Modeling of the next generation of melt blowing

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ABSTRACT

Mathematical modeling provides understanding of melt blowing and allows process optimization. This work expands an earlier model to include novel die head modifications. A particularly exciting modification is using air pulsation in the die. Directing air first to one side of the die and then to the other side in a typical slot die at frequencies of 1–50 Hz uses 10–30% less air to produce the same size of fiber.

Application:

Oscillation of air fed to a melt-blowing die reduces costs associated with compressing, heating, and recycling the air.

PART I OF THIS WORK SHOWED THE development of a detailed mathematical model for the melt-blowing process *(1)*. For all positions along the thread line, the model can predict the fiber attenuation (diameter), fiber stress, and fiber temperature. The model can also predict the amplitude and frequency of the fiber vibration. Like the other predicted quantities, fiber vibration frequency depends on the operating parameters.

All mechanical systems have characteristic vibration frequencies. A classic example of this was the collapse of the Tacoma Narrows suspension bridge in 1940 *(2)*. The action of the wind blowing across the bridge matched the characteristic frequency of the bridge. The collapse of the bridge was a negative effect of this resonance or matching of frequencies. In melt blowing, resonance may have a positive effect.

To test this hypothesis, we modified a melt-blowing die to oscillate the air feed. First only the left die slot was fed air. Then the right slot was fed air followed by repetition of the cycle. Since the model predicted that the characteristic frequencies of melt blowing are usually below 100 Hz, these were the tested frequencies of air oscillation. Several recent patents use this technology *(3, 4)*.

EXPERIMENTAL EQUIPMENT

Figure 1 shows a typical slot die often used commercially for melt blowing. Polymer exits the row of orifices. In a conventional system, air exits continuously from both air slots. Because there are two separate slots, it is easy to modify this type of die to produce air pulsation.

Figure 2 shows such a modification. In oscillating mode, valve 4 is closed and valve 3 is open. The air then passes through oscillating valve 5. This oscillating valve is an electronically controlled solenoid valve activated by a voltage pulse from a signal generator. After passing through the oscillating valve, the air travels either through the branch containing valve 6 and gas heater 8 or the branch containing valve 7 and gas heater 9. The three-way valves (6 and 7) provide flow from valve 5 to the gas heaters.

The experiments used a stainless steel slot die with 76.2-mm (3.00-in.) slot length and a single 0.406-mm (0.016-in.) polymer orifice. The polymer was a commercial polypropylene. An earlier paper provides further details on the experimental equipment *(5)*.

RESULTS AND DISCUSSION

Figure 3 shows the effect of air oscillation frequency on fiber diameter. At a frequency of approximately 1 Hz, the fiber diameter is approximately 66 μm. The diameter then steadily increases as frequency increases until reaching a peak at approximately 14 Hz. At greater frequencies, the diameter steadily decreases until reaching a plateau at approximately 25 Hz. The dotted line is the diameter produced when there is no oscillation. Except frequencies near 14 Hz, observe that the diameter is always less in the presence of pulsation. The solid line in Fig. 3 is an arbitrary fit to the data.

Figures 4 and 5 show similar results at two higher flow rates of 100 and 144 standard liters per minute (SLPM). For 100 SLPM, the peak occurs at approximately 9 Hz, and the plateau begins at approximately 20 Hz. For 144 SLPM, the peak is approximately 15 Hz with the plateau beginning at 30 Hz.

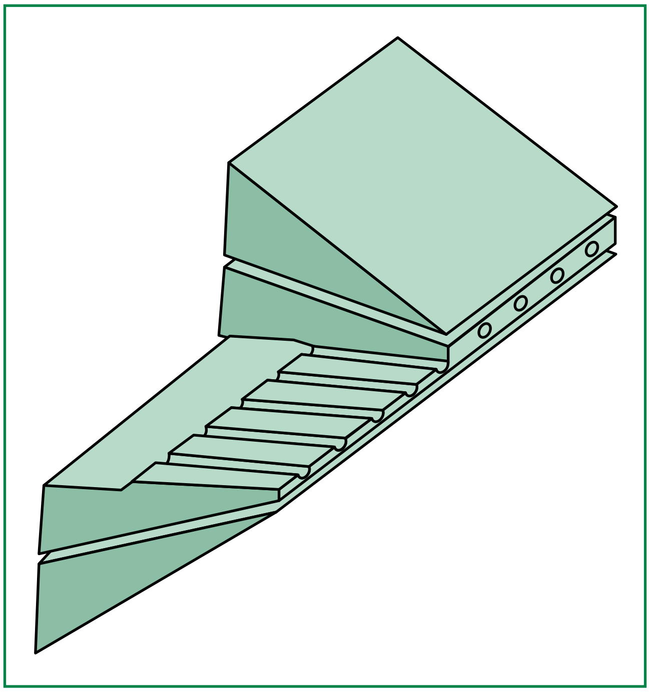
Since the data in Figs. 3–5 showed small diameters at frequencies down to 1 Hz, we investigated even lower frequencies. **Figure 6** shows what happens at frequencies down to 0.1 Hz. As expected, the fiber diameter at 0.1 Hz approaches the diameter produced for continuous flow, i.e., 0 Hz.

