Plastic Foaming Simulation System

Using Teledyne Isco Syringe Pumps

Syringe Pump Application Note
AN20

Overview

Plastics are used extensively as manufacturing materials throughout the world. In particular, foamed plastics products, with high cell density and uniform cell sizes, offer superior mechanical properties (e.g., toughness[1] and fatigue life[2]) and improved thermal insulation[3] in comparison with solid plastics products. Applications of foamed plastics range from household commodities such as packaging and insulation materials, to advanced engineering products such as airplane and automotive parts with high strength-to-weight ratio. Additionally, foamed plastic products reduce material usage, which typically accounts for 50 to 70% of total production cost.

Theory and Practice

In general, all foaming processes involve four main steps:

- dissolution of gas into a polymer matrix
- cell nucleation
- cell growth
- stabilization of foam structures

In the past, intense research has been conducted to improve foaming technologies and products, using small-scale industrial foam processing equipment such as foam extrusion or injection molding systems. However, in these systems, the bubble nucleation and growth phenomena, which determine the final foam structure (e.g., bubble size distribution and density), were not easily observed. Therefore, optimization in processing strategies and conditions was still based on trial and error.

In this context, researchers in the past have developed experimental foaming simulation systems to capture plastics foaming processes in situ to establish a better understanding of the bubble nucleation and growth phenomena.[4-5]

Based on these studies, an experimental foaming simulation system has been developed at the University of Toronto that can induce a high pressure drop rate to simulate microcellular plastic foaming[6] (Figure 1). This system uses a high speed camera with an optical microscope to capture the foaming process in situ. The end result of the research using the simulation system helps to optimize the processing conditions of various foaming processes, and to facilitate the development of materials with improved foamability.

Experimental Method and Results

On the following page, Figure 1 shows a schematic of the batch foaming visualization system developed by Guo et al.[6] The experimental foaming simulation system consists of a high-temperature, high-pressure chamber in which a small plastic sample is enclosed for each foaming experiment. The temperature and pressure inside the chamber are precisely controlled by an electric heater with PID feedback control and a metered stream of gas supply via a Teledyne Isco Syringe Pump, respectively. The chamber is equipped with a set of two sapphire windows to allow for visualization of the plastic sample. An optical system consisting of a high speed camera coupled with a high magnification zoom lens and an optic fibre transmissive light source, is installed to allow for bright field observation and video recording of the plastic sample during the foaming process. A computer system is integrated into the system to control the opening of the gas exit valve of the chamber and to trigger the high speed camera and pressure transducer to record data.

To carry out a foaming experiment, a thin, disk-shaped plastic sample is placed inside the chamber under a high gas pressure. The chamber is then maintained at the designated temperature and pressure for 30 minutes to allow the blowing agent to completely dissolve into the sample. Finally, the blowing agent is released from the chamber by opening the gas exit valve. The rapid pressure drop inside the chamber causes foaming to occur in the plastic sample. The foaming process is captured in situ by the high-speed camera, and the pressure drop profile is recorded via the readings of the pressure transducer. By adjusting the resistance of the gas exit path, different pressure drop rates can be obtained.

