What's Inside: Thermal Process Imaging Permits a Real Time View of Your Extrusion Process

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ABSTRACT

A scanning infra-red thermal imager is used to continuously measure extrudate temperatures in an extrusion coating process. Position dependent and time dependent process variables are recorded and can be used for process improvement. Thermal images are shown and discussed with corresponding machine and process modifications.

INTRODUCTION

Product quality and functional performance are critically related to extruder melt consistency. Melt consistency has been a topic of intense study since the early days of extrusion processing. Bruce Maddock presented the classic study of melting in a single screw extruder at the 1959 SPE ANTEC [1]. The clear implication of this analysis and many subsequent studies is that due to the melting and mixing mechanisms of the extruder and thermal characteristics of the polymers there will always be variability in the consistency of polymer melt. This may be evident in poor constituent dispersion or distribution, by pressure instability, or temperature variation, both time dependent and position dependent.

Gregory and Street began to quantify these temperature variables in the 1960's and many have followed their methods since [2]. Using an exposed junction adjustable thermocouple they measured average position dependent variation of 27.8ºC overlaid with an average time dependent variation of +/- 5.6ºC. If this process were measured with a fixed depth shielded thermocouple at 0.25 inch immersion it would appear to be a constant temperature. Steward has discussed some of the limitations and problems associated with the traditional thermocouple technology when trying to quantitatively understand melt temperature variability [3]. More recent works have attempted to correlate these real temperature variations with predictive simulation tools to better develop corrective actions to improve melt quality [4,5,6].

Recently, improved infra-red temperature sensing tools have become readily available to provide a more direct real time measurement of these melt temperature variations [7]. Plassmann used these tools to analyze cross web temperature uniformity with and without a static mixer [8]. This paper will expand this earlier work by using this technology to better understand the complex process interactions in melt temperature development on a production extrusion coating line. Understanding the interactions between multiple extruders in a coextrusion process will be briefly discussed.

PRODUCTION CHALLENGE

The challenge for all production operations today is to improve product quality and production efficiency. For many operations this challenge is complicated by shorter production runs and more varied products with added complexity and coextrusion. How do you assure that you process a high MI acid copolymer and a fractional melt linear LDPE with equal consistency? How do you establish an optimum extruder temperature profile? Do you increase back pressure to increase work in the screw? Do you add a static mixer? These and many other questions confront the extruder operations manager daily and he often must make a decision with limited or misleading data.

Because of the varied resins run on a single extruder in many extrusion coating operations the screw is frequently run under conditions far from its original optimum design point. Often to compensate for these conditions temperature settings and valve adjustments are required to achieve the desired melt temperatures. Most operations use a fixed position shielded junction melt thermocouple for melt temperature feedback. Figure 1 shows melt temperature data from a 4 ½" extruder running LDPE for extrusion coating. The extruder temperature profile and screw speed were held constant while the back pressure valve was adjusted. The temperatures were measured using an exposed junction thermocouple at a fixed depth in the flow stream of approximately 0.375 inches.

It can be seen from this data that as the back pressure valve was opened the melt temperature dropped. When the valve was fully in (11.5 turns) the melt temperature probe indicated 625ºF. When fully open (position 0) the melt temperature indicated 595ºF. We would anticipate and hope for this type of an increase in temperature as a result of increased work in the screw due to a higher effective shear rate as well as increased shear work in the valve itself. It is surprising that this change in temperature however is not a continuous monotonic decrease as the valve is opened. For much of the center range of the valve the temperature seems to oscillate depending on valve position.

