0	check screw and barrel wear (measure flight diameter, barrel diameter, barrel thickness)
90	2	8.1	center air ring and pin die gap
90	1	4.1	clean die lips
90	1	4.1	clean nip rolls and idler rollers
365	0.25	0.3	Blow out main maotor, check brushes
	Total yearly hours	75.8	
	Hours per working day	0.29	

Extruder 6
PM Checklist

Frequency (days)	Repair Time (hours	Total Repair Hours	Description
365	3	3.0	change oil in upper and lower nip gear box
365	2	2.0	change oil in main gear box and thrust housing
365	0.5	0.5	change oil in rotator gear box
365	1.5	1.5	change oil in winder turret gearboxes
90	0.5	2.0	check oil in winder turret gearboxes
90	0.5	2.0	check oil in upper and lower nip gearbox
90	0.5	2.0	check the oil in the rotator gearbox
90	0.5	2.0	check oil in main gearbox and thrust housing
90	2.5	10.1	pull and clean heat pot
90	1	4.1	check brushes in upper and lower nip drive motor
90	0.5	2.0	check the brushes in the main ext drive motor
365	0.25	0.3	blow out main motor, check brushes
90	0.25	1.0	grease rotator gearbox
30	0.25	3.0	grease pressure gages with silicone grease
30	0.25	3.0	check or replace filter on hopper receiver
90	0.5	2.0	check, purge blower motor filter
365	0.5	0.5	check air ring blower motor belt and filter
365	0.25	0.3	check main ext. drive motor belts
365	2	2.0	check winder and belts
90	0.5	2.0	check the collapsing frame assy and idler rollers
365	2	2.0	check calibration of controllers
365	4	4.0	check screw and barrel wear (measure flight diameter, barrel diameter, barrel thickness)
90	2	8.1	Center air ring and die lips
90	1	4.1	Clean die lips
90	1	4.1	clean nip rolls and idler rollers
	Total Yearly Hours	67.7	
	Hours per working da	0.26	

Extruder 7
PM Checklist

Frequency (days	Repair Time (hours	Total Repair Hours	Description
365	3	3.0	change oil in upper and lower nip gear box
365	2	2.0	change oil in main gear box and thrust housing
365	0.5	0.5	change oil in rotator gear box
365	1.5	1.5	change oil in winder turret gearboxes
90	0.5	2.0	check oil in winder turret gearboxes
90	0.5	2.0	check the oil in the upper nip gearbox
30	0.5	6.1	check the oil level in the main ext gearbox and thrust housing
90	0.5	2.0	check oil in rotator gearbox
90	1	4.1	check brushes in upper and lower nip drive motor
90	0.25	1.0	check ext drive motor brushes
365	0.25	0.3	blow out main motor, check brushes
90	2.5	10.1	pull and clean heat pot or grease
30	0.25	3.0	grease pressure gages with silicone grease
90	0.25	1.0	grease rotator gearbox
90	0.5	2.0	check, purge blower motor filter
30	0.25	3.0	check or replace filter on hopper receiver
365	0.5	0.5	check air ring blower motor belt and filter
365	0.25	0.3	check belts on main drive motor
365	2	2.0	check winder and belts
90	0.5	2.0	check the collapsing frame and idler rollers
365	2	2.0	check calibration of controllers
365	4	4.0	check screw and barrel wear (measure flight diameter, barrel diameter, barrel thickness)
90	2	8.1	center air ring and die lips
90	1	4.1	clean die lips
90	1	4.1	clean nip rolls and idler rollers
	Total yearly hours	70.8	
	Hours per working da	0.27	

Extruder 8
PM Checklist

Frequency (days)	Repair Time (hours)	Total Repair Hours	Description
365	3	3.0	change oil in upper and lower nip gear box
365	2	2.0	change oil in main gear box and thrust housing
365	0.5	0.5	change oil in rotator gear box
365	1.5	1.5	change oil in winder turret gearboxes
30	1	12.2	check oil in winder turret gearboxes
30	0.5	6.1	check oil level in the ext main gearbox and thrust housing
90	3	12.2	check oil in upper and lower nip gearbox
90	0.5	2.0	check oil in rotator gearbox
90	0.5	2.0	check brushes in upper nip drive motor
90	1	4.1	check brushes in lower and upper nip drive motor
90	0.5	2.0	check the brushes in the main ext drive motor
365	0.25	0.3	blow out main motor, check brushes
90	2.5	10.1	pull and clean heat pot, check or grease
30	0.25	3.0	grease pressure gages with silicone grease
90	0.25	1.0	grease rotator gearbox
90	0.5	2.0	check, purge blower motor filter
30	0.25	3.0	check or replace filter on hopper receiver
365	0.5	0.5	check air ring blower motor belt and filter
365	0.25	0.3	check belts on main drive motor
365	2	2.0	check winder and belts
90	0.5	2.0	check the collapsing frame and idler rollers
365	2	2.0	check calibration of controllers
365	4	4.0	check screw and barrel wear (measure flight diameter, barrel diameter, barrel
90	2	8.1	center air ring and die lips
90	1	4.1	clean die lips
90	1	4.1	clean nip rolls and idler rollers
	Total yearly hours	94.1	
	Hours per working da	0.36	

Extruder 18
PM Checklist

Frequency (days)	Repair Time (hours)	Total Repair Hour	Description
365	1.5	1.5	change oil in winder turret gear boxes (2)
365	1	1.0	change oil in main ext gear box
365	0.5	0.5	change oil in rotator gearbox
365	3	3.0	change oil in lower and upper nip gearbox
90	0.5	2.0	check oil in winder turret gearboxes
90	1	4.1	check oil in lower and upper nip gear box
90	0.5	2.0	check oil in rotator gear box
30	0.5	6.1	check the oil in the extruder main gear box and thrust housing
90	1	4.1	check brushes in the upper and lower nip drive motor
365	0.25	0.3	blow out main motor, check brushes
90	0.25	1.0	grease rotator gearbox
30	0.25	3.0	grease pressure gages with silicone grease
30	0.25	3.0	check or replace filter on hopper receiver
90	0.5	2.0	check, purge blower motor filter
365	0.5	0.5	check air ring motor belt and filter
90	2	8.1	check the main ext drive belt
30	0.5	6.1	check air ring blower for noise, loose,damaged or missing duct work, pipe belts or hoses
365	2	2.0	check winder and belts
30	0.5	6.1	check heater bands
30	0.5	6.1	check condition of the rotator chain and any microswitches
30	0.5	6.1	check temperature controllers
30	1	12.2	check over the collapsing frame and rollers
365	2	2.0	check calibration of controllers
365	4	4.0	check screw and barrel wear (measure flight and barrel diameter, barrel thickness)
90	2	8.1	center air ring and die lips
90	1	4.1	clean die lips
90	1	4.1	clean nip rolls and idler rollers
	Total Yearly Hours	103.0	
	Hours per working da	0.40	

Extruder 19
PM Checklist

Frequency (days)	Repair Time (hours)	Total Repair Hours	Description
365	3	3.0	change oil in upper and lower nip gear box
365	1.5	1.5	change oil in rotator gear box
365	2.5	2.5	change oil in main gear box and thrust housing
365	1.25	1.3	change oil in winder turret gear boxes (2)
30	0.25	3.0	check oil level in the extruder main gearbox and the thrust housing
30	1	12.2	check oil level in the upper and lower nip gearbox
90	1.5	6.1	check oil in rotator gear box
90	1	4.1	check oil in winder turret gear boxes
365	0.25	0.3	blow out main motor, check brushes
90	1	4.1	check brushes in upper and lower nip drive motor
30	0.25	3.0	grease pressure gages with silicone grease
30	0.25	3.0	check main extruder motor cooling fan filter
30	0.25	3.0	check and or replace filter on hopper receiver
90	0.25	1.0	check main extruder drive belts
365	2	2.0	check winder and belts
30	0.5	6.1	Listen to the air ring blower for strange noises; look for loose, damaged, or missing duct work, pipes, hoses or belts
90	0.5	2.0	check all the heater bands on the machine to make sure they are working
365	2	2.0	check calibration of controllers
7	0.25	13.0	check water level in water storage tank for cooling system
30	1	12.2	check over collapsing frame and rollers
90	1	4.1	check condition of rotator chain and microswitches
365	4	4.0	check screw and barrel for wear (measure flight and barrel diameter, measure barrel thickness)
90	2	8.1	Center air ring and die lips
90	1	4.1	clean die lips
365	1	1.0	clean nip rolls and idler rollers
7	0.25	13.0	BOR: check perforation teeth
90	0.25	1.0	BOR: check that idlers turn freely, check condition of main drive belt, look for plastic wrapped around shafts, grease zerk fittings
30	0.25	3.0	BOR: check hydraulic fluid, air leaks, fluid leaks, check E stop, check safety cables, check main disconnect
90	0.25	1.0	BOR: check amount and condition of teflon curtain and lower teflon tape; check rubber inserts for missing pieces
90	0.5	2.0	BOR: clean heat exchanger for hydraulic oil system

