

Effective Feed Screw Design Through Simulation

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ABSTRACT

Simulation tools can be an effective method for determining screw design with proper use. Two case studies will be set up and compared with actual results. Pros and cons of simulation will be discussed. Rules of thumb for when simulation is enough for proper screw design will be determined.

DISCUSSION – WHY USE SIMULATION

Feed screws are designed with a certain variety of resins when an initial extruder is purchased. Over time, products may change and the equipment may be fine with the exception of the feed screw. Perhaps the customer has already tried the polymer and found that he can't get the output needed, melt temperature or stability.

If this material is fairly common and the supplier has enough experience with the polymer, a simulation of the new screw offers a quick check. Also, if the screw is a scale up or down to an existing proven design, simulation will work well.

Any previous run data for a new material, even on a screw that is not ideal can be very helpful in simulation work. The existing screw and run parameters can be input into the simulation tool to create a real world model. This model can then be modified to find an appropriate design.

Simulation is not as effective when a material is relatively unknown. Many parameters are needed such as shear rate/viscosity curves, specific heats, melting points and density. Even with very detailed information, it is often difficult to determine the feeding of the material with simulation without hard run data.

It is the job of the screw designer to determine if hard run data is required or if simulation will be sufficient for each design.

DISCUSSION – CASE STUDY 1

BACKGROUND

This case study involves a biodegradable Polyester resin. Since it was relatively new, it was uncertain how it would process. The customer wanted to switch from a standard PET resin to this one to enable their product to be categorized as biodegradable. It was to be tested in the Fulton, NY lab to determine the optimal screw design and to see how their current screw would perform.

MATERIAL SPECIFICATIONS AND PROCESSING

This resin was a hydro/biodegradable polyester resin with an intrinsic viscosity of 0.7. It has a melting point of 195°C (383°F) and an amorphous density of 1.35.

Very little was known about processing this resin, including what feed screw would be the best. The supplier recommended that the material be run at low temperatures with a desired melt temperature of 238°C (460°F). Residence time needed to be kept to a minimum to lower chances of degradation. This material also needs to be very dry and was put into a dessicant dryer overnight.

Since the material is a type of PET, it was deemed a good place to start in looking at screw design. There were two different screw styles chosen. The first style was a single flighted screw with two twisted mixers. This screw was chosen for two reasons. The first was that this was similar to the screw in the customer's plant. The second reason was that it was a shallow screw which would keep the residence time to a minimum. The second style screw chosen was a barrier screw with a single twisted mixer. This screw was chosen as a lower temperature option.

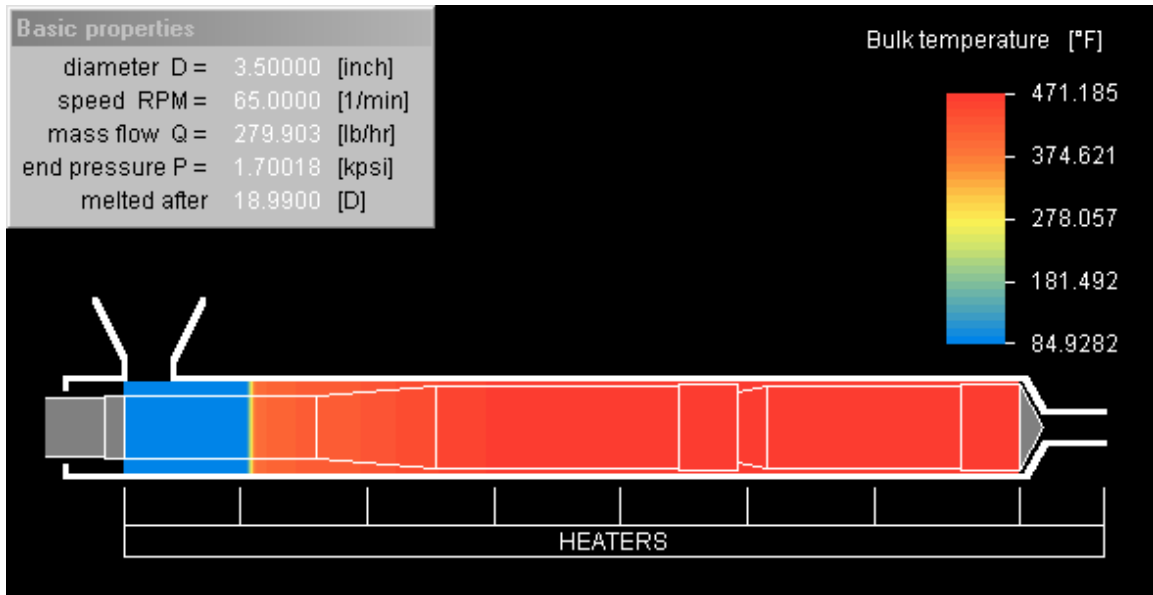


FIGURE 1

SIMULATIONS

The first screw was run with a goal of getting about 127-132 kg/hr (280-290 pph) at about 1700 psi head pressure. Figure 1 shows the melt temperature through the screw. As can be seen from the simulation, the bulk temperature is about 244C (471F). This is with the barrel zones set to achieve about 238C (460F). This means that the simulation is predicting that this resin will overheat in this screw. It was not known if this temperature would be too high for processing this resin. Figure 2 shows the amount of residence time in this screw. As can be seen, the mean residence time is about 133 seconds. This can be compared to a melt separation barrier design screw.

