MAKING THE RIGHT CHOICES:

Gear Pumps and Gravimetric Extrusion Control.

by

Daniel J. Smith
Regional Sales Manager

&

Dana G. Darley
Extrusion Product Manager

Luwa Corporation
Fluids Systems Division

4433 Chesapeake Drive
Charlotte, North Carolina 28297
(704) 394-8341

Presented at RETEC, COEX '89, Chicago, Illinois, October 23 - 25, 1989.

Introduction

Different technologies have been introduced over the last several years for the monitoring and control of extruder output deviations. These variations can be caused by a number of factors, including changes in die back pressure, screen pack condition, regrind levels, raw material densities and screw and barrel wear. The gear pump and various types of gauging systems have enjoyed widespread use in recent years, along with the relatively new Gravimetric Extrusion Control concept which is gaining acceptance both in North America and abroad. Since the goal of all these systems is primarily to control extruder output variations and to ultimately allow tighter control of product dimensional tolerances, how is the processor to know which method or combination of methods is best for his application?

Even though the technologies may at first appear to be in competition, each system promotes process stability by a different method, with each exhibiting distinct strengths and weaknesses. Assuming that the correct questions are asked about the application, a clear and intelligent choice can be made based on the unique circumstances of each application and without bias toward one method or the other. Although gauging systems will be mentioned, only the gear pump and the Gravimetric Extrusion Control system will be discussed in detail here. The first step in this analysis is to evaluate each of the above tools and develop a basic understanding of how each operates.

Gravimetric System Description

The Gravimetric Extrusion Control system continuously weighs and times extruder output, adjusting screw and/or line speed to achieve a constant output in pounds per hour and weight per unit length of the finished product. Since both are directly related to the dimensions of the extruded part, product tolerances can be effectively controlled, where variations are primarily the result of changes in output which occur over a period ranging from several minutes to several hours (see figures 1 & 2). A typical continuous gravimetric control system consists of a weigh hopper resting on load cells and a central computer (see figure 3). The hopper and its contents are continually weighed while the computer measures the weight loss over time which corresponds to extruder material consumption. The computer then compares these values to the set point and makes the appropriate adjustments to screw and/or line speed.

The greatest strength of the gravimetric system is its ability to easily distinguish and control the amount of material contribution of each extruder and the associated layer percentages by weight. These functions are easily performed by keying in the desired results, starting the line and allowing the gravimetric system to do the rest. The gravimetric system also effectively controls total weight per unit length, inventories all material used, and is capable of the gravimetric proportioning of additives. Its drawbacks are that it is not highly effective at controlling short term output fluctuations and has no ability to control or monitor transverse gauge variations.

Gauging systems utilize a number of principles including radioactive isotopes, ultrasonic waves, lasers, infrared rays or calipers to directly measure the dimensions of an extruded product. They are sometimes effective in controlling or at least monitoring both machine and transverse direction gauge. The main drawbacks of these devices are that gauging systems cannot typically distinguish between various layers in coextruded structures, and they can only make adjustments to screw and/or haul off equipment after the fact, and therefore are only capable of controlling long term fluctuations.

Gear Pump System Description

The gear pump in itself is a simple device consisting of a housing with two gears, one gear driving the other, and a shaft seal. As molten polymer enters the pump, it is entrapped by the gear teeth and transported to the discharge of the pump. As the gear teeth mesh, the polymer is forced from the gear roots creating a positive displacement effect and developing pressure as needed to overcome die restriction. The tight rotational clearances of the pump prevent the polymer from leaking back to the inlet side of the pump. The pump is able to almost perfectly isolate extruder output variations, both long and short term, from the die (see figure 4). A typical system includes a gear pump matched to the extruder size and output desired, a DC or AC variable speed drive system capable of a high resolution of motor/pump speed control and a control system designed to assure that the extruder and pump speeds are maintained in their proper relationship (see figure 5). The control system also includes necessary safety interlocks to protect both the equipment and the operator (see figure 6).

The greatest strength of the gear pump is its ability to control both long and short term extruder output within extremely tight tolerances. It does this effectively because the pump is located directly at the die and is highly efficient at filtering out extruder output fluctuations, due to its tight rotational clearances. Its main drawbacks are an inability to operate with materials that are highly degradable or abrasive and its inability to compensate for transverse direction variations. In multilayer structures it is often difficult to determine the percentage of layer contribution for each extruder because factors such as gear pump clearances, melt viscosities and, temperatures and pressures will affect gear pump output.

