Extruder Screw Performance Characterization

Print
(10) » Purging Extruder Systems » The Impact of Barrel and Feedscrew Wear » **Extruder Screw Performance Characterization**

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The purpose of this article is to examine the methodology needed to completely evaluate an extruder's performance. The principle characteristics to be determined for any extruder is its output, melt temperature, pressure uniformity, and melt temperature uniformity as a function of screw speed and back pressure. In addition, the power consumed by the screw to melt and deliver the melt at any pressure is important to know, as it will determine potential screw speed limits for the extruder drive. In reality, we are characterizing the screw, which has been installed in the extruder at a particular set of barrel temperatures (barrel temperature profile). Oftentimes, it is necessary, and desirable, to evaluate a screw at more than one set of barrel profiles to find the optimum barrel temperature profile for the desired level of performance required.

The ideal way to characterize a screw is to isolate the extruder from the down stream equipment. This is accomplished by attaching a backpressure valve to the extruder so that output and melt temperature values vs. screw speed may be obtained at constant discharge backpressure. In many coextrusion systems and plant situations it is not simple or affordable to do this. Neither is it possible, or affordable to uncouple the output of the other coextrusion extruders from the extruder screw under test. This adds to the complexity of the output determination but does not prevent the obtainment of high quality, useful information for the screw under evaluation. In these situations we really are obtaining a system performance characterization. The system is operated with all screws at a low screw speed and the combined output for all screws is measured. Then the screw under test is increased in speed and the system output is measured. This is repeated for a series of screw speeds and the data is plot- ted against screw speed to obtain the specific output (Kgms/hr/rpm) of the screw being tested. This can be repeat- ed for each of the screws to characterize all of the screws while running the system intact. At the same time all of the other parameters for the screw under testing are measured, i.e. horsepower, melt temperature, head pressure and pressure and melt temperature stability.

The basic characteristics of output and melt temperature data obtained from an isolated extruder at constant backpressure are shown schematically in Figures 1 and 2. In Figure 1, the output vs. screw speed curve shows a typically linear increase in output with screw speed. In figure 2 we see the effect of pressure on the output, which is principally due to a decrease in pumping efficiently of the pumping section of the screw. In general we will find a linear decrease in output with increasing backpressure. The slope of this line is sometimes referred to as the "hardness" of the screw. E.g. soft screws show a larger pumping capacity loss than hard screws as the pressure increases. Melt pumps are "hard" or positive dis- placement pumps relative to "soft" or pressure sensitive screw pumps.

An alternate method of plotting output data is to calculate the specific output (Kgms/hr/rpm) or the output per revolution of the screw as a function of screw speed or discharge pressure. The specific output is just the slope of the output vs. speed curve and so represents a good way to compare the performance of different screws and as an aid in understanding the screws melt temperature characteristics. In general, specific output will decrease with increasing screw speed because melting efficiency decreases with increasing screw speed.

Melt temperature also increases with screw speed due to larger amounts of viscous dissipation in the pumping section at higher speeds and Melt temperature also increases with increasing backpressure (less efficient pumping). These curves are not necessarily linear.

Power consumption (Kwatts or Horse power) also shows an increase with increasing screw speed but in general this curve shows some upward curvature due to a less efficient melting mechanism at higher speeds. Pressure has a much smaller effect on the horsepower consumption indicating that the majority of the motor's power is being used to melt the polymer not to pump it. Increases in power consumption due to melt viscosity and molecular weight (MF or IV increase) increases occur from an increase in viscous dissipation in both the melting and pumping sections of the screw. The impact of this on melt temperature is not straight forward depending upon its effect on specific output (Kgms/hr/rpm)

An energy efficiency may be calculated as the ratio of output to power consumption in the units of Kgm/KW or lb/(HP-hr) This is generally found to decrease with increasing screw speed and increasing screw diameter indicating a less efficient extrusion process. This represents another parameter, which can be used to differentiate between the performances of two screws. For instance, if two screws have the same output but very different energy efficiencies, the less efficient screw will probably have a higher melt temperature, but may also be a better mixing screw than the more efficient screw.

In order to complete the evaluation of a screw the discharge pressure and melt temperature stability must also be measured. In typical extrusion processes, a 1% pressure variation results is a 2% to 3% thickness variation in the MD direction. Therefore, the maximum allowed pressure variation would be dependent on the application and acceptable dimensional tolerances.

Melt temperature variations are important because they lead to pressure variations in the die, melt elasticity variations (die swell) and differences in quenching. In general short term melt temperature variations of 1 deg F would be expected with some longer-term drift generally observed. Often times melt filtration systems and melt pipes can have a profound effect on the melt temperature and melt temperature profile so to accurately evaluate the screws performance, melt temperature should be measured as close to the die as practical.