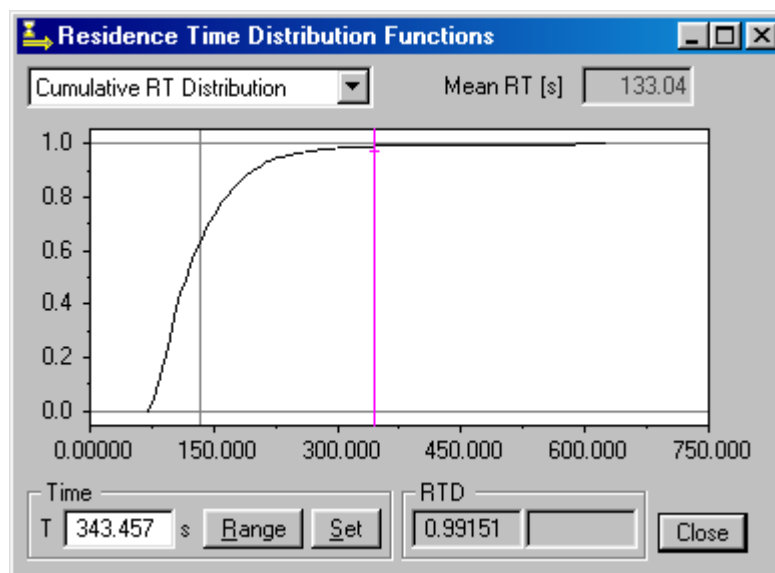


FIGURE 2

A proprietary barrier design (Black Clawson patents 5599097 and 5599098) was examined. Using the same set up conditions and adjusting screw speed to match the output of the previous simulation.

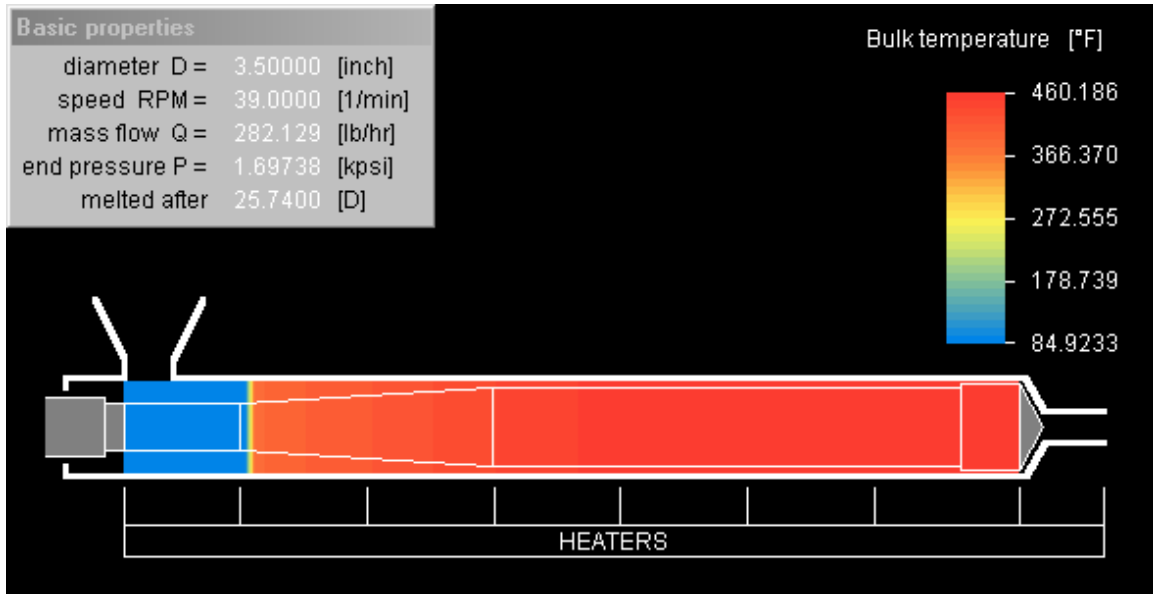


FIGURE 3

As can be seen from Figure 3, this screw keeps the temperature right at 238C (460F). This screw runs at 39 rpm to achieve about the same output as the first screw. The rpm of the first screw was 65 rpm. This screw does have longer residence time due to the increased channel volume.