Neither the gravimetric nor the gear pump system is a "cure-all" for extrusion related problems; yet either properly applied system can be effective at resolution, or at least control of a particular problem. The payback for each of the systems is derived from material savings based on minimization of overweight/size product and elimination of downtime. The table below shows payback in dollars, based on a one percent savings over a 6000 hour year of production.

		Material Cost, Cents Per Pound								
		35	40	45	50	55	60	65	70	75
	200	4200	4800	5400	6000	6600	7200	7800	8400	9000
	250	5250	6000	6750	7500	8250	9000	10500	11250	12000
	300	6300	7200	8100	9000	9900	10800	11700	12600	13500
	350	7350	8400	9450	10500	11550	12600	13650	14700	15750
Output	400	8400	9600	10800	12000	13200	14400	15600	16800	18000
	450	9450	10800	12150	13500	14850	16200	17550	18900	20250
Lbs.	500	10500	12000	13500	15000	16500	18000	19500	21000	22500
	550	11550	13200	14850	16500	18150	19800	21450	23100	24750
Per	600	12600	14400	16200	18000	19800	21600	23400	25200	27000
	650	13650	15600	17550	19500	21450	23400	25350	27300	29250
Hour.	700	14700	16800	18900	21000	23100	25200	27300	29400	31500
	750	15750	18000	20250	22500	24750	27000	29250	31500	33750
	800	16800	19200	21600	24000	26400	28800	31200	33600	36000
	900	18900	21600	24300	27000	29700	32400	35100	37800	40500
	1000	21000	24000	27000	30000	33000	36000	39000	42000	45000

Application Examples

Example 1 - Coextruded Sheet

Two twin screw extruders were being used for the production of two layer rigid PVC sheet. The original line was not equipped with any kind of thickness gauge, gear pump or Gravimetric Extrusion Control system.

Problem

The primary problems to be addressed were the excessive variation in piece weight caused by long term drift in both of the twin screw extruders, due primarily to bulk density changes in the PVC compound, and the control of the more expensive cap layer. The weight per unit length of the product typically varied four to eight percent over the minimum target weight during the course of a production run. In this case a direct gauging system was ruled out due to the cost of the system and the difficulty of adjusting to the irregular surface of the finished product.

Solution

The gear pump was not a practical solution in this case because the rigid PVC compound is heavily filled with an abrasive calcium carbonate filler and is extremely sensitive to thermal degradation. The abrasive filler material would have decreased the life of the gear pump's internal parts and the thermal sensitivity of the compound could have caused degradation problems. Twin screw extruders are relatively good metering devices and short term output variation was not a problem.

Since direct gauging has been ruled out, a gravimetric control system offered the best solution. Gravimetric hoppers were mounted on each extruder starve feeder and the line speed was monitored. The output of both extruders was tied into the central control so that the rate and percentage contribution of each component and total product weight was computer controlled per unit length. The weight variation of the finished product was held within 2% of the minimum, resulting in a direct material savings of 2-6%. A similar savings also resulted from tighter control of the cap layer, which contributed to a payback of less than one year.

Example 2 - ABS/PVC Sheet Extrusion

A 6" and a 3 1/2" vented extruder was being used for the extrusion of sheet to be thermoformed into automotive dashboards. The line was equipped with a nuclear gauging system capable of adjusting haul-off speed to control machine direction gauge and adjusting the die bolts to control transverse direction gauge.

Problem

Large amounts, up to 60% of regrind material, were being added into the 6" extruder causing large swings in short term and long term gauge, due to the differences in bulk density and processing characteristics of the regrind versus the virgin material. The machine direction variation in the sheet was often as much as +/- 7%, causing not only an excessive use of material but a scrap rate at the thermoformer of up to 22%. This scrap rate was largely due to gauge variation in the sheet causing poor heating and forming.

Solution

A gear pump was applied to the 6" extruder between the screen pack and the die virtually eliminating both long and short term output variation. The 3 1/2" extruder is being used to add a small cap layer of virgin PVC for purposes of changing the color of the sheet for various orders; the processor elected not to use a gear pump on this extruder as its stability is sufficient with the virgin material and the thickness of the cap layer is not critical.

