Mixing Study of L Shape Mixheads in Reaction Injection Molding

JOHN A. MOLNAR, JR., and L. JAMES LEE,* *Engineering Research Center for Net Shape Manufacturing* and *Department of Chemical Engineering, The Ohio State University, Columbus, Ohio 43210*

Synopsis

The effect of mixhead geometry on the impingement mixing in the reaction injection molding (RIM) process is largely unknown. In this study, high speed photographs are used to show the flow patterns produced by L shape mixheads. The mixing quality of the conventional I and various L shape mixheads is quantified by an emulsion test. The adiabatic temperature rise of a polyurethane/urea system is followed to further characterize the mixing produced by I and L shape mixheads. The results show that L shape mixheads give a better mixing quality than the I shape mixhead, especially at lower Reynolds numbers. In addition, the L shape mixheads can provide a more laminar flow from the mixhead, which is important for mold filling.

INTRODUCTION

Impingement mixing of fast polymerizing reactants is the crucial aspect of the reaction injection molding (RIM) process. Presently, mixheads are largely designed by experience with insufficient understanding of the relationship between the mixhead geometry and the overall mixing quality. The conventional I shape mixheads have a relatively simple geometry where two or more streams impinge at high velocity in a cylindrical chamber. Many researchers[1-4] have shown that if the impingement velocity is high enough, a chaotic motion occurs in the chamber. Studies on nonreactive[2,4-6] and reactive[3,5,7,8] materials have shown that the characterizing mixing quality is a strong function of Reynolds number Re. However, owing to the simplicity of the I shape design, the role mixhead geometry plays in the success of the process is largely ignored.

The advent of the L shape mixhead makes the mixhead geometry more complicated than the conventional I shape. The L shape mixhead differs from the I shape by the addition of another cylindrical channel at a right angle to the mixing chamber.[9] The reacting mixture is forced to flow through the second chamber from the mixing chamber before filling a mold. At the end of the shot, the mixing chamber plunger moves forward until its face lies flush with the inner surface of the second chamber. A second plunger then moves the full length of the second chamber to press the remaining mixture from the chamber into the mold. A commercial I shape and a commercial L shape mixhead are shown in Figure 1.

*To whom correspondence should be addressed.

Journal of Applied Polymer Science, Vol. 37, 2295–2312 (1989)
 CCC 0021-8995/89/082295-18$04.00

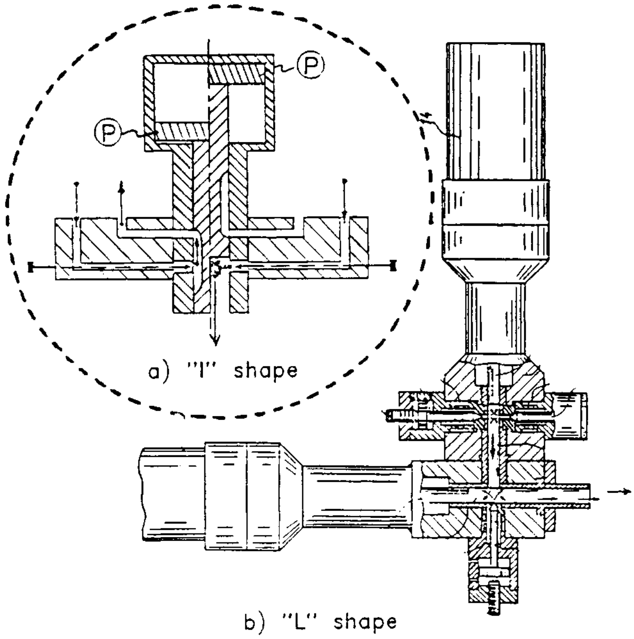


Fig. 1. Typical commercial I and L shape mixheads.

Although patented as early as 1976,[9] questions remain as to how the chamber lengths, diameters, and cross-sectional shapes would affect the mixing quality in the RIM process. This point is vividly illustrated in Figure 2, which shows four commercial L shape mixheads.[9-12] Every design is patented, but the mixing characteristics of each mixhead as influenced by the geometric factors are still uncertain.