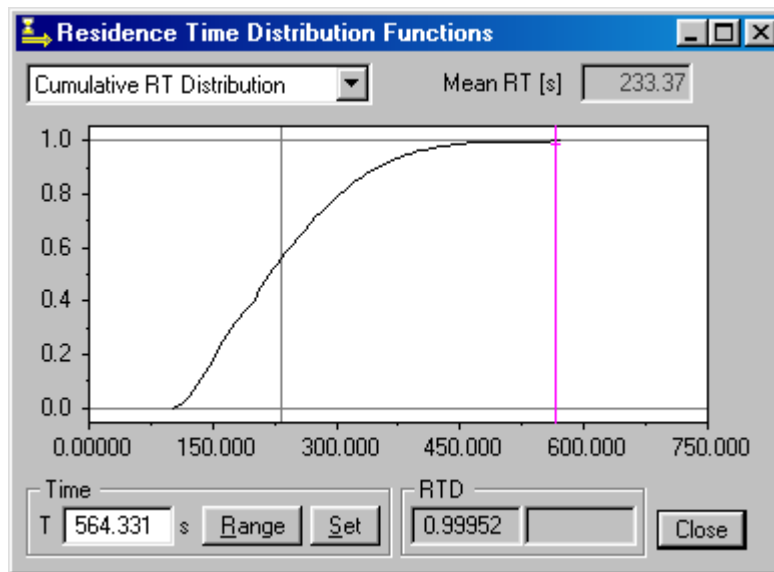


FIGURE 4

In Figure 4, the mean residence time is 233 seconds. This is about 1.67 minutes longer than the time for the first screw. Both screws were run in the lab to determine performance. This afforded us the opportunity to compare the flow simulation software once again to determine if the simulation was giving us the results that we hoped for.

Condition	Simulation	Actual
Screw #1		
Screw RPM	65 rpm	65 rpm
Melt Temperature	243C (470F)	247C (477F)
Head Pressure	1700 psi	1633 psi
Output	127kg/hr (280pph)	127kg/hr (280pph)
Problems	High melt temp	High melt temp
Screw #2		
Screw RPM	39 rpm	39 rpm
Melt Temperature	238C (460F)	238C (461F)
Head Pressure	1700 psi	1400 psi
Output	128kg/hr (282pph)	127kg/hr (280pph)
Problems	none	none

FIGURE 5 – RESULTS CASE STUDY 1

The chart in figure 5 shows that the first screw did overheat. It was actually worse than the simulation predicted. The rest of the variables for this screw were actually very accurate. The results for this material very close. This could be due to many factors that make up each resin. The extrapolation of data from the viscosity curves follows the power law much more closely with this resin most likely being the main reason. The results from screw #2 were just as accurate. From this simulation and lab testing, the customer was able to determine that the existing screw in his plant would have high melt and degradation problems. We were also able to determine a much better screw design for this product.

On a side note, it is important to remember that the horsepower and gear-in need to be checked to ensure that there is sufficient torque for a new screw.

DISCUSSION – CASE STUDY 2

BACKGROUND

This case study involves a scaled down extruder. The customer had a mono extrusion station and wanted to add two extruders. They were currently running the product as a double pass so all of their resins were being processed on one 114mm (4.5”) extruder. They required a 64mm (2.5”) extruder to run a sealing resin. This resin ran well on the 114mm (4.5”). They requested that it be run a few degrees cooler. This was the perfect case for a scale down with simulation.

MATERIAL SPECIFICATIONS AND PROCESSING

The sealant resin has a melt index of 9.3MI. It has no special processing requirements with the exception of needing to run at a melt temperature of less than 293°C (560°F). The customer collected data for this material on the 114mm (4.5”) extruder so that there would be good data to base the model on. The existing screw is single flighted with two twisted mixers

Two run conditions were set up:

Barrel profile: 165/185/245/275/285/285C (329/365/473/527/545/545F)

Condition	Screw speed of 50 rpm	Screw speed of 75 rpm
Output	151 kph (333 pph)	217 kph (478 pph)
Head pressure	1500 psi	1600 psi
Melt temperature	284C (544F)	285C (545F)

FIGURE 6 – Test conditions for existing extruder

SIMULATIONS

The 75 rpm case was used for the first simulation. As can be seen in Figure 7, the output was 190 kph (419 pph) for the specified run conditions. This output was 87% lower than achieved in the testing. The model needed to be modified to match the run conditions more closely. The model was again run for these conditions as shown in Figure 8 and the output was higher with a much better melt temperature also. The model was deemed to be accurate for the run conditions and would be further checked at the 50 rpm conditions.