The machine direction gauge variation was limited to a maximum of +/- 0.75% as verified by the gauging system, and the reject rate at the thermoformer was reduced to less than 2%. The gear pump system also allowed extruder output to be increased approximately 30% as the line had to be run very slowly to hold gauge before the pump was added. System payback was a matter of weeks.

Example 3 - Pipe Extrusion

A single screw extruder producing Polystyrene pipe is the last example to be analyzed. The 3" to 6" pipe has to be made to very high standards, both in appearance and dimensionally, to function in high speed film winding applications.

Problem

The pipe had three distinct areas where quality improvements could be made. There were slight waves in the surface of the pipe on the order of a few mills in depth, which were believed to be caused by screw beat. These waves were not causing a performance problem, but required improvement for aesthetic reasons. Medium to long term drift in the extruder output and puller speed was causing excessive variation in the piece weight of the pipe, resulting in the inside diameter and wall thickness getting out of specification. It was also feared that a melt temperature distribution problem around the circumference of the die was causing eccentricity problems.

Solution

An ultrasonic gauging system was considered for this application but was not implemented since it could only detect, not correct the problems being experienced. Each of the problems required its own individual solution. The short term fluctuations in output caused by screw beat were eliminated by the installation of a gear pump, which also helped to increase the total output of the production line. Gravimetric control of the gear pump speed was also included, which compared the actual line speed to the desired pounds per foot of the finished product to calculate and maintain the required output from the extruder/gear pump system. This helped to eliminate the product weight variations, which were causing excessive material giveaway and quality rejects.

Since neither the gravimetric nor the pump system have any effect on the melt distribution around the die, a static mixer was installed downstream of the gear pump to help eliminate any flow problems caused by a poor melt profile entering the die. The gear pump proved beneficial here as well, by generating the 500 psi extra pressure to go through the mixer.

Conclusions

Both the gravimetric system and the gear pump are effective tools at solving specific extrusion problems. Please refer to Table 1 for a direct comparison of capabilities. In some cases, either system can be applied for an application, but if the right questions are asked, one of the solutions will typically emerge as the best choice. The gear pump is the only device capable of controlling both long and short term output variation, as it is positioned directly at the die and there is no lag time for corrections. However, it is application limited in some cases, and in coextrusion the gear pump does not allow direct control of layer percentages, although it offers an improvement over manually operated lines.

The gravimetric system offers excellent control over long term output fluctuation but offers little or no control over short term variations. It is often less expensive than the gear pump, easy to install and can be used with abrasive or degradation sensitive products, since no additional residence time or shear is added by its installation. In coextrusion applications, layer percentages and total weight per unit length can be directly controlled. Gravimetric additive feeders can also be incorporated into the system and controlled from the central computer allowing complete control of the line by weight, while an accurate record of material usage is maintained continuously. These features make the gravimetric system a natural to complete the picture for a totally computer integrated extrusion line.

In some cases, both the pump and gravimetric systems can be utilized together for the optimum solution, as in a coextrusion line where one or more of the extruders is using regrind, causing surging and short term output control problems. The gravimetric system could be applied to all extruders, with the gear pump applied to the extruders where regrind is used.

Gauging systems can also be used in conjunction with either system. Their primary strength is their ability to identify and sometimes control transverse direction gauge, which neither the gear pump or the gravimetric system is capable of doing.

In summary, the role of the equipment supplier should be one of identifying the problem and applying the equipment indicated by the specific requirements of the application. If the right questions are asked and the proper analysis is done, both the customer and supplier will be winners.