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Extruder 19
PM Checklist

365	1	1.0	Winder: check condition of brushes on DC motors (4)
90	0.25	1.0	Winder: Check condition of cords and plugs on winder and nip station
90	0.25	1.0	Printer: check drive chains and bearings
30	0.25	3.0	Chiller: check coolant level, check for leaks
90	0.5	2.0	Chiller: clean condenser section
	Total yearly repair hour	134.8	
	Hours per working day	0.52	

Co-extruder PM Checklist

Frequency (days	Repair Time (hours	Total Repair Hours	Description
365	3	3.0	change oil in upper and lower nip gear box
365	4.5	4.5	change oil in rotator gear box (all three extruders)
365	7.5	7.5	change oil in main gear box and thrust housing (all three extruders)
365	1.25	1.3	change oil in winder turret gear boxes (all three extruders)
30	0.75	9.1	check oil level in the extruder main gearbox and the thrust housing (all three extruders)
30	3	36.5	check oil level in the upper and lower nip gearbox
90	4.5	18.3	check oil in rotator gear box (all three extruders)
90	1.5	6.1	check oil in winder turret gear boxes
365	0.75	0.8	blow out main motor, check brushes (all three extruders)
90	3	12.2	check brushes in upper and lower nip drive motor
90	0.75	3.0	grease rotator gearbox (all three extruders)
30	0.75	9.1	grease pressure gages with silicone grease
30	0.75	9.1	check, purge blower motor filter
90	0.75	3.0	check and or replace filter on hopper loader (all three
90	0.75	3.0	check main extruder drive belts (all three extruders)
365	6	6.0	check winder and belts
30	1.5	18.3	Listen to the air ring blower for any strange noises and also look for loose, damaged, or missing duct work, pipes, hoses or belts that need repair
90	1.5	6.1	check all the heater bands on the machine to make sure they are working (all three extruders)
30	1.5	18.3	check out all temp controllers, make sure they are reading close to setpoint temp (all three extruders)
365	6	6.0	check calibration of controllers
7	0.5	26.1	check water level in water storage tank for cooling tower
30	1	12.2	check over collapsing frame and rollers
365	4	4.0	check right extruder screw and barrel for wear (measure flight and barrel diameter, measure barrel thickness)
365	4	4.0	check middle extruder screw and barrel for wear (measure flight and barrel diameter, measure barrel thickness)
365	4	4.0	check left extruder screw and barrel for wear (measure flight and barrel diameter, measure barrel thickness)
90	2	8.1	Center air ring and die lips

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Co-extruder PM Checklist

90	1	4.1	clean die lips
90	1	4.1	clean nip rolls and idler rollers
	Total Yearly Hours	247.5	
	Hours per working da	0.95	

Twin Screw
PM Checklist

Frequency (days)	Repair Time (hours	Total Repair Hours	Description
365	2	2.0	Pull off T.W.S. pump and disassemble to clean impeller. Replacee seal if needed
7	1	52.1	Inspect all flexible conduit lines and junctions for tightness
7	2	104.3	Check tightness of T. W. S. pipe connectors. Adjust as needed
7	0.25	13.0	Drain water from air storage tank
14	2	52.1	Pull off access cover to inspect and clean out transfer area
7	0.25	13.0	Sharpen cutter head
7	0.5	26.1	Check the oil level in sight glass, main gearbox, add oil if needed. Use Schaffers Brand
14	1.5	39.1	Test load cells with 10# weight on hoppers
7	1	52.1	Inspect hand sealer for belt wear and proper alignment
7	1	52.1	Inspect all drop rod supports and lock up nuts if needed
7	1	52.1	Inspect all city water supply lines for damage. Repair or replace as needed
7	1	52.1	Inspect all soft air lines for damage. Repair or replace if needed
7	2	104.3	Inspect all soft cords for frays and other damage
60	0.25	1.5	Check fan blades for damage or debris
90	1	4.1	Blow out control cabinet on all panels
180	1.5	3.0	Blow out control cabinet on all panels
30	1	12.2	Check all nuts and bolts for tightness. Correct if needed
90	1	4.1	Check dryer screens for holes
180	1	2.0	Check alignment of pelletizer assembly. Adjust as needed
180	2	4.1	Check for proper weight reading with weights in shop
365	1	1.0	Change main drive brushes and clean commutator with a stone. This may be a double pm
180	1	2.0	Check all flexible air fittings for tightness. Replace flex hoses as
180	0.5	1.0	Check I.C.E. heat unit for correct operation
180	2	4.1	Pull scale out of pit and clean pit of plastic or debris
180	2	4.1	Clean TWS of mineral deposits
365	3	3.0	Change oil and filter, main drive gearbox
365	0.5	0.5	Check balance of fan with the 'nickel' test. Call for balance if failed.
730	2	1.0	Replace top bearing in dryer
365	1	1.0	Replace the sock filters
365	1	1.0	Pull 110 volt motor head and check brushes, replace if needed
97	1	3.8	Grease thrust bearing seal, main drive gearcase

Twin Screw
PM Checklist

4	0.25	23.5	check pelletizer limit switche
10	0.5	18.8	Grease pelletizer motor
10	0.5	18.8	Grease dryer bottom bearing. Do not grease top bearing
49	1	7.5	Check die face height
10	0.5	18.8	Check operation of fluidized bed dryer dump gate, lightly grease flange bearings if needed
10	0.5	18.8	grease chaker motor bearings
97	1	3.8	grease drive couplers between main drive motor and gearbox
97	1	3.8	grease main drive motor and purge blower
10	1	37.5	check main drive brushes and clean commutator with stone
4	0.25	23.5	check die face for chips or grooves
97	0.5	1.9	grease blower motor and pillow block bearings
97	0.5	1.9	grease rear transimission seal
4	0.5	46.9	check the oil level in air compressor pump. Add oil if needed
97	1	3.8	check for broken or cracked V belts on the air compressor
10	0.5	18.8	Clean air filter on air compressor. Replace with a new one if it cannot be cleaned properly.
49	1	7.5	Pull guard and check for broken or cracked v belts
	Total yearly hours	923.3	
	Hours per working da	3.6	

Converting 2
PM Checklist

Frequency (days)	Approximate Time for Repair (hours)	Total Repair hours	Description
30	1	12.2	inspect: condition of capstan drive belt, pulleys, idler
30	1	12.2	inspect: condition of dancer drive belt
30	0.5	6.1	inspect for free turning of capstan rollers
30	0.5	6.1	inspect for free turning of capstan pressure rollers
30	0.5	6.1	inspect for free movement of idler rollers
30	2	24.3	inspect condition of upper/lower pressure rollers on draw rollers
90	0.5	2.0	inspect condition of drive gears on draw rollers
30	1	12.2	inspect condition of draw roller drive belt and idlers (2)
30	1	12.2	inspect condition of clutch disc, armature, stator - also check gap 0.015
30	0.5	6.1	inspect condition of wires on proximity switches
90	1	4.1	inspect condition of push rod linear bearings and cam follower bearings
90	0.5	2.0	inspect air regulator, solenoids, gauges
30	1	12.2	check for "slop" in output of draw roller disco
90	1	4.1	inspect condition of brass block for head assembly
14	0.5	13.0	inspect level of Teflon curtain (upper/lower)
30	1	12.2	inspect gears for conveyor assembly and clamp arm
90	0.5	2.0	inspect counters, all switches and gauges
30	0.5	6.1	inspect condition of conveyor belt
14	0.5	13.0	check for "unusual" noises from main drive motor and the two disco's
30	1	12.2	inspect condition of main drive chain and sprockets
30	1	12.2	inspect condition of machine speed disco drive belt
30	0.5	6.1	check oil levels in disco and grease main crank bearings and jack shaft bearings
30	0.5	6.1	inspect two flex couplers on main motor for slop
90	2	8.1	replace lower Teflon curtain pan screws
90	1	4.1	inspect: condition of lower clamping jaw - rubber, cam following bearings, fram for cracks
14	1.5	39.1	clean plastic out from under machine by main drive
30	1	12.2	inspect flying knife gear box (loose shafts, bad pulleys, low oil, bad flex couplings, and drive shaft
30	1	12.2	inspect flying knife gear box and idlers

Converting 2
PM Checklist

30	0.5	6.1	inspect flying knife belt and blade holder
30	2	24.3	inspect/clean nichrome wire for both upper and lower head
30	2	24.3	inspect knife drive pulley and idler pulley on head
30	1	12.2	inspect condition of brake assembly and gap 0.015
90	2	8.1	inspect draw roller bearings
120	0.5	1.5	inspect bearings on dancer pivot shaft
90	2	8.1	inspect air fingers for plugged tips
	Total Hours	364.8	
	Working hours per day	1.4	