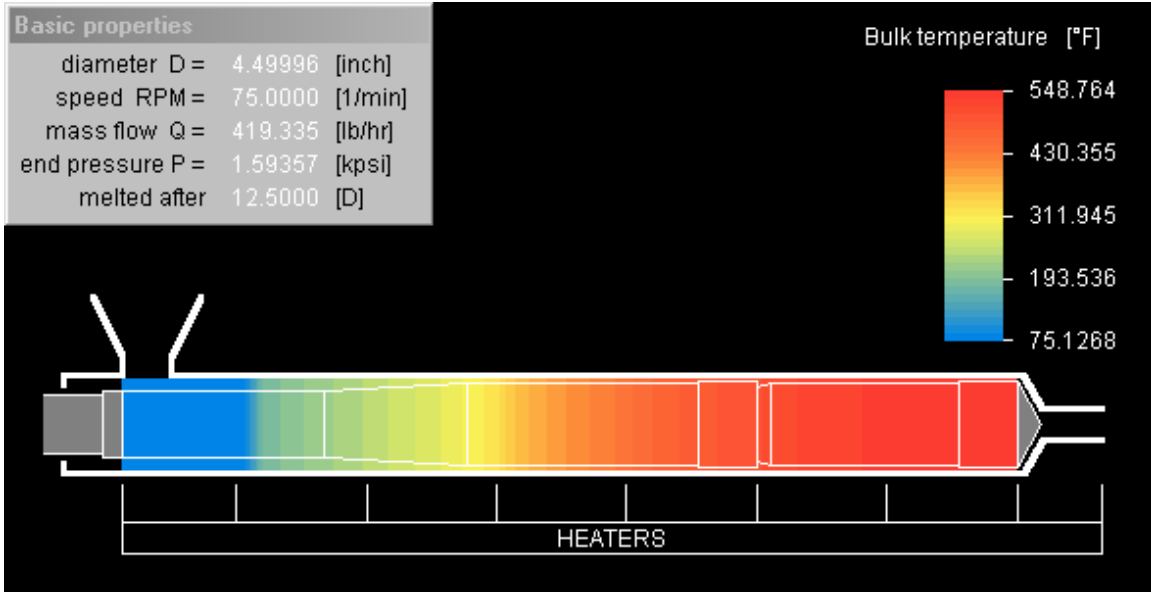


FIGURE 7

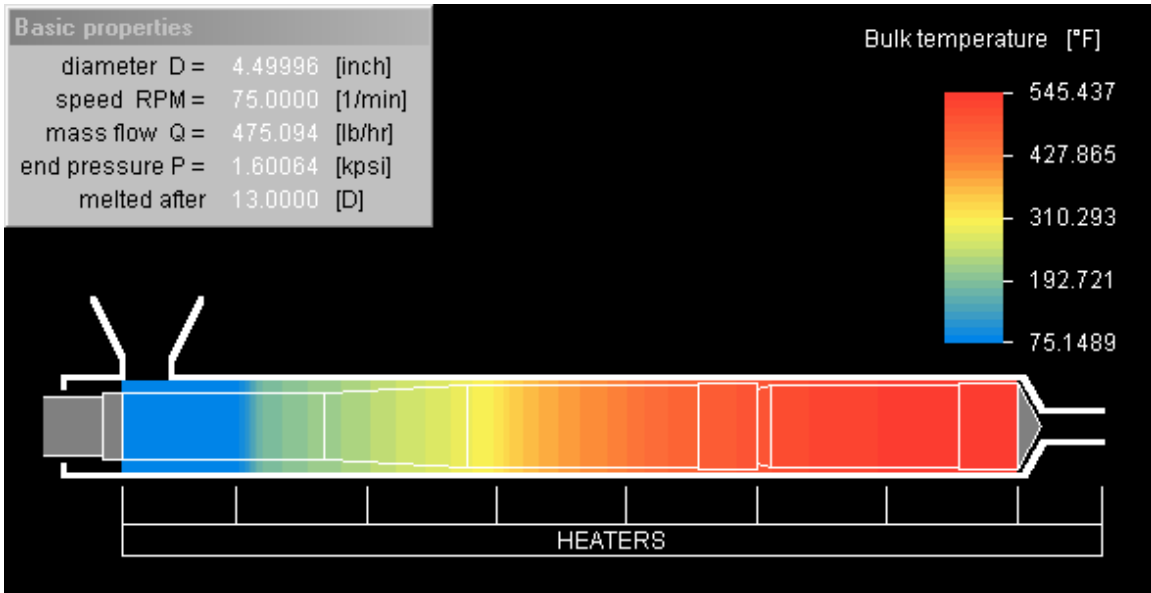


FIGURE 8

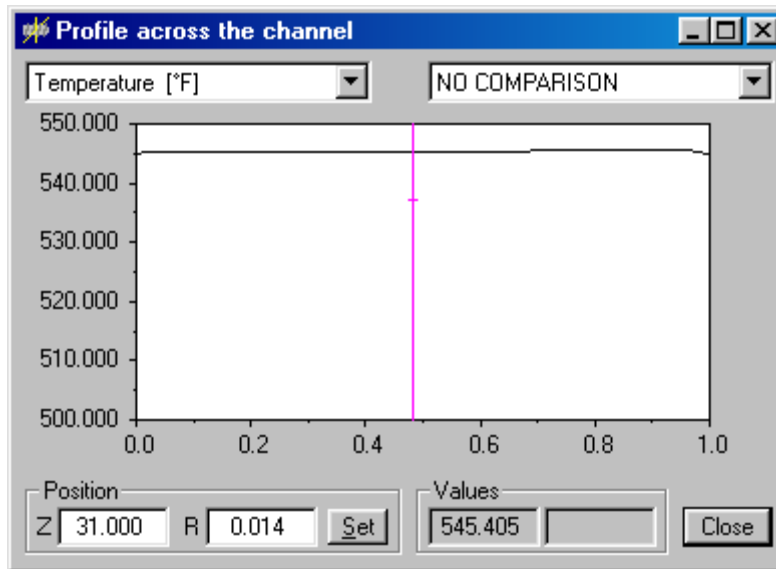


FIGURE 9

Figure 9 shows the profile along the channel at the end of the screw. Zero position is at the root of the screw while 1.0 is the barrel wall. Temperature is very uniform at this point and only slightly warmer than the barrel setting.