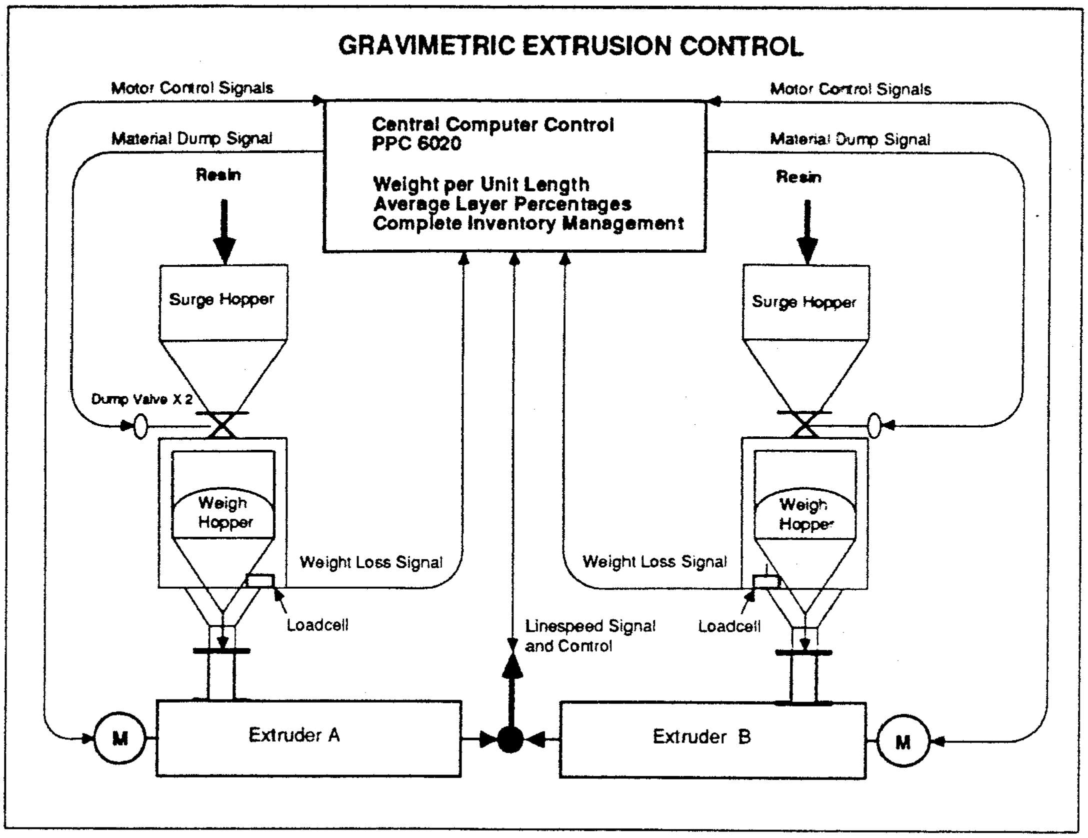

Figure 1

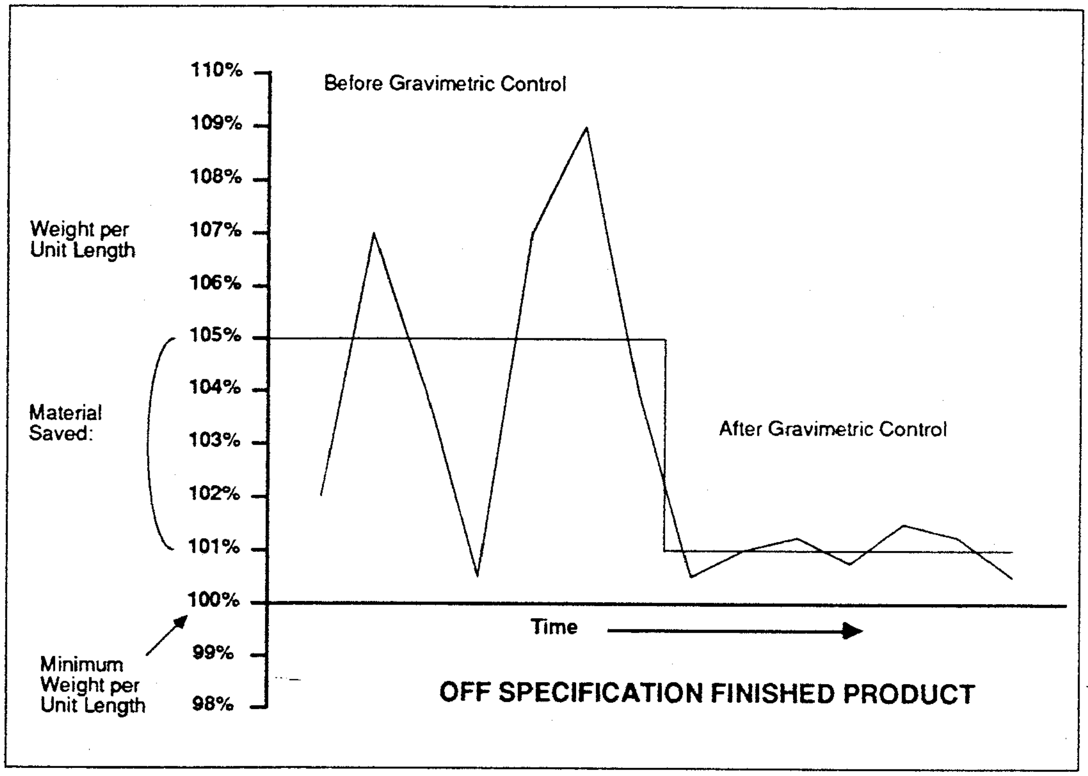

Figure 2

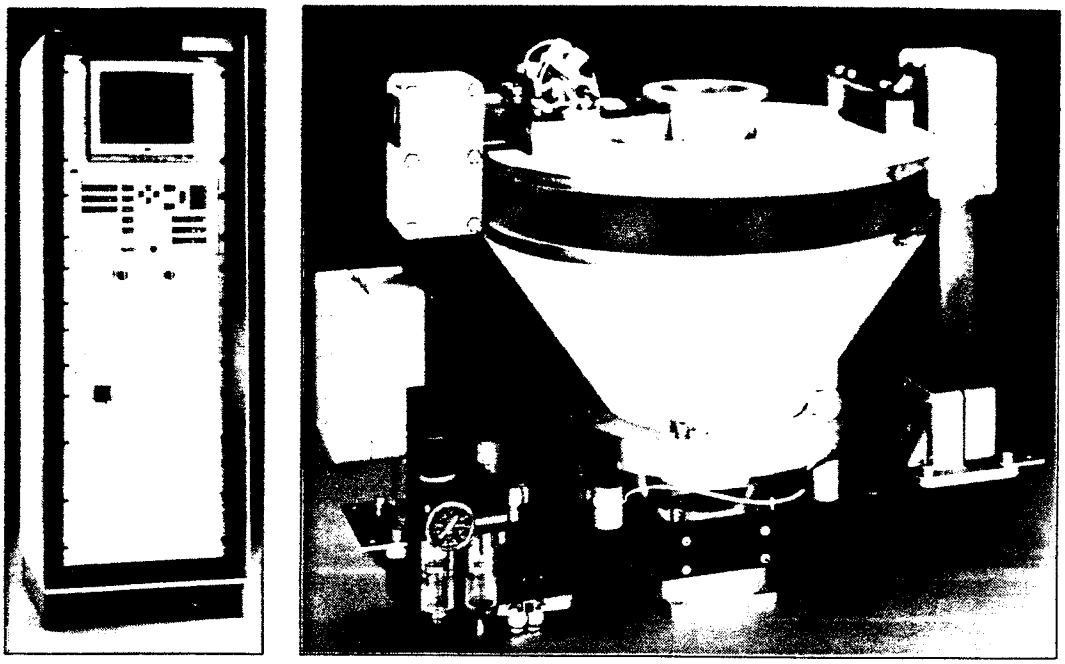

Figure 3. Luwa's PPC 6020 Gravimetric Extrusion Control System includes a central computer and weigh hopper.