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Converting 4
PM Checklist

Frequency (days)	Approximate Time for Repair (hours)	Total Repair hours	Description
30	0.5	6.1	check capstan pressure roller for free turning
14	0.5	13.0	inspect level of Teflon curtain - upper/lower
90	1	4.1	inspect counters, all switches and gauges for proper working condition
30	0.5	6.1	check idler rollers for free movement
90	0.5	2.0	check for "slop" in output of draw roller disco
90	0.5	2.0	inspect: condition of brass block for head assembly
30	2	24.3	inspect condition of upper/lower pressure rollers on draw rollers
30	1	12.2	inspect condition of drive gears on draw
30	0.5	6.1	inspect condition of draw roller drive belt and idlers (2)
30	1	12.2	inspect condition of clutch disc, armature, stator and check gap (0.015)
90	2	8.1	inspect condition of push rod linear bearing and cam follower bearings
90	0.5	2.0	inspect air regulator, solenoids and gauges for proper working condition
30	1	12.2	inspect condition of capstan drive belt, pulleys and idler
30	0.5	6.1	check capstan roller for free turning
14	0.5	13.0	check for "unusual" noises from main drive motor and the two discos
30	1	12.2	inspect condition of main drive chain and sprockets
30	1	12.2	inspect condition of machine speed disco drive belt
30	0.5	6.1	inspect oil levels in disco and grease main crank bearings and jack shaft bearings
90	2	8.1	replace lower Teflon curtain pan screw (set screw T-nut)
90	2	8.1	inspect condition of lower clamping jaw - rubber, cam follower bearings, frame for

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Converting 4
PM Checklist

14	1	26.1	clean plastic out from under machine by main drive
30	0.5	6.1	inspect flying knife gearbox (loose shafts, bad pulleys, low oil, bad flex couplings) and drive shaft
30	1	12.2	inspect flying knife gearbox drive belt and
30	0.5	6.1	inspect flying knife belt and blade holder
30	2	24.3	inspect/clean nichrome wire - upper;lower
30	2	24.3	inspect knife drive pulley and idler pulley on
30	1	12.2	inspect condition of brake assembly - gap to 0.015
90	2	8.1	inspect draw roller bearings
120	0.5	1.5	inspect bearings on dancer pivot shaft
30	2	24.3	inspect air fingers for plugged tips - clean as necessary
	Total hours	321.3	
	working hours per day	1.2	

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Converting 5
PM Checklist

Frequency (days)	Approximate Time for Repair (hours)	Total Repair hours	Description
30	1	12.2	inspect condition of capstan drive belt, pulleys and idler
30	0.5	6.1	check for free turning of capstan roller
30	0.5	6.1	check for free turning of capstan pressure
30	0.5	6.1	check for free movement of idler rollers (20)
30	2	24.3	inspect condition of upper/lower pressure rollers on draw rollers
90	0.5	2.0	inspect condition of drive gears on draw
30	1	12.2	inspect condition of draw roller drive belt and idlers (2)
30	1	12.2	inspect condition of clutch disc, armature and stator - also check gap .015
30	0.5	6.1	check condition of wires on proximity switch
90	1	4.1	inspect condition of push rod linear bearings and cam follower bearings
90	0.5	2.0	inspect air regulator, solendoids and gauges for proper working condition
30	1	12.2	check for slop in output of draw roller disco
90	1	4.1	inspect condition of brass block for head assembly
14	0.5	13.0	check level of Teflon curtain - top/bottom
90	0.5	2.0	inspect counter, all switches and gauges for proper working condition
30	0.5	6.1	inspect condition of conveyor belt
14	0.5	13.0	check for "unusual" noises from main drive motor and the two discos
30	1	12.2	inspect condition of main drive chain and sprockets
30	1	12.2	inspect condition of machine speed disco drive belt
30	0.5	6.1	check oil levels in disco, grease main crank bearings and jack shaft bearings
90	2	8.1	replace lower Teflon curtain pan screw (set T-nut)

Converting 5
PM Checklist

90	1	4.1	inspect condition of lower clamping jaw - rubber, cam follower bearings, frame for
14	1.5	39.1	clean plastic out from under machine by main drive
30	1	12.2	inspect flying knife gearbox (loose shafts, bad pulleys, low oil), bad flex couplings and drive shaft
30	1	12.2	inspect flying knife gearbox drive belt and
30	0.5	6.1	inspect flying knife belt and blade holder
30	2	24.3	inspect and clean nichrome wire for both upper and lower heads
30	2	24.3	inspect knife drive pulley and idler pulley on head
30	1	12.2	inspect condition of brake assembly and gap 0.015
90	2	8.1	inspect draw roller bearings
120	0.5	1.5	inspect bearings on dancer pivot shaft
90	2	8.1	inspect air fingers for plugged tips
	Total	334.4	
	working hours per day	1.3	

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Converting 8
PM Checklist

Frequency (days)	Repair Time (hours)	Total Repair hours	Description
90	1	4.1	check cooling fan for the clutch/brake assembly for proper
90	2	8.1	check the clutch and brake brushes on the draw rollers to make certain they are not broken or worn out
30	0.25	3.0	check for broken/frayed wires on the electric eye assembly
90	0.75	3.0	check idler rollers (behind the draw rollers) to keep them "free spinning"
7	0.25	13.0	Drain water trap on air line to the machine
90	0.5	2.0	check speed pot for the capstan drive roller is in good conditions, replace if needed
30	0.25	3.0	grease the rubber drive roller above the capstan drive and check the bearings for slop and wear
90	0.5	2.0	check bearings on capstan drive roller assembly. Check that pressure roller moves up/down freely
60	1.5	9.1	check crank and pinion assembly for slop; check the adjusting screw/star nut for "slop" as well
180	1.5	3.0	check condition of cam follower bearings on main cam
30	0.25	3.0	check the condition of the chains and sprockets of the teflon
90	1.5	6.1	check the main DC drive brushes, replace if needed
90	1	4.1	check main motor brak assy for badly worn armature or broken or worn out springs
90	0.5	2.0	add oil to the chain oiler by the main crank assy
180	0.5	1.0	check the brushes on the capstan drive roller, replace if needed
90	0.5	2.0	check gears on electro cams
	Total hours	68.8	
	Working hours per day	0.3	

Converting 11
PM Checklist

Frequency (days)	Repair Time (hours)	Total Repair hours	Description
90	1	4.1	inspect: check cooling fan for the clutch/brake for proper working condition
90	0.75	3.0	inspect: check idler rollers (behind the draw rollers) to keep them "free spinning"
60	1.5	9.1	inspect: check crank and pinion assembly for slop; check the adjusting screw/star nut for slop
7	0.25	13.0	inspect: drain water trap on air line to the machine
90	0.5	2.0	check gears on electro cams
90	0.5	2.0	check speed pot for the capstan drive roller is in good condition, replace if needed
30	0.25	3.0	grease the rubber drive roller above the capstan drive and check the bearings for slop and wear
90	2	8.1	check the clutch and brake brushes on the draw rollers to make certain that they are not broken or worn out
90	0.5	2.0	check bearings on capstan drive roller assembly. Check that pressure roller moves up/down freely
30	0.25	3.0	check for broken frayed wires on the electric eye assembly
180	1.5	3.0	check condition of cam follower bearings on main cam
30	0.25	3.0	check the condition of the sprocket and chain
90	1.5	6.1	check the main DC drive brushes, replace if needed
90	0.5	2.0	add oil to the chain oiler in the crank housing
90	1	4.1	check main motor brake assy for badly worn armature or broken or worn out springs
180	0.5	1.0	check the brushes on the capstan drive roller, replace if needed
	Total hours	68.8	
	Working hours per day	0.3	

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PM Economic Calculations

Line 19

Yearly Scrap Production = 189,000 lb/yr

% of Scrap due to equipment failure = 23

Yearly Scrap Production due to equipment = (0.235) (189,000 lb/yr)
= 44,000 lb/yr

Adding a PM program should eliminate 70% of the breakdowns that occur

Scrap reduced from PM = (0.7) (44,000 lb/yr)
= $\boxed{31,000 \text{ lb/yr}}$

Raw Material Cost = (0.315)($0.495/lb) + (0.315)($0.525/lb)
(Recipe 1032) + (0.12)($1.10/lb) + (0.25) ($0.10/lb)
= $0.478/lb

This formulation uses 31.5% LLDPE, 31.5% 1037
12% MB and 25% Repro

costs:

LLDPE	$0.495/lb
1037	$ 0.525/lb
MB	$ 1.10/lb
Repro	$ 0.10/lb

Raw Material Savings = (31,000 lb/yr)($0.478/lb)
= $\boxed{\$15,000/\text{yr}}$

Labor Savings = (31,000 lb/yr)/(550 lb/hr) = 56 hrs
(56 hrs)($20.42/hr) = $\boxed{\$1,200/\text{yr}}$

** There are also costs associated with downtime of the equipment while it is being fixed, but no records exist that show the amount of downtime that has occurred due to equipment failure

Adding a PM program for extruder 19 would require 150 hours of Maintenance labor per year. However, the time spent on breakdowns should significantly decrease. Overall, fewer hours should be spent on maintenance once the program is in place. The hours currently spent on repairs are not known, so this savings cannot be found. It will be relatively small compared to scrap savings, though.