FIVE MELT-BLOWING VARIABLES

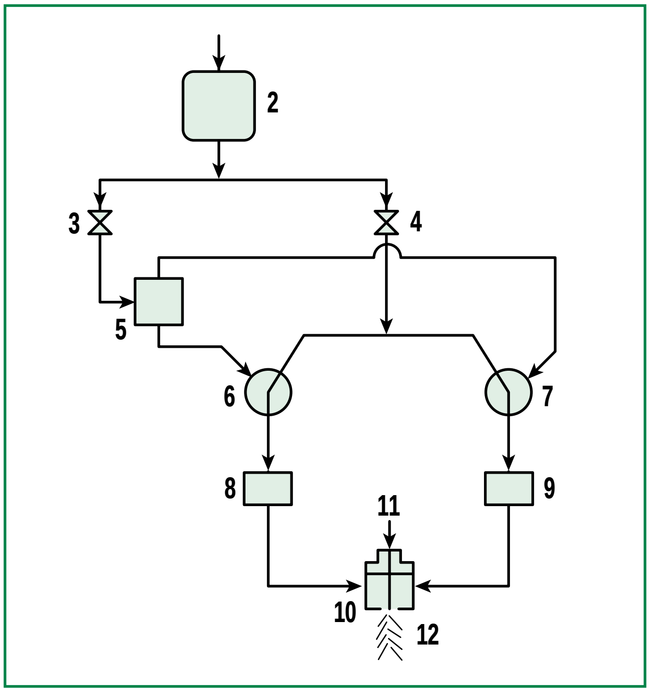
For a fixed die geometry and polymer type, there are four basic variables in conventional melt blowing with an additional variable:

- Polymer flow rate
- Polymer temperature
- Air flow rate
- Air temperature
- Air oscillation frequency.

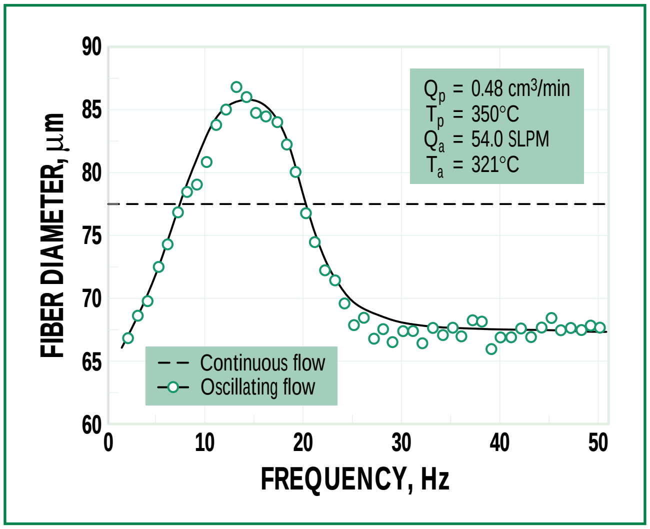
Let us now examine the effects of the other four variables with air oscillation.



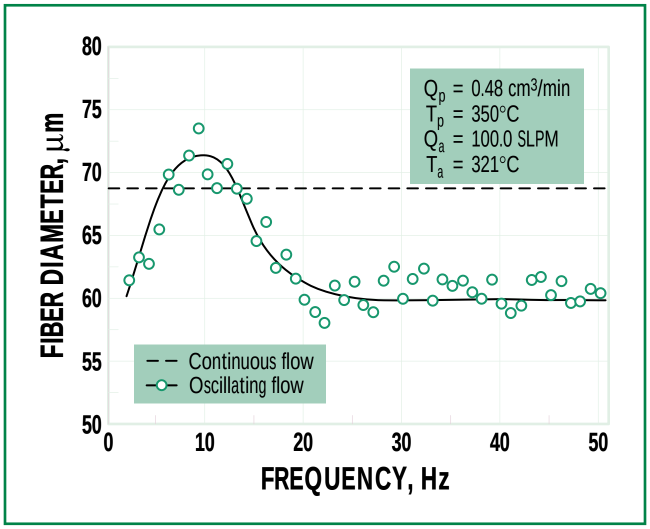
1. Slot melt blowing die



2. Experimental equipment to provide oscillating air to the die: supply air (1), flowmeter (2), on-off valves (3 and 4), oscillating solenoid valve (5), 3-way valves (6 and 7), gas heaters (8 and 9), melt blowing die (10), hot polymer inflow (11), and melt blown fibers (12)