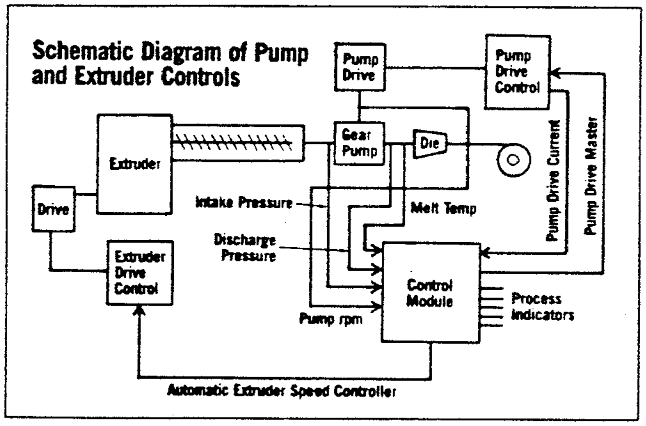

Figure 4

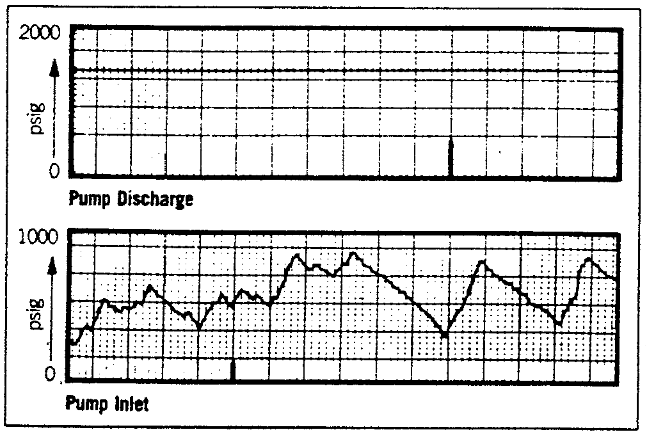

Figure 5

Figure 6. Luwa's Rollpak®, cart-mounted pump system.

Extrusion Optimization, A Case History:
Gear Pump/Static Mixer/Gravimetric Control/Automatic Melt Filtration.

by

DANA G. DARLEY
Extrusion Product Manager

&

PAUL SISCO
Engineering Manager

LUWA CORPORATION
Fluid Systems Division

4433 Chesapeake Drive
Charlotte, North Carolina 28297
(704) 394-8341

INTRODUCTION

Several devices and control systems exist for the optimization and enhancement of the extrusion process. This article will discuss the application of four such devices/systems to an existing extrusion line for the purpose of solving specific and inter-related process problems, affecting product quality and overall line profitability. A 3-1/2" vented, single screw extruder, producing specialty Polystyrene and ABS pipe, is the subject application.

Process and product related problems to be addressed are as follows:

1. There are slight waves on the inner surface of the pipe, which are believed to be caused by "screw beat". These imperfections do not cause a performance problem, but require improvement for aesthetic considerations.

2. Poor melt temperature distribution around the circumference of the die is allegedly causing eccentricity and ovality problems in the finished pipe. As the total line output is increased, the system reaches a point where the pipe eccentricity can no longer be acceptably maintained by manual adjustments.

3. Medium to long term drift in extruder output and puller speed is causing excessive variation in the piece weight of the pipe, resulting in material give-a-way. Extensive quality checks have greatly limited off-specification product, but on occasion the inside diameter and the wall thickness will drift out of tolerance.

4. For economic reasons, the process requires that regrind materials be used for some products, but not at the expense of quality. The regrind material is causing output instabilities, and the higher degree of melt filtration required is becoming a maintenance burden, while reducing total line output.

The pipe production line was retrofitted with an extrusion optimization package which included: a cart mounted gear pump system, an alternating helical twist static mixer, gravimetric extrusion control, and an automatic melt filtration system. A sophisticated microprocessor control system is used to control and coordinate each of these devices. The control system is also used to automate the rest of the extrusion process, including extruder and die temperature control zones, and puller supervision and control. Per the customer's request, there is special software to provide SPC/SQC information for finished product quality reports.

This extrusion optimization package is designed to provide considerable improvements in all of the above areas, through each of the component's own unique capabilities. It is also the intention that with improved control and automation, the system can conserve resin, reduce scrap and increase line yield such that a payback is expected within a relatively short period of time.

SYSTEM DESCRIPTION

The pipe production line is configured with a resin drying hopper situated above the extruder throat which feeds the gravimetric hopper on demand. The gravimetric hopper is mounted directly to the extruder throat, and controls the flow of material from the dryer with its own shut-off valve. The output from the extruder is fed into a heated adapter and then to the automatic screenchanger, which supplies the filtered melt to the inlet side of the gear pump. The gear pump then meters the material through the static mixer and into the die, where the product is extruded into the vacuum forming chamber (see figure 1). The screenchanger, gear pump and drive, and the static mixer are all mounted on a common roll-a-round cart for ease of mounting and removal for cleaning.

GRAVIMETRIC EXTRUSION CONTROL

The gravimetric extrusion control system continuously weighs and times the material input to the extruder, and makes adjustments to the line to achieve a constant output in weight per unit length of the finished product. Product weight and therefore product tolerances, can be effectively controlled, where variations are primarily the result of changes in output which occur over a period ranging from several minutes to several hours. The continuous, gravimetric control system consists of a weigh hopper supported by strain gauge type loadcells and a central computer (see figures 2 & 3). In addition to controlling the output of the extrusion line, the gravimetric system automatically documents the material consumption both in terms of total production run and shift production.