The main uncertainty in the design of L shape mixheads centers on the distance from the impingement point to the right angle bend. The Krauss–Maffei design [Fig. 2(a)] is the first patented L shape mixhead which has a relatively long distance from the impingement point to the containing wall of the 90° bend. In this design, the reactants enter from opposing ports, are turbulently mixed in the mixing chamber, encounter the right angle bend, flow into the second chamber, and finally leave the mixhead. The Afros design [Fig. 2(b)] is very similar to the Krauss–Maffei design except that the distance from the impingement point to the bend is quite small. In fact, the key point in this design is to make the impingement point as close to the bend as machining limitations allow, which provides advantages for ease of operation and compactness. This is also claimed to be able to produce a better mixing and a more efficient flow transition from turbulent mixing to laminar mold filling. There is currently a debate as to which design (i.e., the distance from the impingement point to the right angle bend) gives the better performance.

The other mixheads pictured in Figure 2 are designed for more specialized applications. The Upjohn mixhead [Fig. 2(c)] is designed for use with fillers or additives such as pigments. These additives are injected into the reacting mixture by the second chamber. Since these materials do not have to be intensively mixed, only dispersed, they can be entered into the reacting

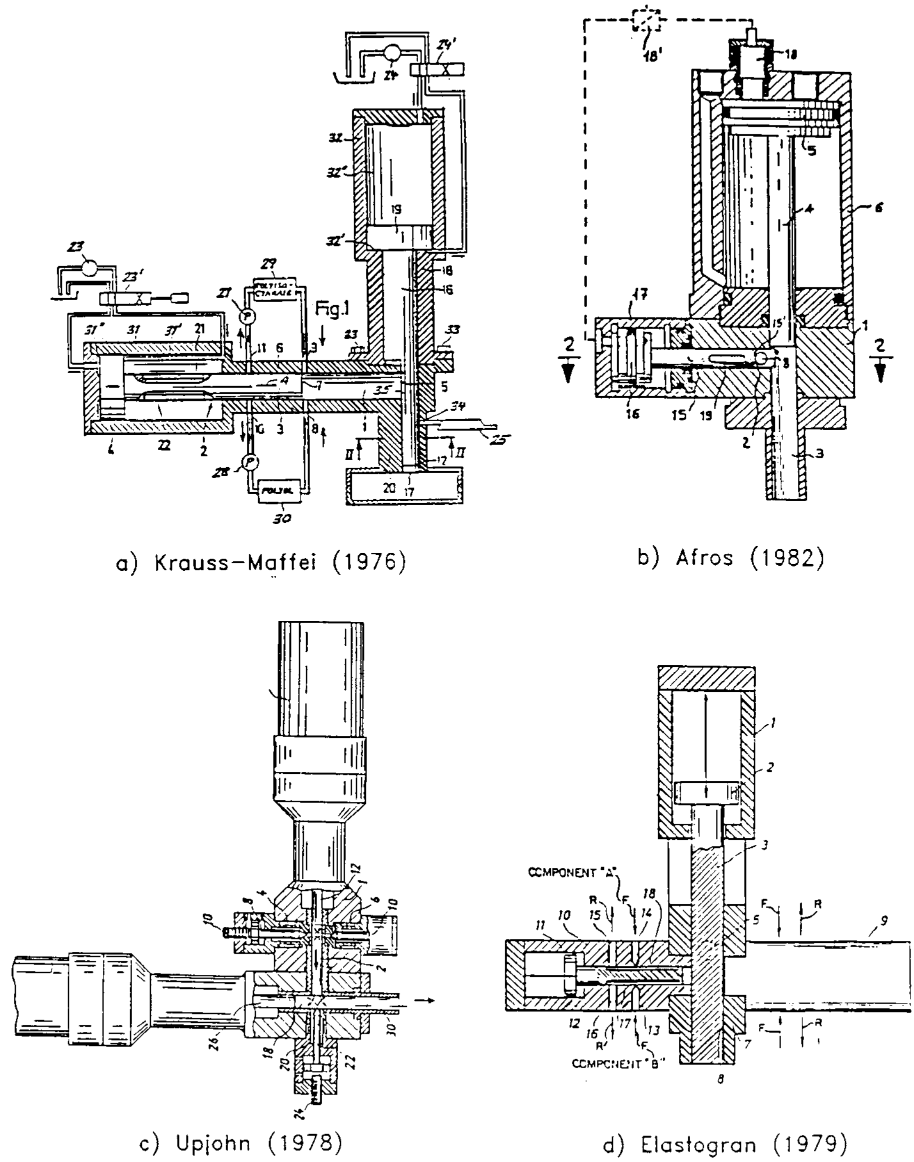


Fig. 2. Commercial L shape mixheads: (a) Krauss–Maffei[9]; (b) Afros[12]; (c) Upjohn[10]; (d) Elastogran.[11]

mixture at a point far downstream from the chaotic mixing zone to prevent clogging of orifices and particle attrition. The Elastogran design [Fig. 2(d)] is actually a T shape mixhead. In this design, two L shape mixheads are combined to allow the processing of incompatible multistream reaction systems.