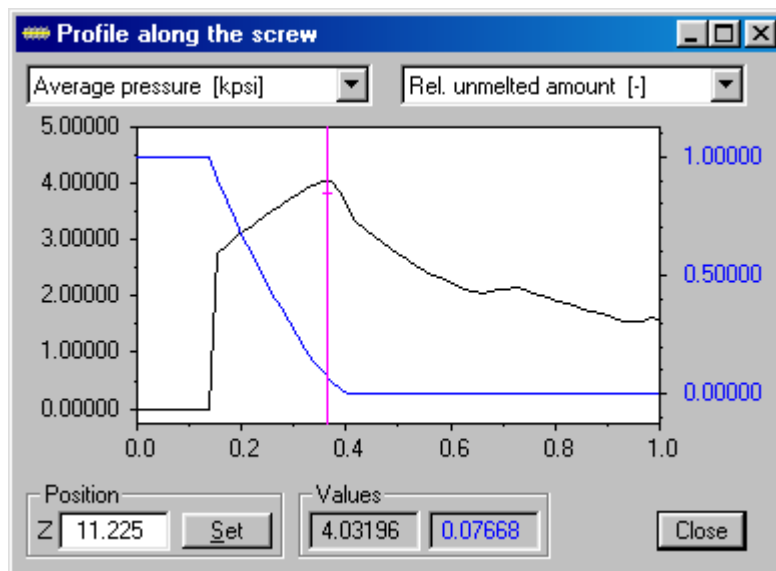


FIGURE 10

Figure 10 shows the pressure profile through the entire length of the screw. Note that the pressure near the end of compression is very high at about 4000 psi. An additional goal would be to try to reduce this pressure by increasing the length of the compression section and thereby decreasing the rate of compression.

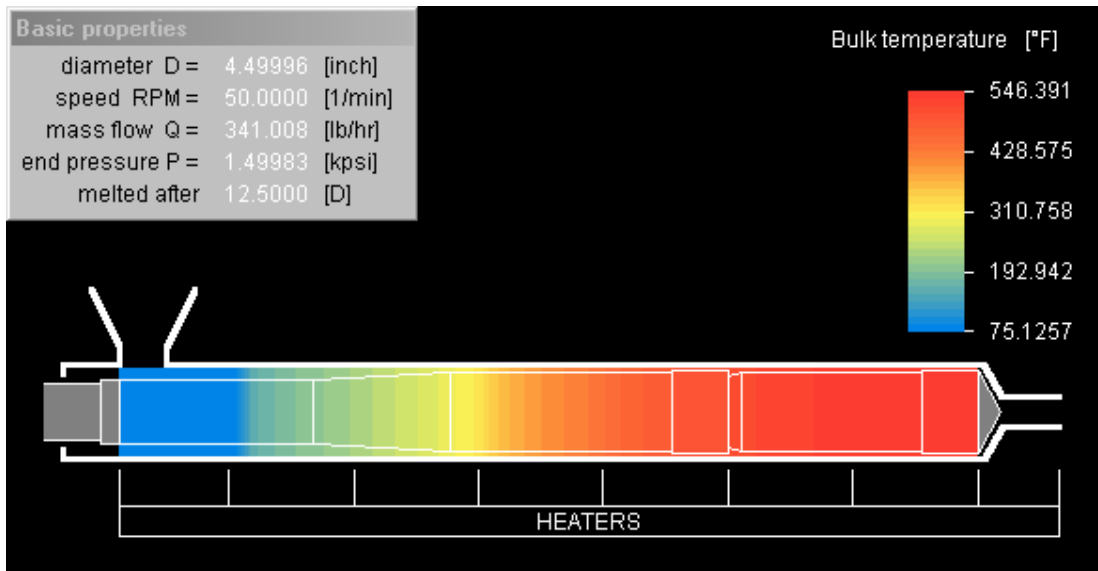


FIGURE 11

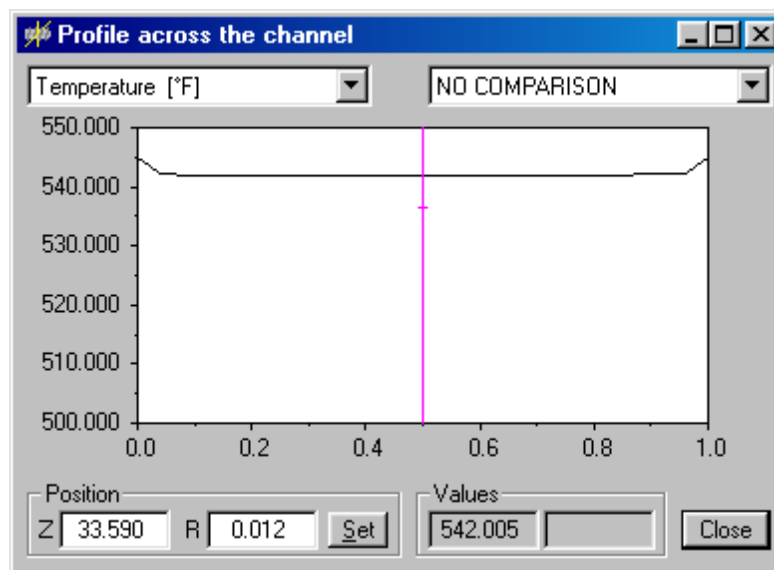


FIGURE 12

Figures 11, 12 and 13 are the simulation results for 50 rpm. Again, these are close to the values recorded in the testing. This model should be good for designing the 64mm (2.5") screw.