AUTOMATIC MELT FILTRATION

The melt filtration system's basic function is to automatically insert clean screen into the melt stream at a controlled rate, while simultaneously removing contaminated screen (see figure 4). By this continual screen changing, the process experiences negligible variations in pressure during the operation of the extruder and requires much less operator attention. A total of eleven screens are installed in the breaker plate wheel and the operator can change up to four at a time. The breaker plate is turned by an air cylinder rotating a pinion gear through a Formsprag overriding clutch, driving a ring gear attached to the breaker plate wheel. The screens are recessed below the sealing surfaces deeper than the metering section of an extruder screw, so any large objects going through the extruder will be ejected by the screenchanger rather than jamming it up.

GEAR PUMP AND DRIVE SYSTEM

The gear pump is a simple device consisting of a housing with two gears, one driving the other, bearings, and a shaft seal (see figure 5). As molten polymer enters the pump, it is entrapped by the gear teeth and transported to the discharge of the pump. When the gear teeth mesh, the polymer is forced from the gear root creating a positive displacement effect and developing pressure as needed to overcome the mixer and die restriction. The tight rotational clearances of the pump prevent the polymer from leaking back to the inlet side of the pump. The pump is able to isolate pressure surges and therefore output variations, both long and short term, from the die. The gear pump system is driven through a reducer and pulley arrangement, and a digital, variable speed drive. The speed for the gear pump is set by the computer, via a 0 - 10 VDC signal into the digital drive control.

MOTIONLESS MIXER

The motionless or static mixer is designed to solve problems created by an uneven melt temperature profile and the associated unpredictable flow behavior through the die. The mixer consists of a string of alternating right and left hand helical elements connected by patented dispersion lugs to further enhance mixing efficiency (see figure 6). This geometric configuration forms a unique pattern of "flow division" and "radial mixing", which occur simultaneously.

CONTROL LOGIC AND SYSTEM OPERATION

The control set point for the extrusion line is the weight per unit length or meterweight of the finished product. The line speed is selected and set for the process through the control system. This allows the computer to calculate a target output rate for the gear pump/extruder, based on the actual measured line speed and the required meterweight (see equation 1). The target output for the line is achieved by gravimetrically adjusting the gear pump speed, since the pump is the primary metering device for the system. The screw speed is adjusted to maintain a preset suction pressure at the inlet of the gear pump. A drop in the suction pressure is an indication that the extruder is not providing enough material for the required pump output and therefore must be adjusted.

(EQUATION 1) $Qm = W (v) (k1)$

Where:

Qm = calculated target total line output, (lbs/hour)
W = desired weight per unit length, (lbs/foot)
v = measured actual line speed, (feet/minute)
$k1$ = time constant, (60 minutes / hour)

The screenchanger is set to increment the filter based on a programmed time cycle, to provide for a constant pressure drop across the screen pack. If the pressure at the inlet of the filter increases above a high setpoint, the time cycle is overridden until the pressure is reduced to the normal level. It is the gravimetric hopper's job to accurately monitor the resin usage of the extruder. The control system will use the weight loss readings to calculate the instantaneous rate of consumption. Since short term rate calculations do not directly reflect the output of the gear pump, these calculated rates must be averaged over several minutes before being used in adjusting the gear pump's actual speed. This patent pending feature allows for the fact that the gear pump is a very accurate metering device, requiring small adjustments to correct long term drifts in output by weight.

GEAR PUMPS AND GRAVIMETRIC CONTROL

Even though these technologies may at first appear to be in competition, each system promotes process stability by different methods. Assuming the correct questions are asked about the application, a clear choice can usually be made between the two devices, without bias. In this particular application, with the usage of regrind, and with the radial marks on the product inside diameter, the gear pump was the first choice, and it would have been selected over gravimetric, if a choice had to be made between the two. If no short term output problems had existed, and the use of regrind had not been required, the gravimetric would have been the clear choice for directly controlling the piece weight variation. It was still felt that the gravimetric system could offer benefits to the overall automation of the line when used in conjunction with the gear pump, so it was implemented as well.