PM Savings

Extruder 1

Yearly Scrap Production = 50,000 lb/yr
Equipment related scrap = (0.25)(50,000 lb/yr)
= 12,500 lb/yr
Scrap reduced from PM = (0.7)(12,500 lb/yr)
= $\boxed{8750 \text{ lb/yr}}$

Raw Material Savings = (8750 lb/yr)($0.478/lb)
= $\boxed{\$4{,}200/\text{yr}}$

$$\text{Labor Savings} = \frac{8750 \text{ lb/yr}}{300 \text{ lb/hr}} = 30 \text{ hrs/yr}$$

$$30 \frac{\text{hrs}}{\text{yr}} \left(\$18.39/\text{hr}\right) = \boxed{\$540/\text{yr}}$$

Extruders 3,4,6

Yearly Scrap Production = 27,000 lb/yr
Equipment related scrap = (0.25)(27,000 lb/yr)
= 6800 lb/yr
Scrap Reduced from PM = (0.7)(6,800 lb/yr)
= $\boxed{4{,}700 \text{ lb/yr}}$

Raw Material Savings = (0.478)(4,700 lb/yr)
= $\boxed{\$2{,}300/\text{yr}}$

Labor Savings = (4,700 lb/yr) / (100 lb/yr) = 47 hrs
47 hrs ($10.65/hr) = $\boxed{\$500/\text{yr}}$

Extruders 5,7,8

Yearly Scrap Production = 7,700 lb/yr
Equipment related Scrap = (0.25)(7,700 lb/yr)
= 1,900 lb/yr
Scrap reduced from PM = (0.7)(1,900 lb/yr)
= $\boxed{1300 \text{ lb/yr}}$

Raw Material Savings = (\$0.478/lb)(1300 lb/yr)
= $\boxed{\$600/\text{yr}}$

Labor Savings = (1300 lb/yr) / (45 lb/hr) = 29 hrs

(29 hrs)(\$10.65/hr) = $\boxed{\$300/\text{yr}}$

Extruder 18

Yearly Scrap Production = 34,000 lb/yr
Equipment related Scrap = 8,500 lb/yr
Scrap Reduced from PM = (0.7)(8500 lb/yr)
= $\boxed{6,000 \text{ lb/yr}}$

Raw Material Savings = (\$0.478/lb)(6000 lb/yr)
= $\boxed{\$2900/\text{yr}}$

Labor Savings = (6,000 lb/yr) / (180 lb/hr) = 33 hrs/yr

(33 hrs/yr)(\$18.39/hr) = $\boxed{\$600/\text{yr}}$

KÜNDIG CONTROL SYSTEMS

Measuring- and Control Systems for Blown Film Extrusion

Kundig International, Inc.
112 Overbrook Drive
P.O. Box 812904
Wellesley, MA 02482-0027, USA
Telephone (781) 235-8787
Facsimile (781) 431-7891
Email: sales@kundig-int.com
www.kundig-int.com

Cortec Advanced Films
410 East First Avenue
Cambridge, MN 55008
USA

Your ref.	Our ref.	Client No.	8630 Rüti ZH,
Ms Vincent	E/A. Keller/jb		July 12, 2002

Your inquiry

OFFER No. E-020469

Dear Ms Vincent

We thank you for your inquiry and are pleased to offer you as follows:

P1		**Width Measuring and control Unit for FE-7** consisting of: detail Page 2	USD	12'912.00
		Options		
P1.5	1	**Thickness sensor Type FE-7** to measure in the collapsing frame, for connection to above width control system	USD	11'915.00
P1.6	1	**Thickness sensor Type K-100** including automatic diameter adjustment, to measure on the cylindric bubble, for connection to above width control system	USD	20'111.00
Option **P2**		**Process control system** consisting of: detail Page 2	USD	14'133.00

Delivery	6-8 weeks
Dispatch	as per your instructions
Conditions	ex Boston
Payment	Within 30 days net, date of invoice
Validity of this offer	3 months

Otherwise according to our „General conditions of sale and delivery“ and „Definition of the extent of the delivery“.

Yours faithfully

HCH. KÜNDIG & CIE. AG

Cortec Advanced Films, Cambridge, MN 55008, USA

July 12, 2002

OFFER No. E-020469

P1		**Width Measuring and control Unit for FE-7** consisting of:	
P1.1	1	**Measuring bar** with measuring range up to 106", total length 119.7", incl. amplifier (MBI) with 4 ft. connection cable to measuring bar, mains supply 100 - 240 V, 50/60 Hz	6'766.00
P1.2	1	**Control Unit FE-7** Alphanumeric display for width, actual and average value, 12 h trend, alarm outputs programmable for target +/- deviation, outputs 24 V=, max. 300mA, mains supply 100 - 240 V, 50/60 Hz	3'083.00
P1.3	1	**Connection cable** MBI - control unit, 30 m / 98 ft	277.00
P1.4	1	**BLOWAIR** air regulation unit for continous rotating dies, for inflation and deflation, controlled by the control unit FE-7, incl. radio remote control	2'786.00
		TOTAL NET-PRICE	**USD 12'912.00**

Option

P2		**Process control system** consisting of:	
P2.1	1	**FILM-CONTROLLER** Process control system for film width and thickness for 1 - 4 lines: recording system for blown film extrusion. Produces reel reports with width and thickness trend, displays thickness profiles continuously oriented to the die bolts and registrates operator intervention. Cabinet 19" rack including 17" screen, drawer with printer, computer Pentium and keyboard H = 2100 mm, W = 620 mm, L = 620 mm (H = 82,6 inch, W = 24,4 inch, L = 24,4 inch) incl. connection module of 1st line	
		TOTAL NET-PRICE	**USD 14'133.00**

Water Usage

Year	Month Received	Month Used	Gallons	Water Price	Sewer Price	$/gal water	$/gal sewer
2001	July	May	55835	203.50	483.55	0.0036	0.0087
2001	August	June	50005	194.26	467.51	0.0039	0.0093
2001	September	July	50000	194.25	467.50	0.0039	0.0094
2001	October	August	50000	194.25	467.50	0.0039	0.0094
2001	November	Septemeber	304775	726.28	1168.13	0.0024	0.0038
2001	December	October					
2002	January	November	578135	1300.33	1919.87	0.0022	0.0033
2002	February	December	500005	1139.26	1705.01	0.0023	0.0034
2002	March	January	500000	1181.95	1766.25	0.0024	0.0035
2002	April	February	500000	1181.95	1766.25	0.0024	0.0035
2002	May	March	500000	1181.95	1766.25	0.0024	0.0035