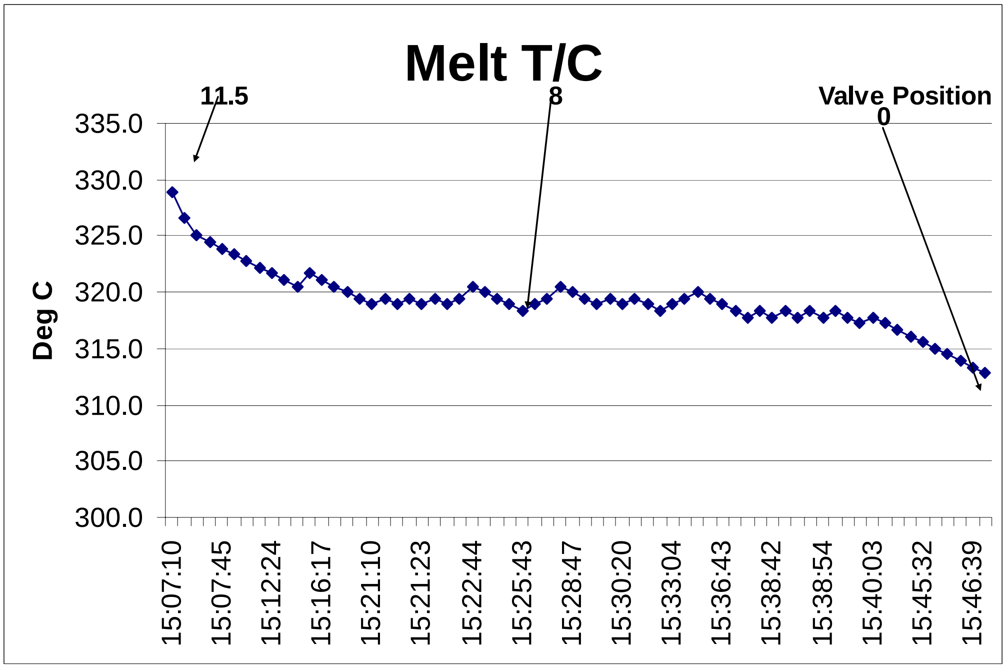
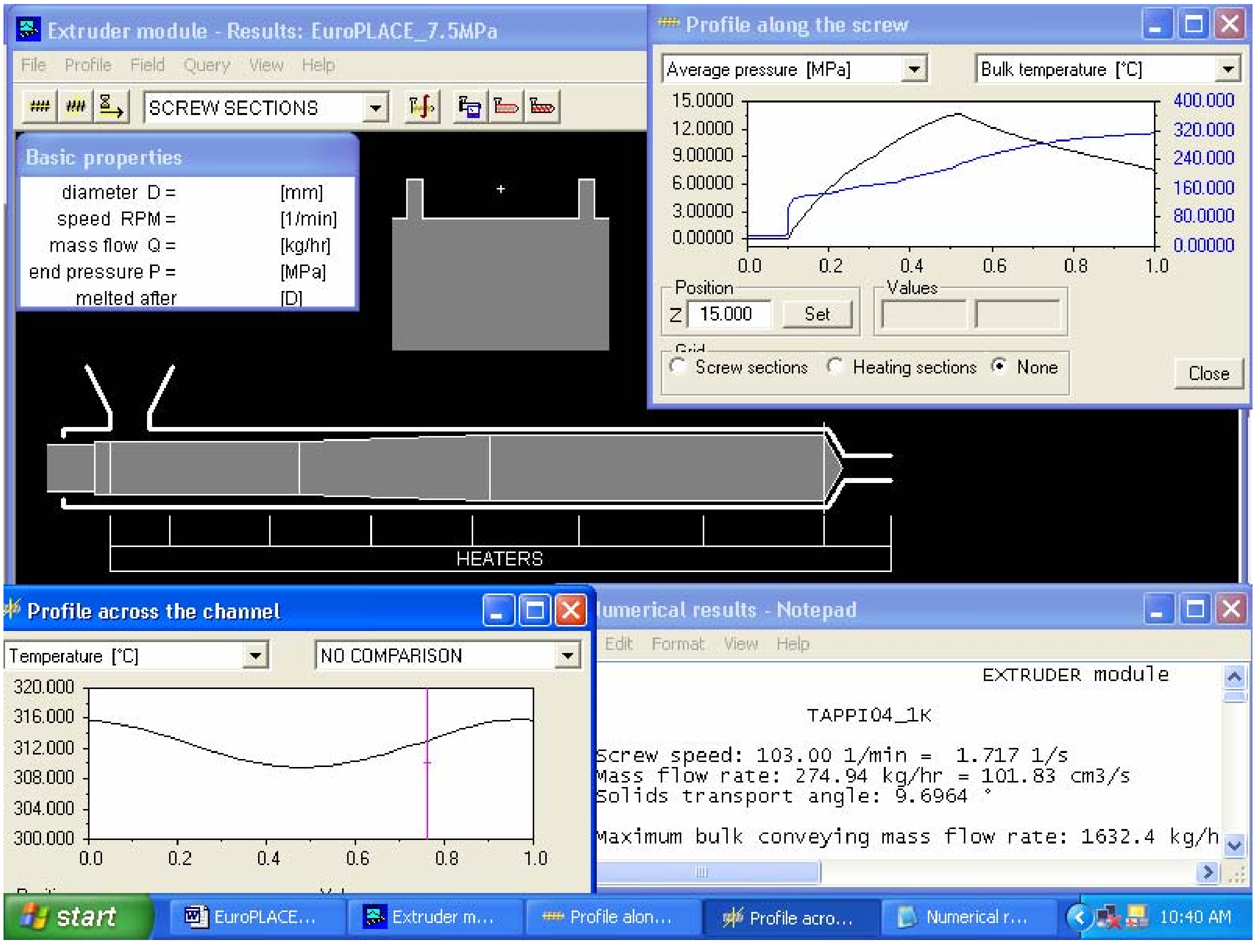