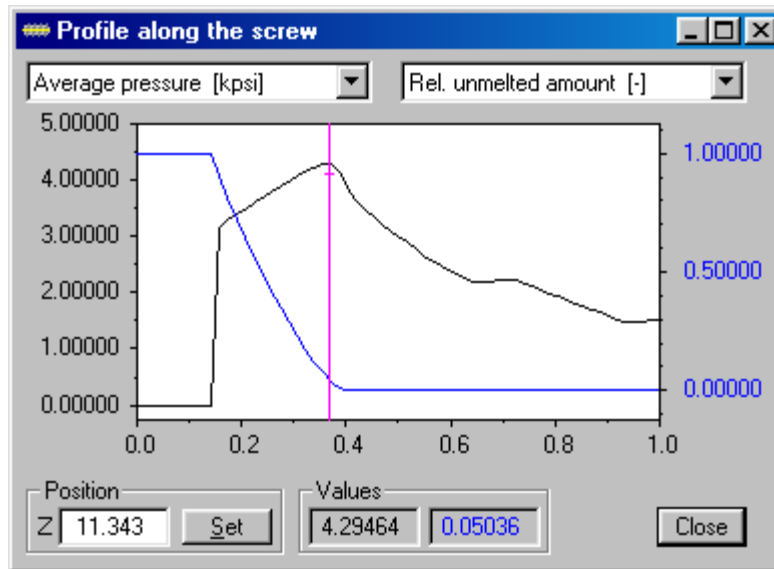


FIGURE 13

NEW SCREW DESIGN

A new 64mm (2.5”) feed screw was designed. This new screw has a longer compression section to try to reduce pressure in this section. It is a scale down version of the original with the exception that it is slightly deeper to lower melt temperature.

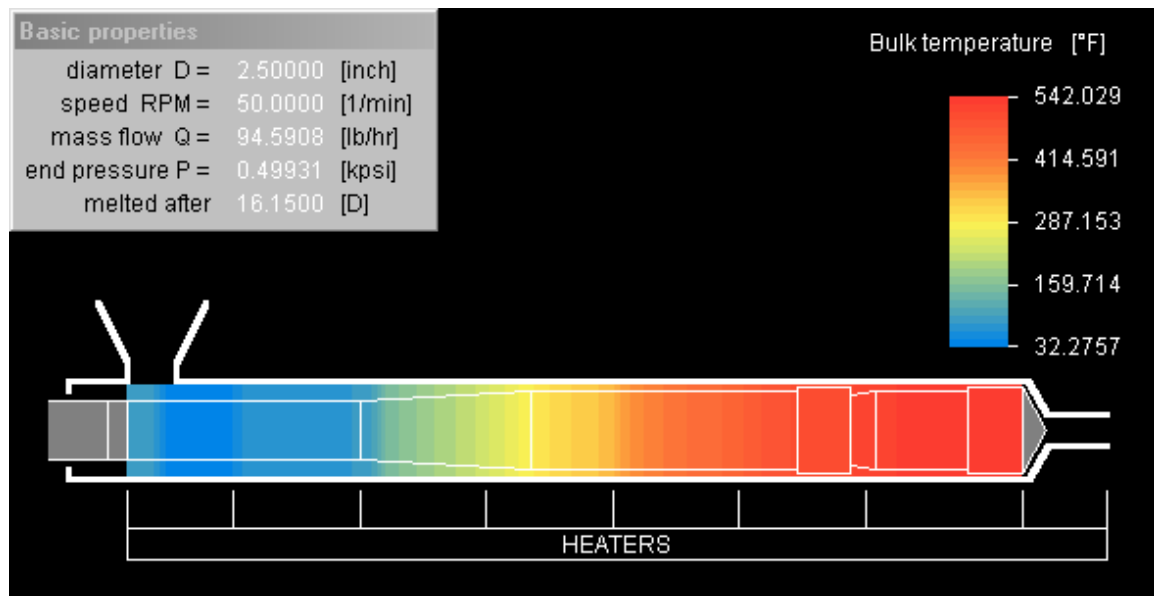


FIGURE 14

Figure 14 shows that at 50 rpm, output is 43 kph (95 pph) and bulk temperature is 283°C (542°F). This does get the melt temperature down slightly from the 114mm (4.5”).

This accomplishes one of the goals. The other is shown in Figure 15. At 50 rpm, the screw sees a pressure high of 3340 psi. The larger screw has a high pressure of 4000 psi. The longer compression keeps the pressure lower than the previous design.

