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Engineering: Heat Transfer in Extruders III—Simultaneous Heating and Cooling

In my last column (*Cereal Foods World*, January-February 2010), I continued discussion about heat transfer in extruders. The issue of heat transfer and scale up, when heating or cooling of the extruder is required, was discussed. In this column, I continue with my discussion of this subject. In particular, the discussion of the efficacy of heating or cooling.

In the last column, the following equation describing the efficacy of heat transfer was introduced.

$$q = UA(T_{\text{extrudate}} - T_{\text{medium}})$$

In the above equation, q is the amount of heat transfer per unit time, U is an overall heat transfer coefficient, and A is the area of the barrel. This equation shows how much heat can be transferred given a local extrudate and cooling or heating medium temperatures, or, conversely, one can use the equation to solve for the heating/cooling medium temperatures required.

Obviously, the key factor that one must establish is the value of the heat transfer coefficient, U . This is where one runs into difficulty. I have reviewed all of the literature that I've been able to locate on the subject. The fact is that there isn't much literature to review, some of it is difficult to locate, and the results found can be contradictory.

Before discussing further, allow me to elaborate on the overall heat transfer coefficient, U . U is a combination of heat transfer resistances. It's calculated with the following equation.

$$\frac{1}{U} = R_{\text{wall}} + R_{\text{medium}} + \frac{1}{h_{\text{inside}}}$$

R_{wall} and R_{medium} are the heat transfer resistances of the wall and medium; h_{inside} is the heat transfer coefficient inside the extruder.

The resistances of the wall and the heating/cooling medium are usually readily calculated, or estimated, using well known engineering equations. In fact, they amount to only about 10–20%, or less, of the value of $1/h_{\text{inside}}$. So, as a first approximation, they are often neglected. The problem one faces is that $1/h_{\text{inside}}$ is not readily calculated. There are a few engineering correlations for estimating its value, but the correlations are somewhat contradictory. Part of the problem is that the correlations have been established at different conditions, such as screw speed, material rheology, speeds, screw geometry, etc. As a con-

sequence, correlations show different relative significances of various groups in the correlations. This is not a very great impediment, since the values somehow end up about the same, no matter which correlation is used.

Below is a summary of what I've found (Tables I and II):

Table I. Single-screw extruders

| Heat Transfer Coefficient (watts/[m ² ·K]) | Speed Range (rpm) |
|---|---|
| 170–420 | 10–32 |
| 300 | Not specified. For a pasta machine, probably 20–30. |
| 136–420 | Not specified, but calculated for similar condition as above. |

Both the first and third examples show that the heat transfer coefficient increases, with increasing speed, which is part of the explanation for the ranges.

Table II. Twin-screw extruders

| Heat Transfer Coefficient (watts/[m ² ·K]) | Speed Range (rpm) |
|---|---|
| 500 | 200–300 (Source and speed not specified; speed range is approximate.) |
| 191–768 | 150–450 |
| 500 | 100–300 (Source not specified.) |
| 226–340 | 50–200 |
| 310–902 | 200–300 |

The second, fourth, and fifth examples show that the heat transfer coefficient increases with increasing speed, which is part of the explanation for the ranges.

What sense can be made of this? It seems that the “typical” or maximum values for heat transfer coefficients for twin-screw extruders are higher than for single-screw extruders. This has been attributed to the better mixing that occurs in twin-screw extruders, but it might simply be the result of the fact that the single-screw data is taken on much lower screw speeds and more deeply threaded machines. In fact, the fourth example for twin-screw extruders was taken on a machine that has deeper threads than is typical for these machines and it appears to show somewhat lower coefficients. Unfortunately, there is no published data for single-screw cooking extruders, which typically have shallower threads and run at higher speeds than the single-screw machines for which data is available.

What is one to do? If I don't have data, I generally make choices based on experience and the limited data available in the literature. It would seem that for “typical” twin-screw extruders,

operating at their normal operating speed ranges, a reasonable value for the heat transfer coefficient is about 500 watts/(m²·K). For forming extruders, such as pasta machines, a value of about 250 watts/(m²·K) seems reasonable. I have, for forming extruders operating at speeds higher than typical speeds for pasta machines (20–30 rpm), somewhat higher values, perhaps 300 watts/(m²·K). For single-screw cooking extruders, we know the value will be somewhere in between the values given for forming extruders and twin-screw machines. As a first guess, I would say about 400 watts/(m²·K).

The fact is that it's difficult to get good data on the heat transfer coefficients, but if I had a process for which heat transfer was critical, I would take some time to actually take my own measurements on the extruder type and material of interest. If no data was available, I would use the numbers above.

Before closing, it is worth mentioning that measuring heat transfer coefficients is not a trivial exercise. In order to measure the heat transfer coefficient in an extruder, several things must be known, which unfortunately, are not readily measured. One must measure the inlet and outlet temperatures in the barrel section of

interest. This is difficult, especially if the inlet of the barrel section is not at the beginning and end of the screw. One must estimate how much contact area there is between the extrudate and the barrel wall in the section of interest. That is, one must know the degree of fill of the barrel section of interest. This also is generally not known with any degree of accuracy.

And finally, one must know the energy dissipation in the section of interest. The energy dissipation is generally only known for the entire length of the screw. When one gets done, one generally only has a rough estimate of the true value of the heat transfer coefficient, but with careful analysis, and applying certain design constraints, this rough estimate is sufficient. The actual analysis of this data is beyond the scope of this column. Perhaps I will discuss this in a future column, if I can figure out how to make it understandable in the limited space available.

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A C. W. Brabender ad appeared here in the printed version of the journal.