FIGURE 1 Single Point Melt Temperature Data

We can see when the valve was adjusted to position #8 the temperature indicated was at a local minimum, 318.3ºC. If the valve was adjusted in or out, position #7.5 or position #8.5, the indicated melt temperature would rise to 320.6ºC. This measurement is counter to what we would anticipate. Increasing the pressure at the discharge of the extruder would be expected to increase the amount of work done by the screw resulting in an increased average temperature. We would also anticipate that the change in pressure profile along the metering section of the screw would improve the mixing. To understand these interactions a simulation was performed on a simple screw design using Compuplast's Flow 2000 simulation software. Figures 2 & 3 below show simulation results for a simple screw design operated at constant output (275 kg/hr) comparing performance at 7.5 MPa and 15 MPa. Note that to maintain the fixed output at the higher pressure the screw speed had to increase by 11%. At the increased pressure the average melt temperature of the simulation increases from 312.6ºC to 314.4ºC. Melt temperature uniformity improves from a 6.3ºC spread to 4.7ºC.

Unfortunately to increase the pressure in the real world we must introduce a restriction or an obstruction in the polymer flow stream. When we use a typical pin style back pressure valve this creates an annular flow channel. Depending on the polymer viscosity and the annular gap a very high shear stress is imparted to the polymer. Due to this viscous shear input energy is released raising the melt temperature. This energy is not input uniformly as the polymer exposed to higher shear rates experiences a greater temperature rise. Additionally because of the flow path around the pin a portion of the flow stream is repositioned. For a typical right angle pin style valve this rearrangement is described in the work by Skabrahova [8] . It was apparent that the single point temperature data would be insufficient to allow us to understand the complex temperature distribution in this polymer flow.



Average pressure [MPa]

Bulk temperature [°C]

Z 15.000

Grid: ○ Screw sections ○ Heating sections ● None

Temperature [°C]

NO COMPARISON

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                                    EXTRUDER module

                         TAPPI04_1K

Screw speed: 103.00 1/min =  1.717 1/s
Mass flow rate: 274.94 kg/hr = 101.83 cm3/s
Solids transport angle: 9.6964 °

Maximum bulk conveying mass flow rate: 1632.4 kg/h
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FIGURE 2 Extruder Simulation at 7.5 MPa

Average pressure [MPa]
Bulk temperature [°C]
Z 15.000
○ Screw sections ○ Heating sections ● None
Temperature [°C]
NO COMPARISON

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                                             EXTRUDER module

                          TAPPI04_2K

Screw speed: 114.00 1/min =  1.900 1/s
Mass flow rate: 275.72 kg/hr = 102.12 cm3/s
Solids transport angle: 8.7782 °

Maximum bulk conveying mass flow rate: 1806.7 kg/h
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FIGURE 3 Extruder Simulation at 15 MPa

Since the critical point in the extrusion coating process is at the application of the extrudate to the substrate we decided to look at the field temperature distribution of the melt curtain. We used a Raytek EC100 Process Imaging System Model MP50P31 [6,7]. This is an infrared scanner that operates in a temperature range from 100 to 350ºC. It scans the full width of the melt curtain at 36 Hz and displays the data in a scrolling color image with a selectable color display correlation. Multiple scans can be combined and averaged in the display to adjust the time scale of the image. A graphical representation at any time position is also available to provide specific correlations between position, temperature and time. Cross width sections may also be defined and data within these sections can be manipulated mathematically (average, mean, maximum, etc) and displayed as a time dependent trend.