Since the conventional I shape mixhead is generally simpler than the L shape mixhead, the question arises as to why use the L shape mixhead. This question can be answered by analyzing flow patterns inside a RIM mixing

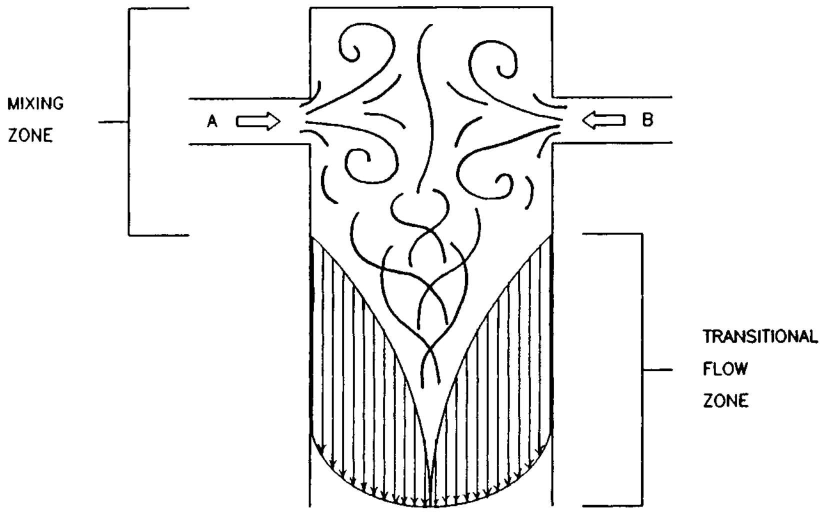


Fig. 3. Schematic of flow patterns inside a RIM mixhead.

chamber and by realizing the functions of the mixhead. As shown in Figure 3,[13] a mixhead must perform two main functions. The first is to provide a good mixing of the individual reactant streams. This is done in a turbulent mixing zone created by the high speed impingement of the feed components. The second function is to provide as laminarlike a stream as possible from the mixhead to insure proper mold filling. The I shape mixhead performs both tasks adequately in typical RIM processes mainly due to the design of the conventional RIM mold.[14,15] In these molds, an aftermixer and runner system is attached to the end gate of the mold to provide additional mixing and the back pressure for a transition to laminar flow needed in mold filling. However, in open mold foam blowing processes, such a system cannot be used. Thus, the mixhead must provide the good mixing and the necessary flow transition. This makes the L shape mixhead an attractive option for such open mold operations.

Another application for the L shape mixhead may be found in the structural RIM (SRIM) process. In this process, a performed continuous or woven fiber mat is placed directly into the mold prior to filling. The reacting resin stream is then injected into the closed mold, allowing the resulting resin and mat system to be demolded as a composite. A center gate design is typical in SRIM molds to minimize the flow path and to stabilize the mat against the pressure generated from mold filling. This center gate makes the incorporation of an aftermixer and runner system into the mold impractical, giving the L shape mixhead an expected advantage over the I shape mixhead.