3. Effect of air oscillation frequency on fiber diameter for a gas flow of 54 SLPM



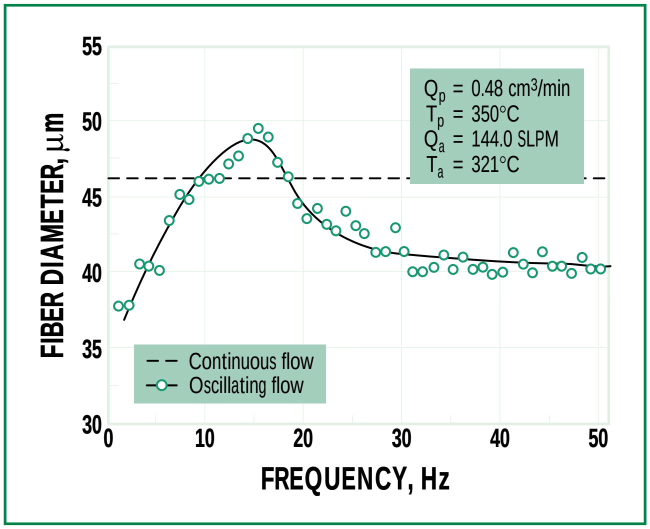
4. Effect of air oscillation frequency on fiber diameter for a gas flow of 100 SLPM

KEYWORDS

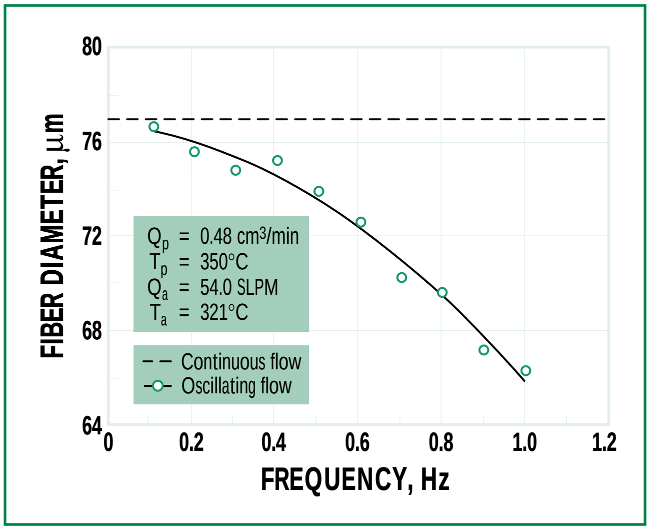
Air flow, dies, fabric, fluid flow, gas flow, mathematical models, melt blowing, models, nonwovens, oscillation, process variables, pulsation, variables.

Figure 7 shows the effect of polymer flow rate on fiber diameter when air oscillation is present. Data show both continuous air flow and oscillation frequencies of 28 Hz and 46 Hz. In Figs. 3–5, these frequencies are in the plateau region where the effect of oscillation is significant. For the entire range of polymer flow rates, Fig. 7 shows there is always a reduction in fiber diameter when using oscillation. In addition, there is no significant difference between the results for 28 Hz and 46 Hz.

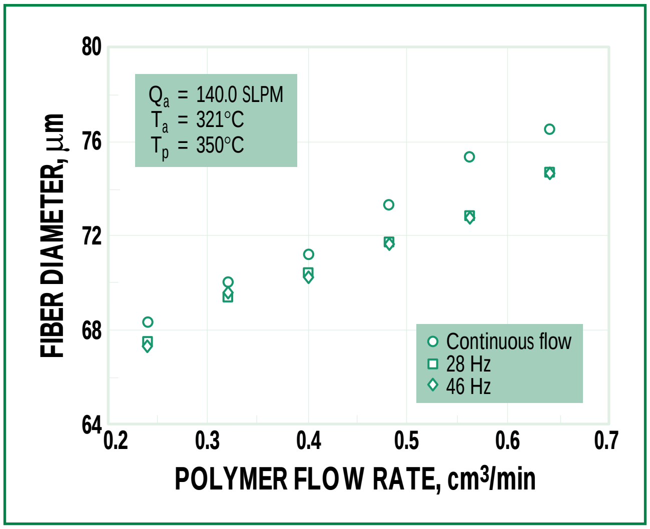
Figure 8 shows the effect of polymer temperature on fiber diameter.