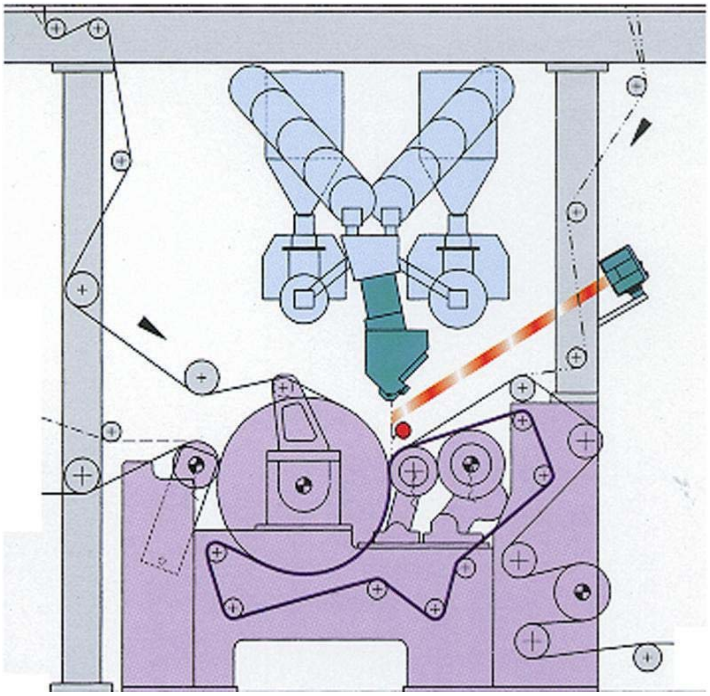


FIGURE 4 Typical arrangement for thermal scan of melt curtain

The typical set up for scanning the melt curtain is shown in Figure 4. The air gap between the die and the coating nip must be sufficient to allow a clear line of sight from the scanner to the melt curtain. Apparatus mounted on the die may need to be relocated to allow use of the scanner in production. Accurate temperature readings are dependent on selecting a sensor that has a spectral response that matches the IR wave length emitted from the product of interest. For most polyolefins a wave length of 3.43 µm is required. Since the polymer cools rapidly as it exits the die the temperature measured will be highly dependent on the distance from the die lips. A laser line generator is affixed to the thermal imager to facilitate the set up of the scanner. The work to be presented here was taken on several separate customer visits. An exact measurement was not made to assure that the same position below the die lips was used as our primary interest was cross stream uniformity.

The following three figures, 5, 6, & 7, show the cross web polymer temperature distribution as measured by the IR process imager as the valve is adjusted. This data was taken at steady state operating conditions with the only change being valve position. The single point temperature measurement in this range showed an oscillating temperature variation of approximately 1.7 – 2.8ºC dependent on valve position. Although the average temperature for these three scans shows very little change a comparison of the change at just position 26 shows a variation in excess of 2.8ºC. If the single point thermocouple is located at this position in the flow field it will reflect this variation. We can also observe in these profiles a high temperature edge at the drive side of the machine which was predicted by Skabrahova's simulations [8]. The customer reported that the drive side edge was less stable and more prone to failure than the operator side edge.