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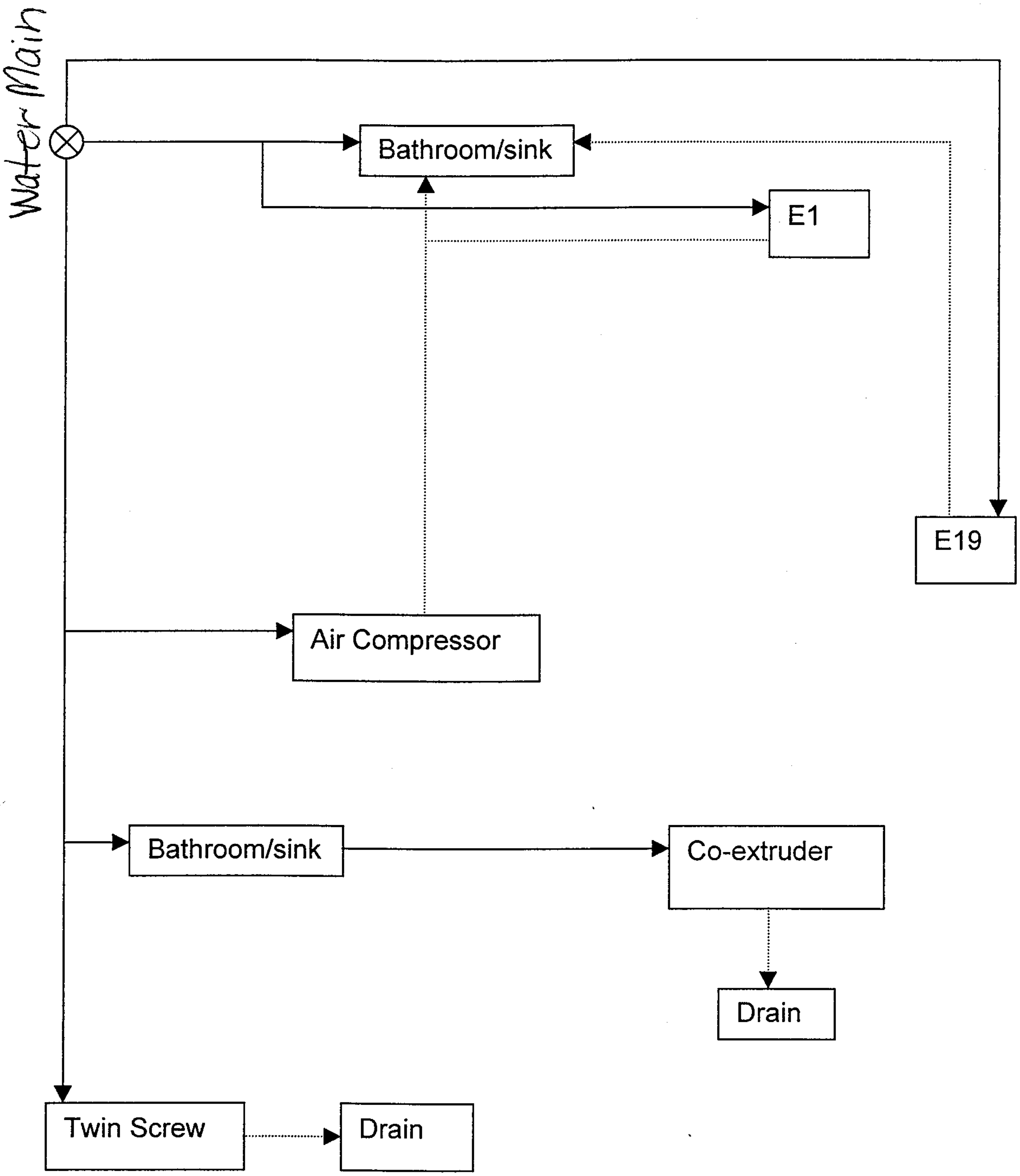
	Date	Time	Meter Reading (gallons)	Equipment in Use	
M	6/10/02	3:00 pm	9670770	air compressor 2	
T	6/11/02	8:30 am	9671610	air compressor 2, EX 3-8, EX1 for a couple of hours	
	6/11/02	3:00pm	9672990	↓ ↓ ↓	
	6/12/02	8:30am	9679540	↓ ↓ ↓ EX19 started @ 4:30 on 6/11	
W	6/12/02	3:00pm	9682410	↓ ↓ ↓ ↓ (off + on)	
	6/13/02	8:30 am	9689940	↓ ↓ ↓ EX20 started	(19 off)
Th	6/13/02	3:00pm	9693130	↓ ↓ ↓ ↓	
M	6/17/02	8:30am	9705760	no extruders operating; air compressors	
	6/17/02	3:20pm	9707170	no extruders operating; air compressors	* extruders started on night shift
T	6/18/02	8:30 am	9710420	air compressors, extruders 4, 6, 7	
	6/18/02	3:00pm	9713950	Extruders 18, 4, 6, 7, 20; air compressors; extruders 1 + 19 (late afternoon)	
W	6/19/02	8:30 am	9722910	All extruders using water; air compressors	
	6/19/02	3:00 pm	9726740	All " " " " washing floors cleaning	
Th	6/20/02	8:30 am	9736140	extruders 1, 19, 20; air compressors	
	6/20/02	3:00pm	9740440	extruders 1, 19, 20; air compressors	
M	7/1/02	8:30 am	9817630	no equipment running	
	7/1/02	4:30 pm	9821480	co-extruder, E1, E19, compressor	
T	7/2/02	8:30am	9830480	" " " " "	
	7/2/02	3:30pm	9835180	coextruder, E1, E19, compressor	
W	7/3/02	8:30am	9844440	E1, E19, co-extruder, air compressor	
	7/3/02	4:00pm	9845860	air compressor	
M	7/8/02	8:30am	9850210	air compressor	
	7/8/02	3:30pm	9852430	air compressor, E1, E19	

E1 ...filling running

	Date	Time	Meter Reading (gallons)	Equipment in Use
T	7/9/02	8:00am	9862000	air compressor, E1, E19, E20
	7/9/02	3:00pm	9866830	air compressor, E1, E19, E20
W	7/10/02	9:30am	9878040	air compressor, E1, E19, E20
	~~7/10/02~~		~~9894370~~	~~air compressor,~~
Th	7/11/02	9:30am	9894310	air compressor, E1, E19, E20
	7/11/02	4:15pm	9897960	air compressor (shut off at ~3:00pm)
M	7/15/02	5:15pm	9906130	air compressor, E1, E19, E20
T	7/16/02	10:00am	9917450	air compressor, E1, E19, E20
W	7/17/02	10:00am	9930640	air compressor, E1, E19, E20
	7/17/02	4:00pm	9934650	air compressor, E1, E19, E20
Th	7/18/02	2:00pm	9949600	" "
Th	7/25/02	3:00pm	0003820	" "
~~Th~~	~~8/08/02~~			~~" "~~



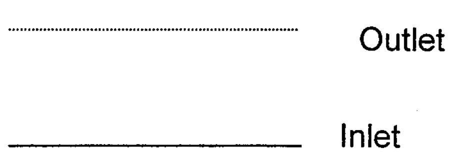


Figure 5
This figure shows the water flow throughout the plant

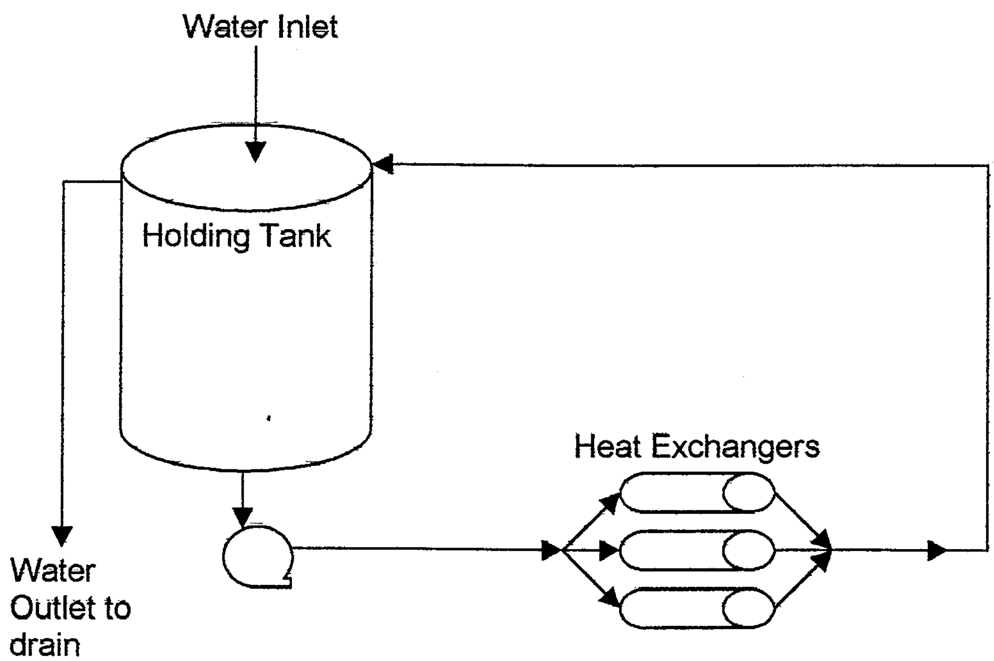


Figure 6
This figure shows the water flow through the heat exchangers that are used to cool the co-extruder.