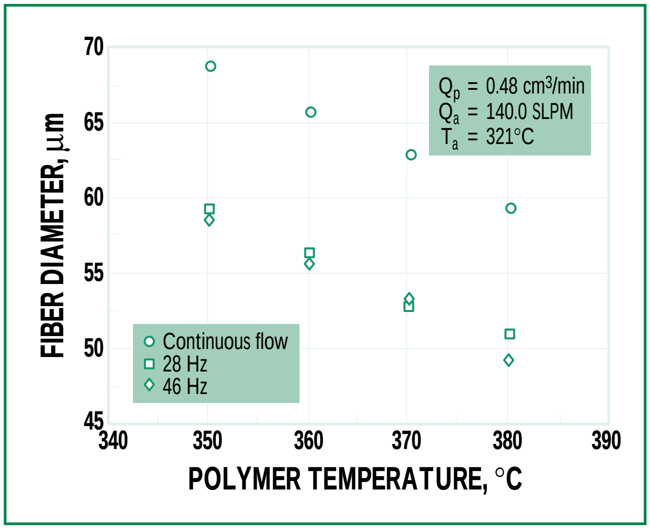
5. Effect of air oscillation frequency on fiber diameter for a gas flow of 144 SLPM



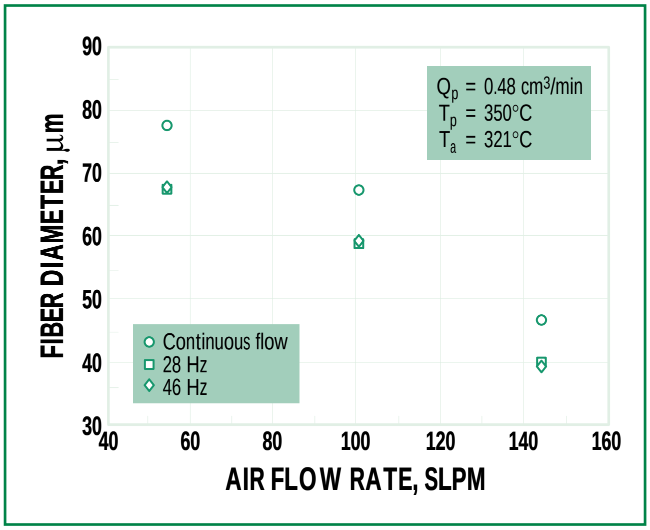
6. Effect of very low oscillation frequency on fiber diameter for a gas flow of 54 SLPM



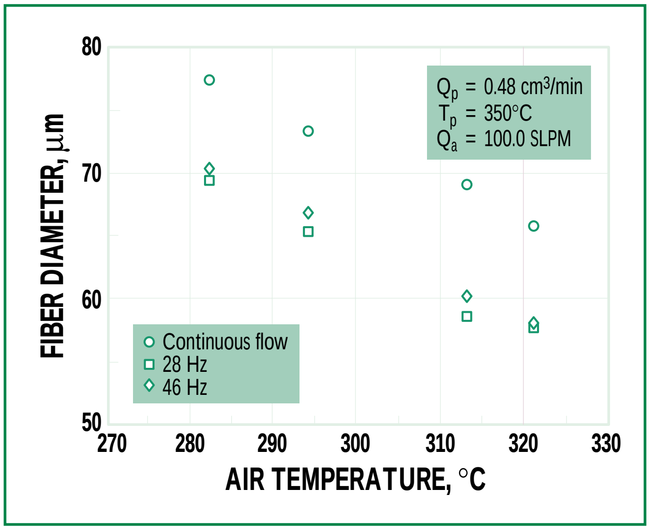
7. Effect of polymer flow rate on fiber diameter when air oscillation is present



8. Effect of polymer temperature on fiber diameter when air oscillation is present



9. Effect of air flow rate on fiber diameter when air oscillation is present



10. Effect of air temperature on fiber diameter when air oscillation is present

Like Fig. 7, it includes data for continuous flow and oscillation frequencies of 28 Hz and 46 Hz. Similar to Fig. 7, the effect of oscillation is significant. There is little difference between the results for 28 Hz and 46 Hz.

Figures 9 and 10 show, respectively, the effects of varying the air flow rate and the air temperature. The results on these two figures are similar to the results for Figs. 7 and 8.

CONCLUSIONS

Feeding oscillated air to a melt-blowing die results in finer fiber diameters. This means that oscillation will allow production of the same size fibers with less air. Oscillation therefore could reduce air handling costs associated with compressing, heating, and recycling.

Use of oscillation may also apply to other fiber spinning processes such as conventional melt spinning and spunbonding. Oscillation could affect the strength and appearance of the meltblown mat. For example, oscillating some fibers in the transverse direction and some fibers in the longitudinal or machine direction could impart a woven look to the mat. **TJ**

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