Position 6 - 80 RPM

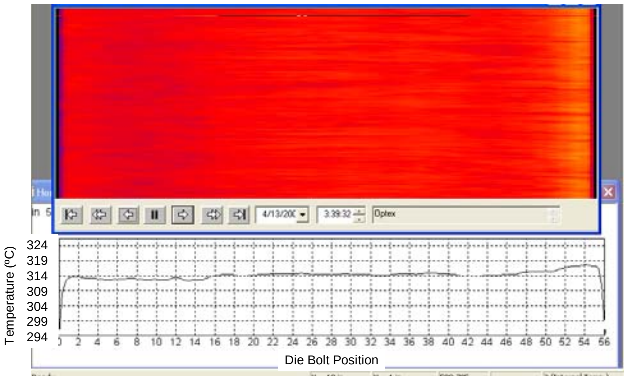


FIGURE 5

Position 6.5 - 80 RPM

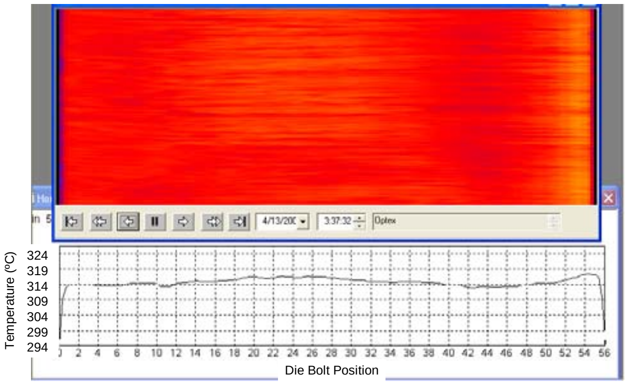


FIGURE 6

Position 7 - 80 RPM

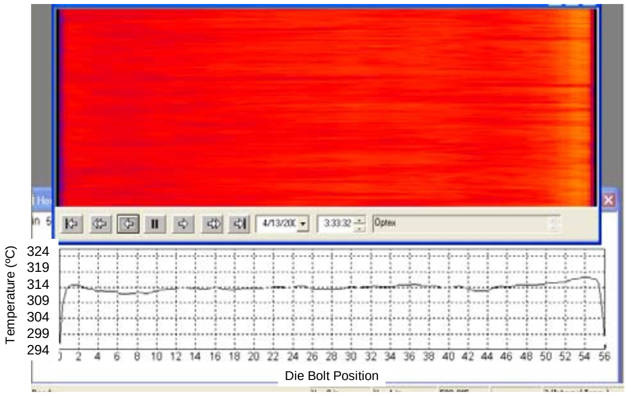
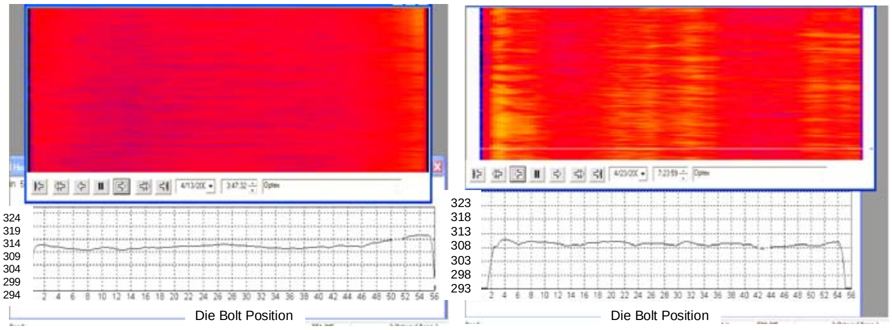


FIGURE 7

We hypothesized the cause of the valve position dependent melt temperature variation to be an out of center valve stem. This was not specifically verified as several machine modifications were implemented as part of a scheduled system upgrade. The extruder feedscrew and barrel were replaced, the valve was replaced, and a stationary mixer was added to the downspout before the entrance of the die. The following series of figures, 8, & 9, compares the before and after cross web profiles at two different valve positions.