Evaluation of the mixing performance of a screw is not yet a straightforward test. In some very special or critical applications on line measures of mixing have been made, but in general product performance or an off line evaluation of “mixing quality” must be made. The closest measure we might make would be the residence time distribution by the addition of colored pellets or an easily measured additive followed by a color intensity or additive level measurement in the melt stream as a function of time. For particles the dispersion of the particles should be determined microscopically.

PROCEDURES FOR TAKING SCREW DATA:

Line data:

Prior to the start of the actual test, take the time to develop your own data sheet for all the dependent and independent variables. Fill the form out completely for each data point during the collection of the output sample or just prior to its collection after equilibrium has been established. Take your time and do not be rushed.

The time waited between samples is very important in determining the quality and accuracy of the data collected. A rule of thumb for barrel temperature changes is 10 minutes for each inch of barrel diameter. For screw speed changes, the wait is not so important for the output data as for the melt temperature data. The output will increase during the average residence time of the screw, which is several minutes. However, the melt temperature will take considerably longer due to the interaction of the screws heat generation and the barrels temperature control system. The best way to determine the minimum time between data collection is to monitor the temperature change as a function of time or to watch the die pressure come to steady state indicating equilibrium between output and melt temperature.

In general, I have used a rule of thumb of waiting 10 minutes for every inch of diameter of the extruders, but with more modern extruders with thinner barrel walls and faster controllers, 5 minutes per inch of diameter may be sufficient, if pressed for time.

Another formulation that I have found for the time to wait for temperature data and the time to steady state is:

Time to steady state (hours) = 50 x (screw diameter in meters) 2

Which predicts a 2-hour wait or 15 min/inch of diameter for an 8-inch screw.

However, the best way to determine steady state is to watch (plot) temperature vs. time as described above.

Output:

This is simply the weight of melt collected for a period of time after the barrel temperatures have come to equilibrium or back to set point after a screw speed change. The longer the sample collection time period the better the accuracy will be but the larger the scale that must be used. In general a six to ten minute sample is desirable. The logistics of the melt collection, weighing and disposal should be thought out in advance. Care should be exercised in starting and stopping the sample collection at the same point and in the same fashion, and as close to the melt outlet as possible. This becomes more critical as the sample time decreases as at high output when drooling melt on the floor for sample collection. Screw speed readouts should be checked by manually counting screw RPM each time data taken and all instruments should be calibrated.

When drooling on the floor or into tared weighing pans from a die, have one person timing the sample and another starting the sample by cutting the melt at the die face with a brass tool. If the sample is being collected on a scrap winder, mark the beginning and end of the sample with magic marker as close to the exit from the die as safety permits. On lines with gravimetric weighing, you can estimate output from the resin consumption by timing the time it takes to consume a known amount of resin added to the hopper. The output rate can also be estimated from a film or cast line conditions from:

Output rate = line speed x sheet width x sheet thickness x polymer density

Some measure of sheet thickness, which accounts for the thickness variation across the sheet should be made.

Always the best practice is to measure the output directly by weighting.

Melt temperature:

Should be measured with a melt immersion thermocouple at 1/3 the diameter of the melt pipe or flow channel diameter if at all possible. Never accept the reading from a flush mounted thermocouple as it will measure barrel or melt pipe wall temperature not melt temperature. Take the millivolt signal from the thermocouple to a chart or digital recorder to determine the temperature variation with time. If it is not possible to measure the melt temperature in the melt stream then obtain a mixing cup temperature by having the melt flow over the thermocouple until a maximum temperature is recorded. In this situation it will not be possible to record temperature variations.

Pressure variations:

These should be measured using a Dynisco type pressure transducer and recorded on a high speed, fast response chart recorder. This allows both long term and short (once per revolution) pressure variations to be recorded.

Drive Horsepower:

The drive power (in watts) consumed is a product of the armature voltage and armature current. To convert to horsepower divide by 746 (watts/HP)

P (watts) =E (armature voltage) x I (armature current, amps)

HP = P / 746

Alternately a kilowatt meter can be installed on the drive to read out power directly. Armature current is directly readable for almost all drives. Armature voltage is not as readily available and must be obtained off of the drive board with a voltmeter or a recorder. However, this requires an open drive cabinet and an electrician and measuring points will be dependent on the drive itself. This generally makes it extremely difficult to obtain. However, we may get a very good estimate of armature voltage by using the drives maximum screw speed and the maximum armature voltage (obtained form the motor tag). Since screw speed is linearly related to motor speed (or screw speed after reduction) a simple relationship between the measured screw speed (N), maximum screw speed (N max) and maximum armature voltage (E max) may be set up to closely approximate the actual armature voltage:

E = (N x E max)/ (N max)

These methods may be used for all DC drives not just the extruder drive

Screw speed:

This may be measured by direct counting up to about 120 RPM. It can also be monitored by recording the voltage from the motor tachometer used by the drive for speed control. Under no circumstance should you trust the panel values even if you are told they have just been calibrated. Always count the screw speed to confirm accuracy at the beginning of a test or better for each data point.