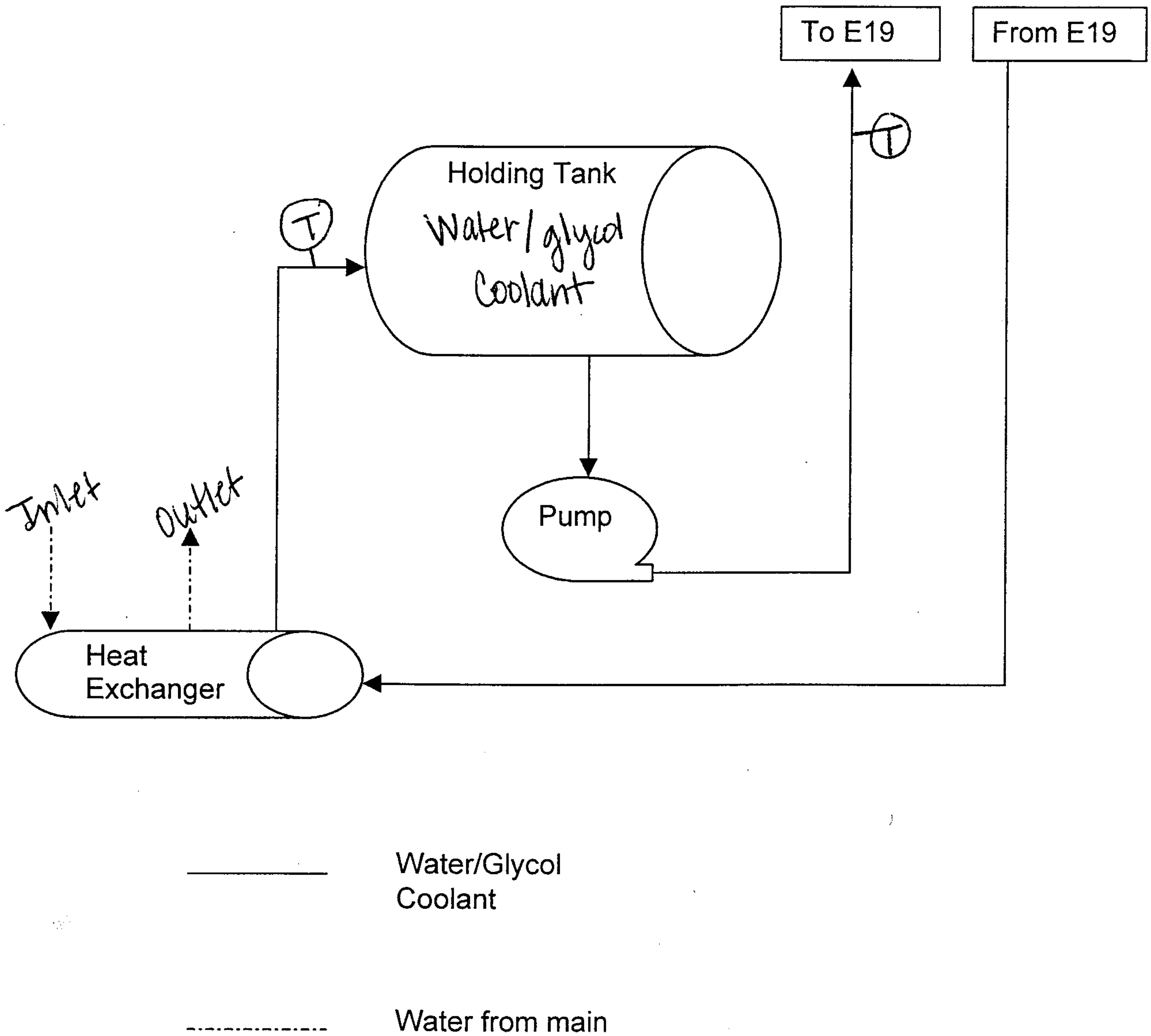


Figure 7
This figure shows the water flow for extruder 19 (E19).

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Water Flow Measurements

Air Compressor

6/11/02

Volume	Time
0.5 gallons	1 min

$$\text{volumetric flow rate} = \left(\frac{0.5\ \text{gal}}{1\ \text{min}}\right)\left(\frac{60\ \text{min}}{1\ \text{hr}}\right) = \boxed{30\ \frac{\text{gal}}{\text{hr}}}$$

Operating 24 hours a day, 31 days per month
$22,320\ \frac{\text{gal}}{\text{month}}$

6/18/02

Total Weight (lb)	Tare (lb)	Time (min)
6.8	1.4	1

$$\left(\frac{6.8\ \text{lb} - 1.4\ \text{lb}}{1\ \text{min}}\right)\left(\frac{60\ \text{min}}{1\ \text{hr}}\right)\left(\frac{1\ ft^3}{62.4\ \text{lb}}\right)\left(\frac{7.48\ \text{gal}}{1\ ft^3}\right) = \boxed{39\ \frac{\text{gal}}{\text{hr}}}$$

Operating 24 hours a day, 31 days per month
29,016 gal/month

** Couldn't get 3 measurements because had to take pipes apart

$$\boxed{\text{Average flow rate} = 35\ \text{gal/hr} = 26{,}040\ \text{gal/month}}$$

$\boxed{\text{Co-extruder}}$

Run	Time (min) (+/-0.1)	Total Weight (± 0.1 lb)	Tare (±0.
1	1.0	19.3	2.1
2	0.5	9.8	0.8
3	0.5	9.6	0.8

Run 1

$$\text{mass flow rate} = \frac{(19.3\ \text{lb} - 2.1\ \text{lb})}{1\text{min}} = 17.1\ \text{lb/min}$$

$$\text{volumetric flow rate} = \left(\frac{17.1\ \text{lb}}{\text{min}}\right)\left(\frac{1\ \text{ft}^3}{62.4\ \text{lb}}\right)\left(\frac{7.48\ \text{gal}}{1\ \text{ft}^3}\right)\left(\frac{60\ \text{min}}{1\ \text{hr}}\right)$$

$$= \boxed{122\ \frac{\text{gal}}{\text{hr}}}$$

Run 2

$$\text{mass flow rate} = \frac{(9.8\ \text{lb} - 0.8\ \text{lb})}{0.5\ \text{min}} = 18.0\ \text{lb/min}$$

$$\text{volumetric flow rate} = \left(\frac{18.0\ \text{lb}}{\text{min}}\right)\left(\frac{1\ \text{ft}^3}{62.4\ \text{lb}}\right)\left(\frac{7.48\ \text{gal}}{1\ \text{ft}^3}\right)\left(\frac{60\ \text{min}}{1\ \text{hr}}\right)$$

$$= \boxed{130\ \frac{\text{gal}}{\text{hr}}}$$

Run 3

$$\text{mass flow rate} = \frac{9.6\ \text{lb} - 0.8\ \text{lb}}{0.5\ \text{min}} = 17.6\ \text{lb/min}$$

$$\text{volumetric flow rate} = \left(\frac{17.6\ \text{lb}}{\text{min}}\right)\left(\frac{1\ \text{ft}^3}{62.4\ \text{lb}}\right)\left(\frac{7.48\ \text{gal}}{1\ \text{ft}^3}\right)\left(\frac{60\ \text{min}}{\text{hr}}\right)$$

$$= \boxed{126\ \text{gal/hr}}$$

$\boxed{\text{Average flow rate} = 126\ \text{gal/hr}}$

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Water Measurements from E19

Time	Weight (lb)	Tare (lb)	Outlet Temp (°F)
30 s	15.2	1.5	105
30 s	15.7	1.5	99.2
30 s	15.9	1.5	98.6

Inlet temperature of water is estimated at 50°F. It comes directly from the main ~~drain~~ water supply. (Cold water coming from sink was 52°F)

Run 1

$$\left(\frac{15.2\ \text{lb} - 1.5\ \text{lb}}{30\text{s}}\right)\left(\frac{60\text{s}}{1\text{min}}\right) = 21.4\ \text{lb/min}$$

$$\left(\frac{27.4\ \text{lb/min}}{62.4\ \text{lb/ft}^3}\right)\left(\frac{7.48\ \text{gal}}{1\ \text{ft}^3}\right)\left(\frac{60\ \text{min}}{1\text{hr}}\right) = \boxed{197\ \frac{\text{gal}}{\text{hr}}}$$

Run 2

$$\left(\frac{(15.7\ \text{lb} - 1.5\ \text{lb})}{30\text{s}}\right)\left(\frac{60\text{s}}{1\text{min}}\right) = 28.4\ \text{lb/min}$$

$$\left(\frac{28.4\ \text{lb/min}}{62.4\ \text{lb/ft}^3}\right)\left(\frac{7.48\ \text{gal}}{1\ \text{ft}^3}\right)\left(\frac{60\ \text{min}}{1\text{hr}}\right) = \boxed{204\ \frac{\text{gal}}{\text{hr}}}$$

Run 3

$$\left(\frac{(15.9\ \text{lb} - 1.5\ \text{lb})}{30\text{s}}\right)\left(60\text{s}/1\text{min}\right) = 28.8\ \text{lb/min}$$

$$\left(\frac{28.8\ \text{lb/min}}{62.4\ \text{lb/ft}^3}\right)\left(\frac{7.48\ \text{gal}}{1\ \text{ft}^3}\right)\left(\frac{60\text{min}}{1\text{hr}}\right) = \boxed{207\ \frac{\text{gal}}{\text{hr}}}$$

$$\boxed{\text{Average flow rate} = 203\ \frac{\text{gal}}{\text{hr}}}$$

Water/Glycol Mixture Measurements

Flow Meter Reading = 14 gal/min

Temperature of Copper pipe at inlet to heat exchanger = 115°F

Temperature of copper pipe at outlet of heat exchanger = 96°F

Actual temperature of mixture at outlet to heat exchanger = 101°F (thermocouple measurement

Extruder 1, Extruder 19 and Compressor (combined)

flows into sink 18" x 18"

Run	Time	Height
1	1 min	3.75"
2	1 min	3.80"
3	1 min	3.90"

Run 1

$$\text{Volume} = (18")(18")(3.75") = 1215 \text{ in}^3$$

$$\text{volumetric flow rate} = \left(\frac{1215 \text{ in}^3}{1 \text{ min}}\right)\left(\frac{1 \text{ ft}}{12 \text{ in}}\right)^3\left(\frac{7.48 \text{ gal}}{1 \text{ ft}^3}\right)\left(\frac{60 \text{ min}}{1 \text{ hr}}\right)$$

$$= \boxed{316 \text{ gal/hr}}$$

Run 2

$$\text{volume} = (18")(18")(3.8") = 1231 \text{ in}^3$$

$$\text{volumetric flow rate} = \left(\frac{1231 \text{ in}^3}{1 \text{ min}}\right)\left(\frac{1 \text{ ft}}{12 \text{ in}}\right)^3\left(\frac{7.48 \text{ gal}}{1 \text{ ft}^3}\right)\left(\frac{60 \text{ min}}{1 \text{ hr}}\right)$$

$$= \boxed{320 \text{ gal/hr}}$$

Run 3

$$\text{volume} = (18")(18")(3.9") = 1264 \text{ in}^3$$

$$\text{volumetric flow rate} = \left(\frac{1264 \text{ in}^3}{1 \text{ min}}\right)\left(\frac{1 \text{ ft}}{12 \text{ in}}\right)^3\left(\frac{7.48 \text{ gal}}{1 \text{ ft}^3}\right)\left(\frac{60 \text{ min}}{1 \text{ hr}}\right)$$

$$= \boxed{328 \text{ gal/hr}}$$

$\boxed{\text{Average} = 321 \text{ gal/hr}}$

Extruder 1

$$\text{volumetric flow rate from E1} = \text{Combined flow rate} - \text{flow rate from air compressor} - \text{flow rate from E19}$$

$$= 321 \frac{\text{gal}}{\text{hr}} - 35 \frac{\text{gal}}{\text{hr}} - 203 \text{ gal/hr}$$

$$= \boxed{183 \text{ gal/hr}}$$

Extruder 1

Estimated inlet temperature = 50°F
Measured outlet temperature = 57°F

Water is used to cool feed throat of the extruder. It must stay below 198°F, which is the melting point of polyethylene.