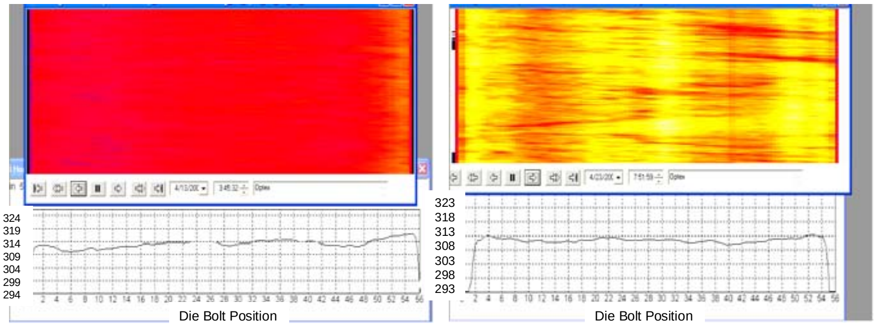
Position 0 – 80 RPM


Before Modifications

After Modifications

FIGURE 8

Position 5 – 80 RPM


Before Modifications

After Modifications

FIGURE 9

It can be seen in these figures that the cross web variation is now half of that before the modifications. The hot edge has been reduced or nearly eliminated. The cross web profile remained uniform independent of valve position.

COEXTRUSION ANALYSIS

It is often difficult to understand flow distribution problems in coextrusion applications. A converter was experiencing flow problems in an AB coextrusion coating application. The application was a film to foil lamination using a LDPE/Acid Copolymer (AC) coextrusion. The AC required a processing temperature of less than 310ºC. The LDPE was run at approximately 325ºC. Although the converter did not have detailed rheology curves on the polymers an initial thermal image showed that the lower temperature AC polymer was encapsulating the LDPE, see Figure 10. The concentration of the low temperature polymers at the edges indicates that at 310ºC the AC is still lower viscosity than the LDPE and therefore is encapsulating as it distributes through the die. The small plot inserted on the right shows the machine direction trends of the temperatures at the center and quarter points of the die.

Coextrusion IR Scan

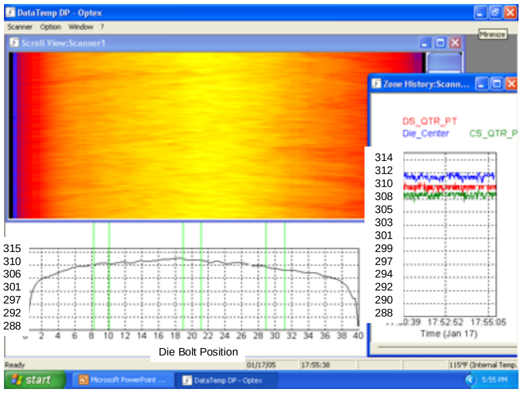


Figure 10

The system was fitted with an adjustable feedblock which incorporates a flow distribution pin design specifically to compensate for viscosity encapsulation. The distribution pin that was presented to the AC layer was rotated to provide free flow to the center of the channel. Figure 11 shows the thermal response of the system to this adjustment. The flow distribution was significantly improved and local (~ quarter point) interlayer disturbances were eliminated.

IR Scan Showing
Response To Feedblock Adjustment

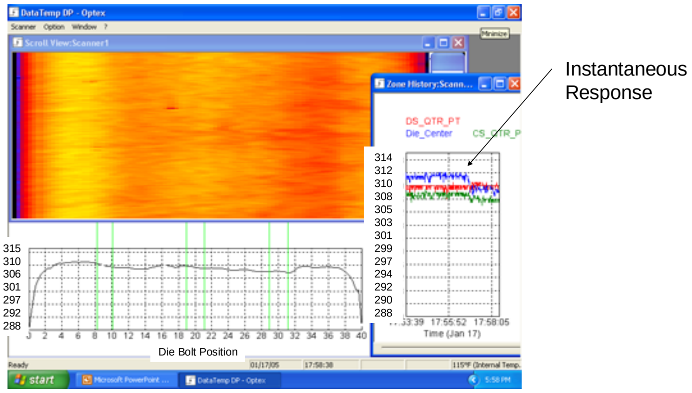


Figure 11

SUMMARY

Although these analyses were not conducted as controlled experiments it is apparent that the IR process imager allows us to begin to see into the extruder. The IR process imager is a useful tool for analyzing and understanding the temperature field variation in extrusion processing. This tool allows simultaneous monitoring of both cross web (position dependent) temperature as well as down web (time dependent) temperature variation. Coupling this process data with simulation analysis greatly enhances our capability of understanding and interacting with our extrusion processes for process improvement and optimization. Software utilities will further allow the use of this system for process control.

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