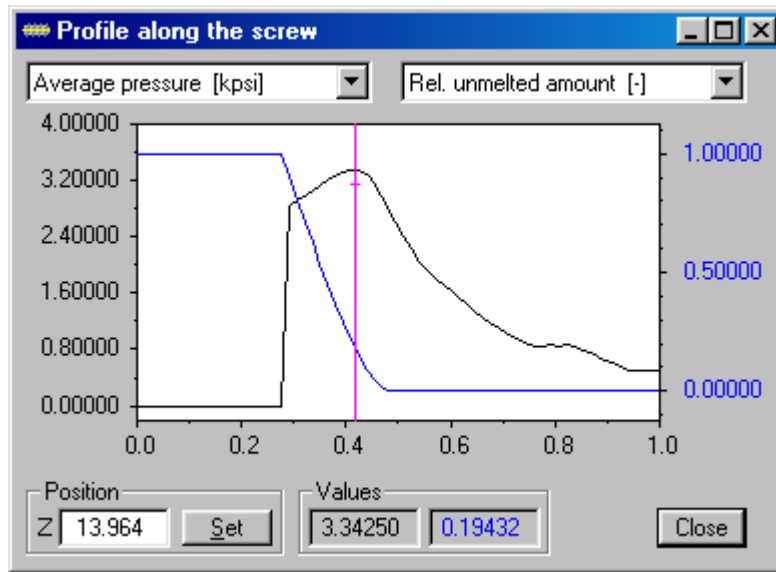


FIGURE 15

The last check to be made is shown in Figure 16. This one shows that the melt is very uniform at the end of the screw and remains cooler than the 114mm (4.5") extruder.

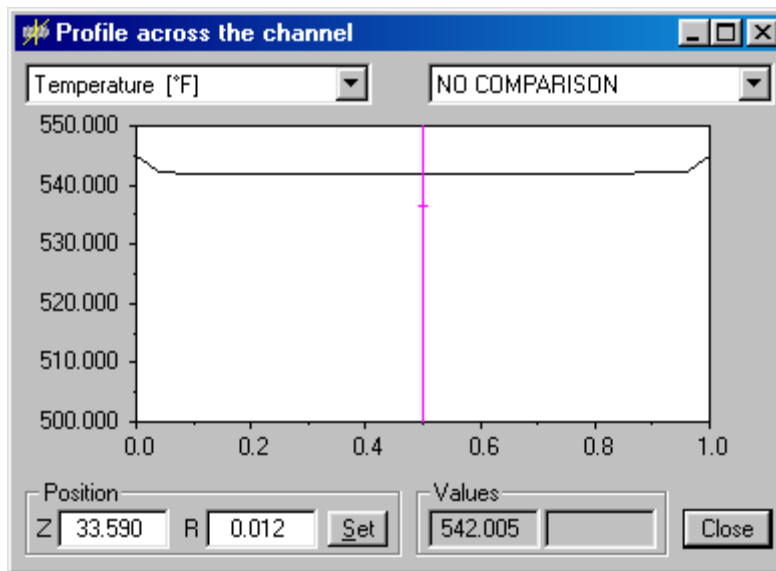


FIGURE 16

This simulation was also run for 75 rpm. Figure 17 shows an output of 62 kph (136 pph). Melt temperature is lower than it was at 50 rpm. With the temperature being lower than the setpoint of the last barrel zone, it is important to be sure that there is not a large variation across the melt channel of the screw. Figure 18 shows the variation. It is essentially flat with a rise near the hotter ends towards the barrel wall. The setpoint of the last zone can be lowered to even out the channel profile more.