Overall Material Balance

Monthly Water Readings

7/10/02	6/10/02
9878040 gal	9670770 gal

Monthly Usage = 9878040 gal − 9670770 gal
$= 207{,}270 \frac{gal}{month}$

Monthly Usage

Air Compressor

- Operates 24 hours/day, 31 days/month

$$35 \frac{gal}{hr}\left(\frac{24\ hrs}{day}\right)\left(\frac{31\ days}{month}\right) = \boxed{26{,}040 \frac{gal}{mont}}$$

E1

- Operates 24 hours/day, 3.5 days/week, 4 weeks/mont

$$83 \frac{gal}{hr}\left(\frac{24\ hrs}{day}\right)\left(\frac{3.5\ days}{week}\right)\left(\frac{4\ weeks}{month}\right) = \boxed{27{,}888 \frac{ga}{mo}}$$

E19

- Operates 24 hours/day, 3.5 days/week, 4 week/m

$$203 \frac{gal}{hr}\left(\frac{24\ hrs}{day}\right)\left(\frac{3.5\ days}{week}\right)\left(\frac{4\ weeks}{month}\right) = \boxed{68{,}208 \frac{g}{mo}}$$

Co-extruder

- Operates 24 hours/day, 3.5 days/week, 4 weeks/mon

$$126 \frac{gal}{hr}\left(\frac{24\ hrs}{day}\right)\left(\frac{3.5\ days}{week}\right)\left(\frac{4\ weeks}{month}\right) = \boxed{42{,}33 \frac{gal}{mont}}$$

Employee Use (estimate of 20 gal/day person)

$$20 \frac{gal}{day \cdot person}(30\ people)\left(\frac{31\ days}{month}\right) = \boxed{18{,}600 \frac{gal}{month}}$$

Other Uses: lab, cleaning, twin screw

Estimate for lab use, cleaning, twin screw $= 207{,}270 \frac{gal}{month} - 26{,}040 \frac{gal}{mon} - 27{,}888 \frac{gal}{mon} - 68{,}200 \frac{gal}{mon} - 42{,}336 \frac{gal}{mon} - 18{,}600 \frac{gal}{mo}$

$= 24{,}198 \frac{gal}{month}$

* This is reasonable, so material balance checks out

Estimates Used Based on Measurements

Source	Usage (gal/month)	Water Cost ($\frac{\$0.0024}{gal}$) ($/month)	Sewer ($0.0035/gal) ($/month)
Air Compressor	26,000	62.40	91.00
E1	28,000	67.20	98.00
E19	68,000	163.20	238.00
Co-extruder	42,000	100.80	147.00
Employee	19,000	45.60	66.50
Other	24,000	57.60	84.00
Total	207,000	496.80	724.50

Yearly Water Costs

Source	Total Yearly Cost ($)
Air Compressor	1840.80
E1	1982.40
E19	4814.40
Co-extruder	2973.60
Employee	1345.20
Other	1699.20

Reduction Options

1) Reduce Water flow from air compressor to 3.5 days/week
Currently, water flows continuously to the air compressor even thought it is only in operation for 3.5 days per week.

$$\text{Reduced Flow} = 35\,\frac{\text{gal}}{\text{hr}}\left(\frac{24\text{ hrs}}{\text{day}}\right)\left(\frac{3.5\text{ days}}{\text{week}}\right)\left(\frac{4\text{ weeks}}{\text{month}}\right)$$

$$= 12{,}000\ \text{gal}/\text{month}$$

$$\text{Water Savings} = 26{,}000\ \text{gal/mon} - 12{,}000\ \text{gal/mon}$$

$$= \boxed{14{,}000\ \text{gal}/\text{month}}$$

$$\text{Cost Savings} = 14{,}000\,\frac{\text{gal}}{\text{month}}\left(\frac{\$0.0024}{\text{gal}}\right) + 14{,}000\,\frac{\text{gal}}{\text{month}}\left(\frac{\$0.0035}{\text{gal}}\right)$$

$$= \$83/\text{month}$$

$$= \boxed{\$1000/\text{year}}$$

Cost of value $\cong \$100$

$$\text{Payback} = \frac{\$100}{1000/\text{yr}} = 0.1\ \text{year}$$

$\sim$ 2 months

2) Use exit water from E19 to cool E1

<u>Heat removed from E1</u>

$$T_{in} = 50°F = 283\,K$$
$$T_{out} = 57°F = 287\,K$$
$$m = \text{mass flow rate} = 83\,\frac{gal}{hr}\left(\frac{1\,ft^3}{7.48\,gal}\right)\left(\frac{62.4\,lb}{ft^3}\right) = 692\,\frac{lb}{hr}$$
$$= 314\,\frac{kg}{hr}$$

$$Q = m\,C_p\,(T_{out} - T_{in})$$
$$= \left(314\,\frac{kg}{hr}\right)\left(4.2\,kJ/kg\,K\right)(287K - 283K)$$
$$Q = 5275\,\frac{kJ}{hr}$$

If inlet temperature was changed to 100°F, (outlet temp from E19) the outlet temperat of the water would be:

$$T_{out} = \frac{Q}{m C_p} + T_{in}$$
$$T_{out} = \frac{(5275\,kJ/hr)}{\left(314\,\frac{kg}{hr}\right)(4.2\,kJ/kg\,K)} + 311\,K$$
$$T_{out} = 315\,K = 107°F$$
(keeping flow rate the same)

This would keep the feed through temperatu below 198°F, the melting temperature of the polyethylene.

$$\boxed{\text{Water Reduced} = 28{,}000\ gal/month}$$

Cost Savings $= 28{,}000\,\frac{gal}{month}\left(\frac{\$0.0024}{gal}\right) + 28{,}000\,\frac{gal}{month}\,(\$0.0c$

$= \$165.20/month = \boxed{\$2000/yr}$

Reduction Options (cont.)

)) Install a water cooling tower to close the loop on E19. The following calculations show how the specifications for the water cooling tower were found and the economics involved.

Heat Exchanger Specifications

$$\begin{array}{lcl} W\ T_W^{IN} \longrightarrow & \boxed{\quad\quad} & \longrightarrow T_W^{OUT}\ W \\ X\ T_X^{OUT} \longleftarrow & & \longleftarrow T_X^{IN}\ X \end{array}$$

variables: W = volumetric flow rate of water

X = volumetric flow rate of water/glycol mixture

T_W^{IN} = inlet water temperature

T_W^{OUT} = outlet water temperature

m_W = mass flow rate of water

m_X = mass flow rate of mixture

ρ_W = density of water

ρ_G = density of glycol

ρ_X = density of mixture

T_X^{IN} = mixture inlet temperature

T_X^{OUT} = mixture outlet temperature

Cp_W = heat capacity of water

Cp_G = heat capacity of glycol

Cp_X = heat capacity of mixture

$W = 200\ gal/hr = 0.76\ m^3/hr$

$m_W = 1700\ lb/hr = 770\ kg/hr$

$\rho_W = 62.4\ lb/ft^3 = 1000\ kg/m^3$

$Cp_W = 4.2\ \frac{kJ}{kg\,K}$

$X = 840\ gal/hr = 3.18\ m^3/hr$

$\rho_G = 1120\ kg/m^3$

$Cp_G = 2.42\ kJ/kg\,K$

$$\rho_x = 0.5\rho_G + 0.5\rho_w = (0.5)(1120\ kg/m^3) + (0.5)(1000\ kg/m^3)$$

$$\rho_x = 1060\ kg/m^3$$

$$m_x = \rho_x X = 3.18\ \frac{m^3}{hr}\ (1060\ kg/m^3)$$

$$m_x = 3400\ \frac{kg}{hr}$$

$$C_{p_x} = 0.5\,C_{p_G} + 0.5\,C_{p_w} = (0.5)(4.2\ kJ/kgK) + (0.5)(2.42\ kJ/kgK)$$