SYSTEM START-UP

Once the dryer and gravimetric hopper are full of material and all equipment is heated and ready for production, the gear pump and extruder are started together. The customer enters a pre-production and production speed into the computer for the puller and gear pump. During the "auto start-up" sequence, the extruder will run at low speed until it has built up enough discharge pressure for the pump to run. Once this target pump inlet pressure is reached, the pump will automatically go to the low production set point and switch to extruder control to maintain this target pressure. The pipe is then ready to string up, and once it is in the system, the pump and puller are raised to the production speed set point.

While the start-up material is moving through the sizing and cooling equipment and towards the puller, the gravimetric control system is establishing the performance criteria for the gear pump extrusion system. Once the pipe is through the entire system and in the puller, the gravimetric control system has made itself ready for automatic control. The operator has entered the required meterweight for the product, while the control system is monitoring the puller speed and extruder material consumption. All that is left for the operator is to engage full automatic line control.

EXTRUSION LINE PERFORMANCE

With the addition of the gear pump and static mixer, there are very noticeable improvements in the appearance of the finished pipe. The flow of material to the die has been improved and stabilized both in terms of pressure and melt temperature distribution. Monitoring of the inlet and discharge pressure of the gear pump reveal that the die is almost completely isolated from any pressure fluctuations at the extruder discharge. While the discharge pressure of the extruder is continually varying between 900 and 1100 psig, with a set point of 1000 psig, the gear pump discharge pressure changes less than 2-3 psig total.

Prior to the installation of the extrusion optimization package, control of the pipe eccentricity was the limiting factor for the total production rate. For each product, if a specific output was exceeded, dimensional tolerances were impossible to maintain. With the almost perfect melt temperature distribution provided by the static mixer, the material flow around the circumference of the die is much more predictable and repeatable. This improvement provided up to a 20% increase in total line output for most of the products being produced, with less attention to the die required for maintaining the product quality.

The inside diameter and eccentricity of the pipe are the primary determining factors for product quality. These parameters are established when the line is started-up and continually verified during production. Any drift in the total weight of the finished product will result in material give-a-way and eventually off-specification product. With the addition of gravimetric/gear pump output control to the line, the total weight of the product is entered and maintained automatically. The new control system reduces the piece weight variation of the finished product from ±5.0% to less than ±0.5%, with significantly less scrap material due to quality rejects.

The use of regrind materials presents several process related problems to be overcome, if strict quality criteria are to be maintained for the finished product. Regrind materials can cause output fluctuations in a normal extruder due to the varying feed and bulk density, and maintenance of the screen pack can become excessive, with the increased amount of contaminants. The gear pump, in conjunction with the gravimetric control system, is able to manage any output fluctuations caused by pressure surges and varying bulk densities normally associated with regrind. The melt filtration system completely automates the removal of contaminants, resulting in even less operator attention now, than when running the line on virgin materials alone before the new system was installed. The net result is that regrind materials can now be utilized with no additional operator attention and without compromises in product quality or total line output.

Other benefits which have resulted from the use of the new system are the reduction of start-up and changeover time and the associated scrap, and the inventory management capabilities. Once the line is strung up, with pipe in the puller, it previously took 30 minutes to an hour to get the pipe on specification. With the desired total weight of the product entered into the system, this time has been cut in half, since the only operator adjustment to the line is with the die bolts to eliminate eccentricity. The control system documents the material usage and the length produced, both by shift and by total production run. Combined with information on raw materials purchased and finished product shipped, production management can now easily determine scrap rates and production line efficiencies.

SUMMARY

Each of the four specific problems originally documented for improvement have been addressed by the extrusion optimization package. The start-up and change-over process has been automated and made much more efficient, with reduced operator attention and scrap production. Higher quality pipe is being produced at a higher total line yield and with less raw material usage per piece. The extrusion line is easier to use and more versatile, with the line automation provided, and the option of utilizing regrind materials when necessary. The gear pump, static mixer, gravimetric extrusion control and automatic melt filtration system each make unique contributions to the overall success of this extrusion line conversion. The gear pump and the gravimetric control system do work well together, with the gear pump providing the most significant over all impact in this application. Based on the documented improvements to the production line and product itself, it has been projected that the extrusion optimization package will pay for itself in one to two years time.