Technology Notebook: Milking the sacred cows—myth and reality in extrusion

Editor's note: Allan L. Griff is a consultant and educator in extrusion, author of the Plastics Extrusion Operating Manual, and presenter of both private and public extrusion seminars since 1979.

In George Gershwin's classic folk opera, Porgy & Bess, a character named Sportin' Life sings "It ain't necessarily so!" These are good words of wisdom for any scientist, as doubt is the essence of science: If it ain't reproducible, it ain't necessarily so.

In extrusion, as in life, we have some "sacred cows"—ideas that seldom get challenged and have become accepted without question. They are dangerous, especially since they often have some basis in truth and can be defended if needed by those whose technological security is threatened by the prospect of fuller understanding. The key to understanding extrusion, as in most scientific endeavors, is quantification. One must ask: How much? How many? What are the real physical dimensions? What is the real duration (time)?

One of the privileges of experience, as well as one of the obligations, is to deal with sacred cows and desanctify them with numbers and logic.

Sacred Cows of Extrusion

1. Power is expensive. It takes a certain amount of heat to melt plastic and raise it to extrusion temperature. For example, to get LDPE from 20 to 220C (68 to 428F), requires .16 kWh/kg, or .073 kWh/lb (Rao & O'Brien, Design Data for Plastics Engineers, Hanser, 1998, p. 30). At a cost of $.10/kWh, that comes to a mere .7 cents/lb, and all of that is necessary.

But what about heat loss, inefficiency, and so on? Extruders are efficient machines, as they are enclosed and most of the heat is generated inside the barrel by friction, except in very small extruders. Kruder & Nunn studied extruder efficiency and found values of 30 to 70 percent (Plastics Engineering, June 1981), so 50 percent efficiency is a typical value.

For example, if we need .7 cents/lb in theory, we need 1.4 cents/lb in practice—this is for a semicrystalline polymer, which needs more heat than the amorphous ones. Rao gives theoretical figures of .03 kWh/lb for UPVC (20 to 180C) and .04 kWh for HIPS (20 to 210C), which convert to costs of .6 cents/lb and .8 cents/lb respectively.

Since half of this is absolutely necessary, how much of the rest can be saved? Also, is it worth the trouble to save it—compared to efforts to save material by re-using scrap or better thickness control—or sell more product? In passing, it is worth noting that PVC, a common target of environmentalists, is the best of all plastics from an energy-saving point of view.

2. Scrap/regrind is of poorer quality than virgin material. This is a tricky one, as much scrap is indeed inferior. Processors have blamed scrap for a multitude of sins, some well-deserved. Some have even been sued for using scrap in their products—watering the ketchup, as it were. But quality needs a more precise definition. Scrap (trim or off-gauge material) is usually slightly discolored and more contaminated from handling, but in many applications these things won't matter, especially in view of the cost savings. Aggressive filtration can get most of the contaminants out, and adding antioxidant or stabilizer concentrates can compensate for molecular degradation.

With some polymers, notably HDPE, reprocessed resin may actually be stronger than virgin, if a chain crosslinking reaction takes place faster than chain breakage and there is enough antioxidant left to protect the mass. The quality of the scrap greatly depends on how it is handled, and if it is kept separate, covered, and clean.

3. The right screw design solves all problems. Screw design is important, to be sure, but it is only one of many solutions and may be an expensive one at that. Before replacing a screw at considerable expense, make sure you understand the problem and can't solve it by changing conditions or formulation.

Even if a new screw is indicated, be sure that the new one is designed to run the desired material at the desired rate. Just buying a screw for polypropylene, for example, is not enough. The screw designer should know grade and formulation, or else have a good set of data showing viscosity as a function of temperature and shear rate. In this computerized world, simulations are easy and should be done for all but the smallest screws, unless real-world data are available for the same materials.

Screw wear is related to the question of screw design. A worn screw isn't necessarily a bad screw. Sometimes wear is even beneficial for mixing, or for increased output if there is a pressure peak. It is useful to establish the location, and thus the cause, of the wear. However, the real need is to prove that the wear is causing trouble, possibly by reducing pumping capacity, which may mean a higher melt temperature for a given throughput. Tracking output/rpm for a known material shows if a screw's pumping capacity is really falling.

4. Don't mess with my profile. In this case, profile means the relation of barrel temperatures to one another: a flat profile has all settings the same; a rising profile has the rear cooler and the front hotter; a reverse profile has the inverse; a camel profile is hottest in the middle; and a valley profile is coolest in the middle. Profiles are acceptable, but to focus on profiles distracts from the specific numeric settings and discourages thinking about each zone for itself.

A good example of separate-zone thinking is the management of rear-barrel temperature to control sticking/slipping on the wall, and thus control of solids conveying. Too much sticking might overfeed the metering section and cause high pressure there. Consequent excessive melt temperatures and too little sticking would reduce feed. This would require higher rpm for a given throughput, and maybe even produce excess melt temperature for that reason.

Here's an example of how focusing on profiles can stifle clear thinking. A film extruder was running LDPE with a flat 450F profile. A high-flow pigment concentrate was sticking in the throat or on the screw root—it was unclear which. The pigment would break off at irregular intervals, causing showers of pigment particles in the product. It was hard to convince the processor that only the rear zone needed be lowered. To a profile practitioner, if one temperature is reduced, then all the temperatures should be reduced.

5. Faster is better. Who could argue with increasing output, perhaps the holiest cow of all? It is usually desirable to run as fast as is reasonable, but there are practical limits. If higher speed increases thickness variation, it may cost more—too thick wastes material, too thin risks failure—than the economies gained by the speed. Sometimes an extruder could run faster but is limited by puller speed, printing, sealing, forming, or even inspection and packing.

Last but not least, you must answer the question: Can you sell the increased output? If you can, then the efforts and costs of running faster may pay off in increased gross profit. If you can't, running four hours at 500 lb/hr may not be any better than running five hours at 400 lb/hr.

Contact information

Edison Technical Services and Griff Extrusion, Bethesda, MD
Allan L. Griff
(301) 654-1515; algriff@griffex.com

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