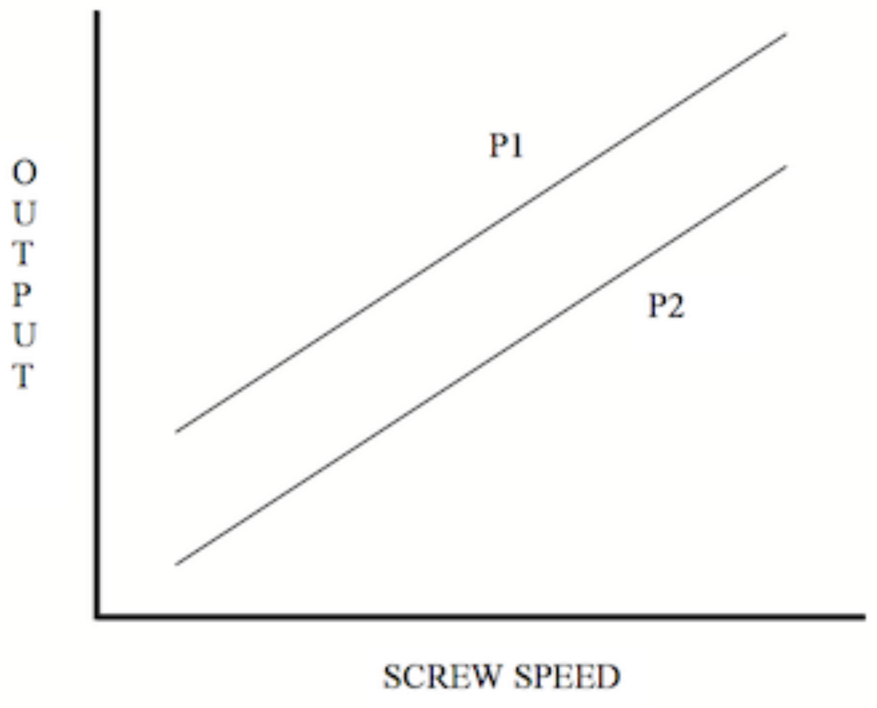

FIGURE 1. Output vs. Screw Speed at constant head pres- sure for two discharge pressures where P2>P1.

Data Evaluation:

Having the data, take the time to plot the output, melt temperature, specific output and power consumption vs. Screw speed. Then plot the melt temperature vs. output (thermal load for cooling). When plotting the power, compare with the drive limits to determine if the drive is power limited.

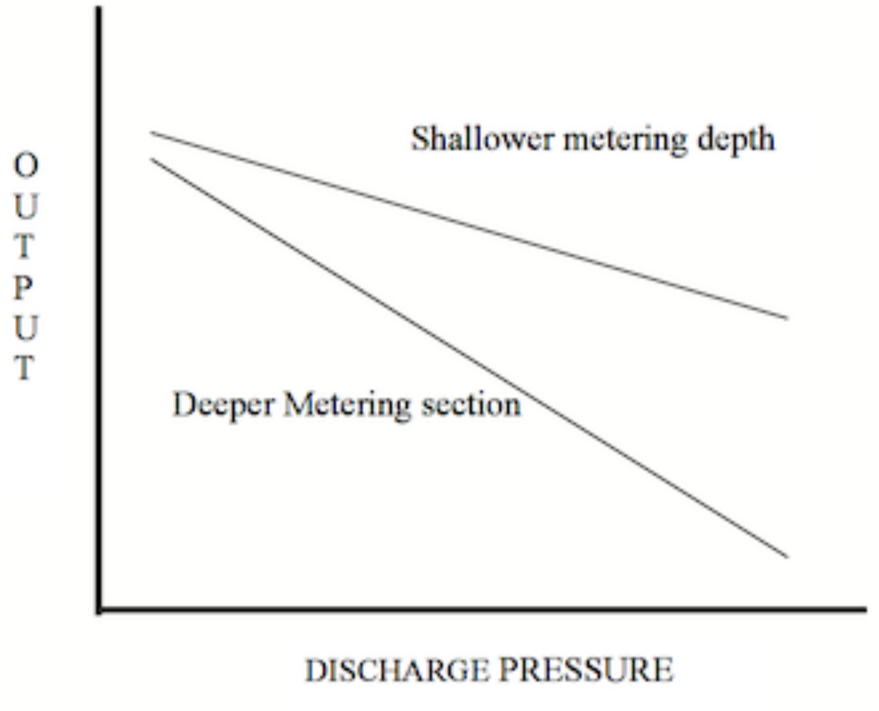

FIGURE 2. Output vs. Screw Speed at constant head pressure for two discharge pressures where P2>P1.

– Eldridge Mount III, EMMOUNT Technologies, LLC

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