$$C_{p_x} = 3.31\ kJ/kg\,K$$

$$Q = m\,C_p\,\Delta T$$

$$T_w^{OUT} = 311K$$

$$T_w^{IN} = 283K$$

water: $Q_w = m_w C_{p_w}(T_w^{OUT} - T_w^{IN})$

$$Q_w = (770\ \frac{kg}{hr})(4.2\ \frac{kJ}{kgK})(311K - 283K)$$

$$Q_w = 90{,}000\ \frac{kJ}{hr}$$

mixture: $Q_x = m_x C_{p_x}(T_x^{IN} - T_x^{OUT})$

$$T_x^{OUT} = 312K$$

$$T_x^{IN} = 319K$$

$$Q_x = (3400\ \frac{kg}{hr})(3.31\ kJ/kgK)(319K - 312K)$$

$$Q_x = 79{,}000\ kJ/hr$$

* This number may be low because temperatures were approximated based on pipe temperatures

$$Q = UA\,\Delta T_{lm}$$

$$\Delta T_{lm} = \frac{\Delta T_L - \Delta T_R}{\ln(\Delta T_L/\Delta T_R)}$$

where $\Delta T_L = T_x^{IN} - T_w^{OUT}$

$\Delta T_R = T_x^{OUT} - T_w^{IN}$

$$\Delta T_{lm} = \frac{(319\,K - 311\,K) - (312\,K - 283\,K)}{\ln\left(\frac{(319\,K - 311\,K)}{(312\,K - 283\,K)}\right)} = 16.3\,K$$

$$UA = Q/\Delta T_{lm} = \frac{90{,}000\ kJ/hr}{16.3\,K} = 5510\ kJ/hr\cdot K$$

When installing a water-cooling tower, the inlet temperature to the heat exchanger will change from 50°F to 80°F (300. The flow rate must be increased as well, because 10 gal/min was the lowest flow rate I saw when researching towers. With these new inlet conditions, the new outlet conditions from the heat exchanger must be found to give the specifications of the water-cooling tower. I used Heat exchanger effectiveness to calculate this.

(Geankoplis, C.J. p.272-274)

$$m_w = \left(10\frac{gal}{min}\right)\left(\frac{1\,ft^3}{7.48\,gal}\right)\left(\frac{62.4\,lb}{ft^3}\right)\left(0.454\frac{kg}{lb}\right) = 37.9\ kg/min$$
$$= 2270\ kg/hr$$

$$C_{min} = m_w C_{p_w} = (2270\ kg/hr)(4.2\ kJ/kg\,K) = 9500\ kJ/hr\cdot K$$

$$C_{max} = m_x C_{p_x} = (3370\ kg/hr)(3.31\ kJ/kg\cdot K) = 11{,}000\ \frac{kJ}{hr\cdot K}$$

$$\varepsilon = \frac{1 - \exp\left[-\frac{UA}{C_{min}}\left(1 - \frac{C_{min}}{C_{max}}\right)\right]}{1 - \frac{C_{min}}{C_{max}}\exp\left[-\frac{UA}{C_{min}}\left(1 - \frac{C_{min}}{C_{max}}\right)\right]}$$

Assume: UA stays relatively constant

$$\varepsilon = \frac{1 - \exp\left[-\frac{5520}{9500}\left(1 - \frac{9500}{11000}\right)\right]}{1 - \frac{9500}{11000}\exp\left[-\frac{5520}{9500}\left(1 - \frac{9500}{11000}\right)\right]} = 0.38$$

$$Q = \varepsilon\, C_{min}\,(T_{Hi} - T_{ci})$$

where T_{Hi} = hot stream inlet temperature $= T_x^{IN} = 319K$

T_{ci} = cold stream inlet temperature $= T_w^{IN} = 300$

$$Q = (0.38)\left(9500\ \frac{kJ}{hr \cdot K}\right)(319K - 300K)$$

$$Q = 69,000\ \frac{kJ}{hr}$$

$$Q = C_{min}\,(T_w^{OUT} - T_w^{IN})$$

$$69,000\ \frac{kJ}{hr} = \left(9500\ \frac{kJ}{hr \cdot K}\right)(T_w^{OUT} - 300K)$$

$$T_w^{OUT} = 307\ K = 93^\circ F$$

Will this cool mixture?

$$Q = 69,000\ \frac{kJ}{hr} = C_{max}\,(T_x^{IN} - T_x^{OUT})$$

$$69,000\ \frac{kJ}{hr} = \left(11,000\ \frac{kJ}{hr \cdot K}\right)(319K - T_x^{OUT})$$

$T_x^{OUT} = 312.7\ K$ OK (very close to 312 previous outlet)

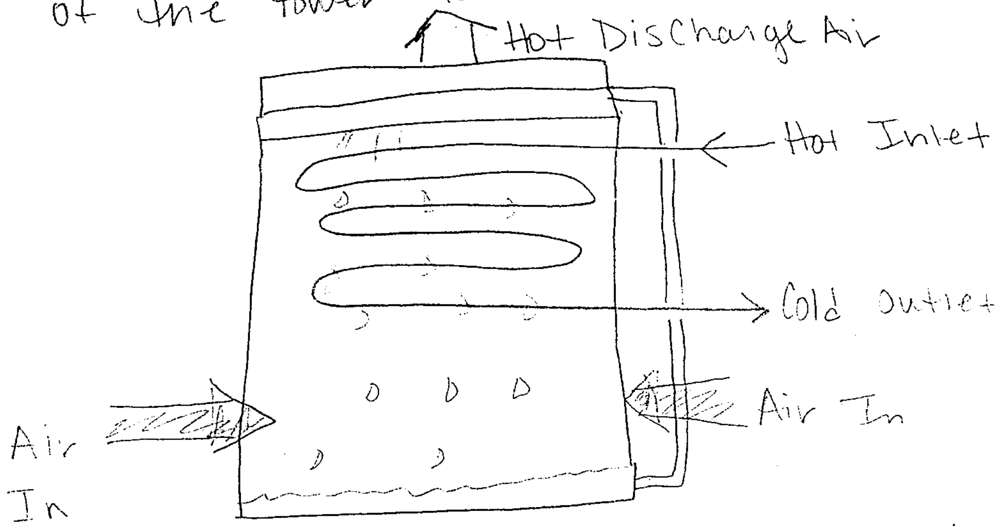
Water Cooling Tower Specifications:

cool 10 gal/min from ~95°F to 80°F and remove ~80,000 kJ/hr (1300 kW) of heat.

Water Cooling Economic Calculations

Quote from Systems H_2O: (Joe 1 800-888-[illegible] ext 22)

Use a water cooling tower to directly cool the water glycol mixture. The mixture would run through the tower in coils. Water is sprayed over the coils to cool the mixture. Air is fed through the bottom of the tower to cool the water.



* Cools 14 $\frac{gal}{min}$ of 50/50 mixture of water and glycol from 115°F to 100°F

Cost: $10-12,000

1-2 hp fan needed

½ gal/min of water needed to recoup evaporative loss

Water Cost $0.0024/gal water + $0.0035/gal sewer

$$\left(0.5\,\frac{gal}{min}\right)\left(\frac{60\,min}{hr}\right)\left(\frac{24\,hrs}{day}\right)\left(\frac{3.5\,days}{week}\right)\left(\frac{4\,weeks}{month}\right) = 10{,}080\ gal/month$$

$$\$ = \left(10{,}080\ \frac{gal}{month}\right)(\$0.0024/gal) + (10{,}080\ gal/month)\left(\$0.0035\,\frac{}{gal}\right)$$

$$\$ = \$59.47/month = \$714/year$$

Electricity Cost $\quad \$0.027 / kWhr$

$$(2 hp)\left(0.74570 \frac{kW}{hp}\right) = 1.4914 \ kW$$

$$\left(1.4914 \frac{kJ}{s}\right)\left(\frac{3600 s}{hr}\right) = 5370 \ kJ/hr$$

$$\left(5370 \frac{kJ}{hr}\right)\left(\frac{24 \ hrs}{day}\right)\left(\frac{3.5 \ days}{week}\right)\left(\frac{4 \ weeks}{month}\right) = 1,804,000 \ \frac{kJ}{month}$$

$$\left(1,804,000 \frac{kJ}{month}\right)\left(\frac{1 \ month}{31 \ days}\right)\left(\frac{1 \ day}{24 \ hrs}\right) = 2425 \ kWhr$$

$$(2425 \ kWhr)(\$0.027/kWhr) = \$65/month$$

$\$780/year$

Total electricity and water charges $= \$1494/yr$

Savings: $\$4800/yr$ in water charges

$$\text{Net Savings} = \$4800/yr - \$1500/yr = \$3300/yr$$

$$\text{Payback Period} = \frac{\$12,000}{\$3,300/yr} = 3.64 \text{ years}$$

* This is the highest it will be, the actual ~~tower~~ may cost less and use less electricity if a 1hp fan is needed.