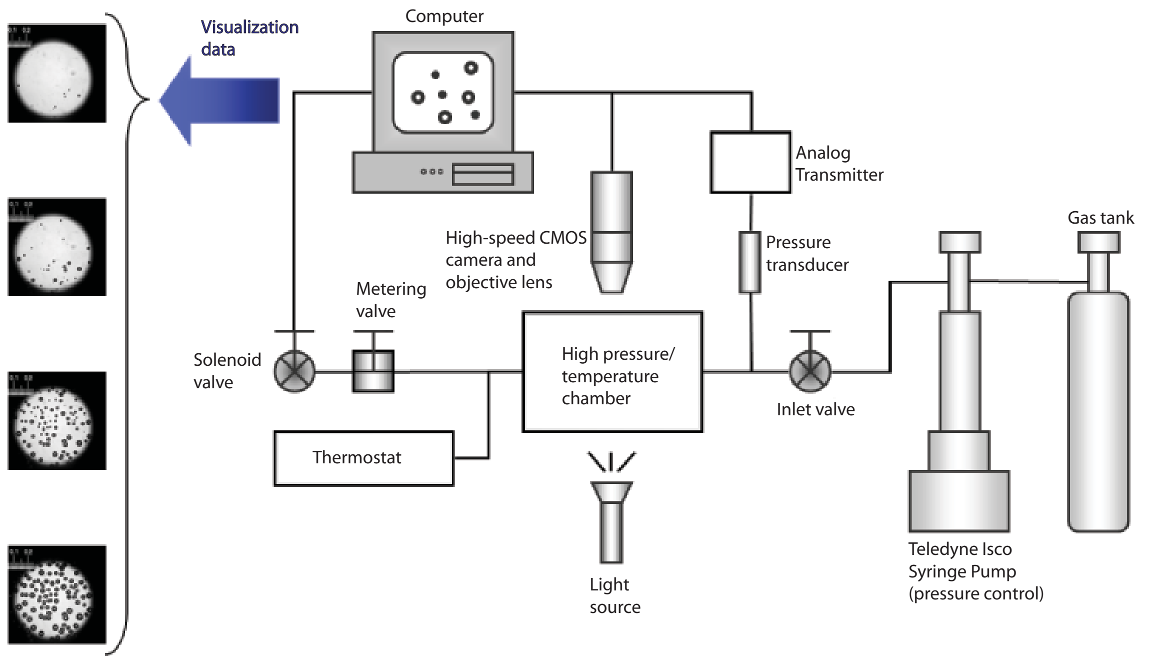

Figure 1: Plastic Foaming Simulation System

The pressure inside the chamber is one of the system's most important experimental parameters for this system. To be specific, it determines the amount of gas that dissolves in the plastic sample and influences the pressure drop rate inside the chamber when gas is released to the surroundings to initiate foaming. Both the gas content and the pressure drop rate were shown to be significant factors for foaming in the previous research;[7,8] hence, it is very important that the pressure inside the chamber be controlled as accurately and precisely as possible.

The Teledyne Isco Syringe Pump supplies gas at a constant pressure inside the chamber. The pressure used in the foaming experiments is normally within the range of 300 to 3,000 psi, well within the capability of the syringe pump. As mentioned previously, for each experiment, the gas pressure is to be maintained at the set level for approximately 30 minutes to allow the gas to be completely dissolved into the polymer sampler before the gas release. During that time, the gas pressure must be accurately maintained at the set level, with minimal fluctuation, because any instability in gas pressure can potentially cause premature foaming inside the plastic sample, which undermines the validity of the experimental results. Therefore, the syringe pump's accurate feedback control of constant pressure with short settling time and minimal steady state error is very crucial to the experimentation of this system and hence is the research behind it, which has a far reaching significance as discussed earlier.

The batch foaming simulation system was used to verify the effects of various experimental parameters on plastic foaming behavior. Similar to the extrusion foaming results, it was found that foaming with a higher pressure drop rate and dissolved gas content leads to increased cell densities[9] Using polystyrene and polycarbonate foaming with carbon dioxide as examples, it was found that the cell growth rate increases with increasing temperature, but cell density decreases slightly due to the accelerated gas depletion rate.[10]

Figure 2 depicts a general trend for cell nucleation rate profile vs. time, and Figure 3 depicts cell density profile vs. time.[11] In the initial foaming stage, the nucleation rate increases due to supersaturation caused by the pressure drop. As the gas concentrate in the polymer decreases due to cell nucleation and growth, the nucleation rate decreases and eventually drops to zero. This results in the nucleation rate profile depicted in Figure 2. The integration of the cell nucleation rate results in the cell density.

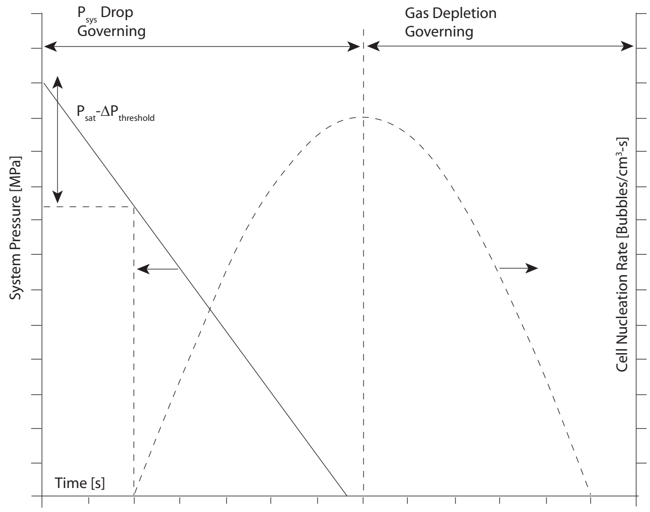

Figure 2: Nucleation rate vs. time

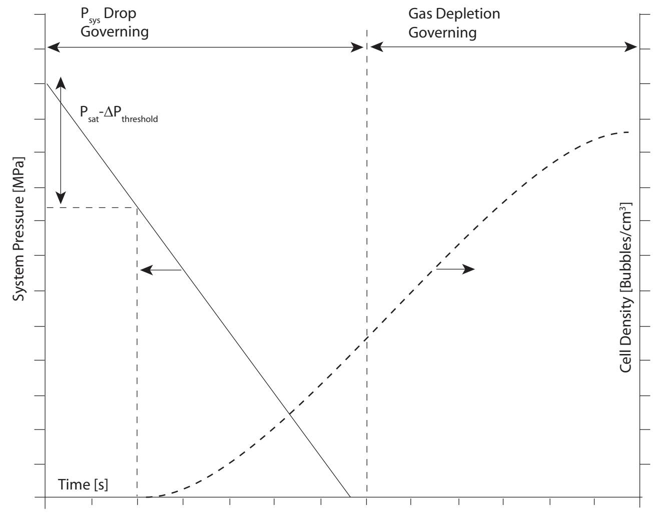

Figure 3: Cell density vs. time

Table 1: Commonly Recommended Pumps

	1000D	500D	260D	100DM	65D
Flow Range (ml/min)	0.100 - 408	0.001 - 204	0.001 - 107	0.00001 - 30	0.00001 - 25
Pressure Range (psi)	0 - 2,000	0 - 3,750	0 - 7,500	0 - 10,000	0 - 20,000

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