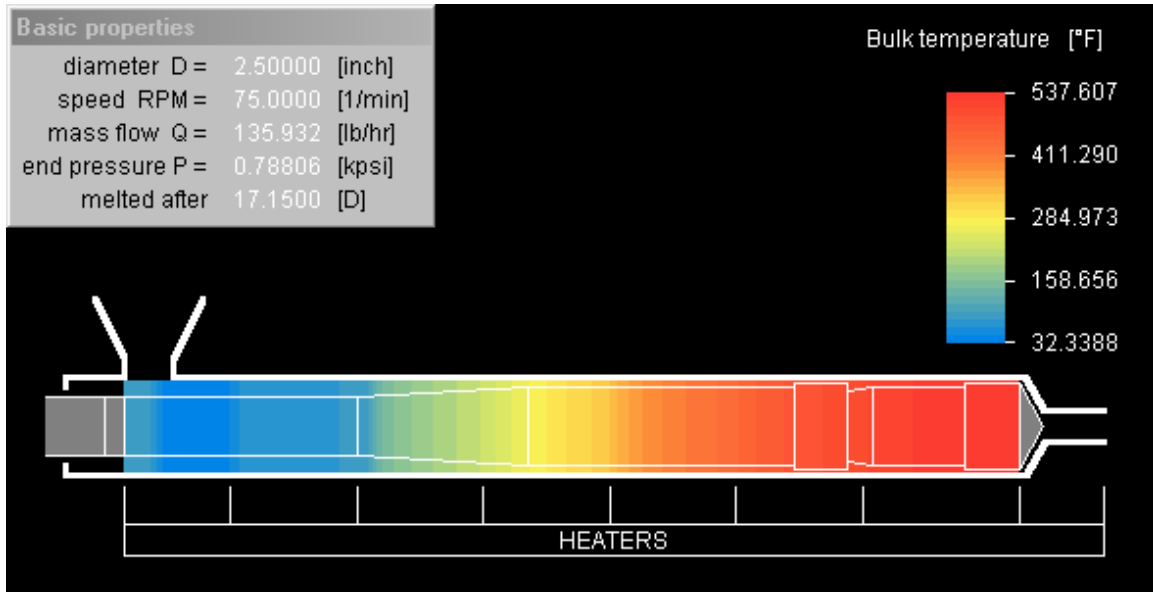


FIGURE 17

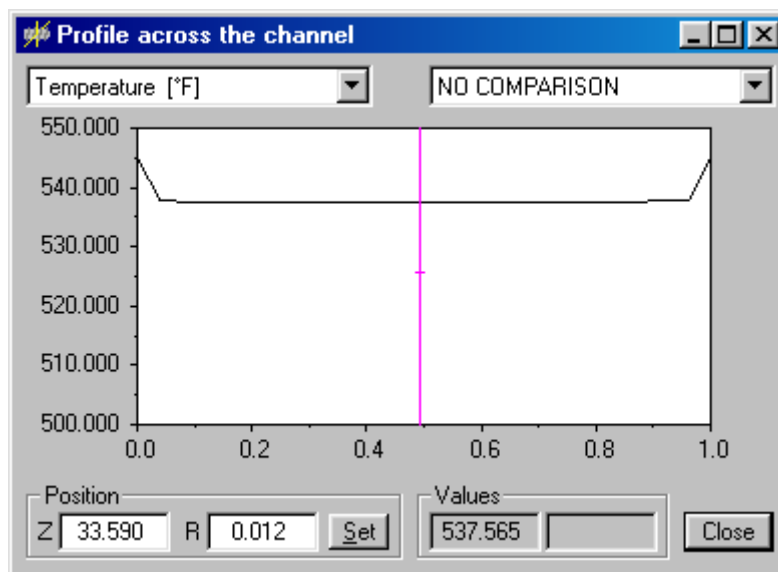


FIGURE 18

The previous design had a high pressure through the screw of over 4000 psi. The new design maximum pressure dropped to 3800 psi.

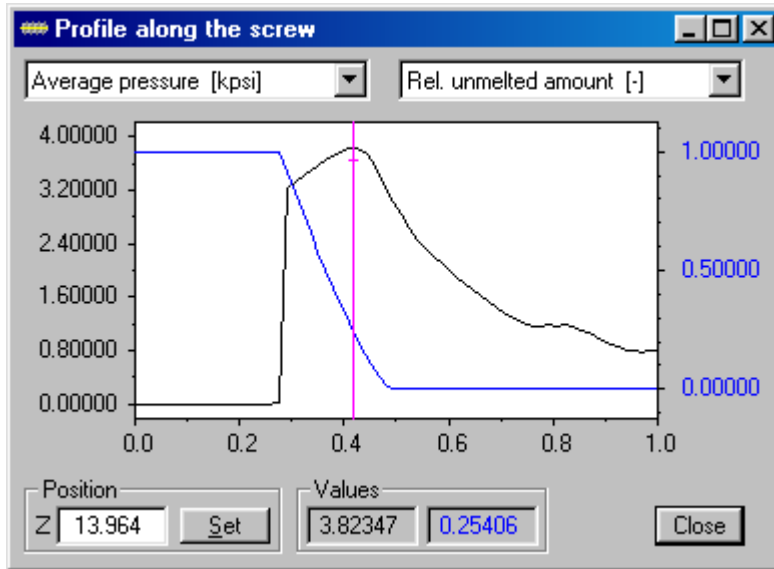


FIGURE 19

The next step was to test the screw after it was installed in the field. The following chart in Figure 20 compares the simulation results with the actual results.

Condition	Simulation	Actual
Screw RPM	50 rpm	50 rpm
Melt Temp.	287C (542F)	288C (550F)
Head Pressure	500 psi	498 psi
Output	43 kg/hr (95 pph)	45 kg/hr (99 pph)
Screw RPM	75 rpm	75 rpm
Melt Temp.	280C (537F)	285C (545F)
Head Pressure	700 psi	766 psi
Output	62kg/hr (136pph)	64kg/hr (140pph)

FIGURE 20

The simulation predicted that the temperature would drop as the screw rpm was increased. This was true in the actual also but the actual results showed higher melt temperatures but these were still less than the existing 114mm (4.5”) screw. Output was

accurate to less than 5% with the simulation showing less output than was achieved. Overall, the results from the simulation correlated very well to the final results.

CONCLUSION

It has been shown that simulation tools can be an effective method for determining screw design. Simulations are a good tool for screw design when resins are well known. Also, it can be used for scale up/down designs, especially if run data exists for the original design. Unusual or new resins without good shear rate/viscosity data or properties should be trialed first. As always, the screw designer should examine the result carefully to ensure that they make sense.