This work discusses the flow patterns in various L shape mixheads using flow visualization. An attempt to quantify the extent of mixing for different L shape mixheads by using the emulsion test is presented. Finally, the adiabatic temperature rise method is used to study the mixing of reactive systems for an I and an L shape mixhead.

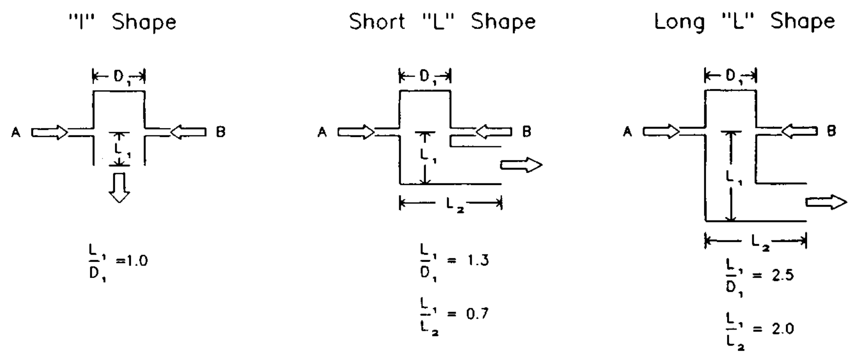


Fig. 4. Schematic diagram of the experimental RIM mixheads: (a) I shape; (b) short L shape; (c) long L shape.

EXPERIMENTAL

The experimental work in this study was carried out in a laboratory scale RIM machine. The detailed description of this machine is given elsewhere.[8] This machine is capable of delivering up to 250 mL of liquid at rates up to 125 mL/s and a maximum pressure of 2000 psi in the material cylinders.

An I shape mixhead consisting of a plexiglass block with two opposing 1.18 mm diameter impingement nozzles and a 6.35 mm diameter mixing chamber (D_1) with a 6.6 mm length (measured from the impingement nozzle to the end of the chamber) was fitted to the lab RIM machine. Two L shape mixheads were constructed by screwing on attachments consisting of a 6.35 mm diameter chamber with a right angle bend of varying lengths to the basic I shape block. The joint was sealed with an O ring. These L shape mixheads were classified as a short, a medium, and a long L depending on the ratio of mixing chamber length (L_1) to the second chamber length (L_2). The long L has $L_1/L_2 = 1.5$ ($L_1/D_1 = 2.5$), while the medium L has $L_1/L_2 = 1.0$ ($L_1/D_1 = 2.0$). Additionally, a single piece short L mixhead, $L_1/L_2 = 0.2$ ($L_1/D_1 = 1.3$), was also built. A schematic of these three mixheads is shown in Figure 4.

For reactive material testing, an aluminum mixture chamber with two 1.18 mm diameter impingement nozzles and a 6.35-mm diameter chamber was used. The two impingement nozzles were angled 120°, instead of face to face, to avoid any flow crossover. The clean out plunger was retracted about 3 mm from the nozzles during impingement. An I shape mixhead (L_1 = 3.28 cm) and a long L shape mixhead ($L_1/L_2 = 1.35$, $L_1/D_1 = 5.4$) were constructed for the test.

Flow Visualization

A DOP oil (diphenyl–octyl–phthalate) with a viscosity of 80 cP was used for the flow visualization study. The small density fluctuations of fluid generated during mixing were found to satisfactorily trace the fluid motion in the mixhead. Photographs of the L shape mixheads were taken with a 35 mm camera (Olympus, PM-6) mounted on a binocular microscope (Olympus, SZ-Tr) set at 7× magnification with a flash strobe mounted approximately 10 cm above the mixhead. The exposure time was determined by the flash speed (10^{-3}–10^{-4} s). The mixhead geometries were varied, and photos were taken at various flow rates. Since the whole mixhead could not be covered in a single picture, photos from two different shots at the same conditions were pieced together to cover the entire fluid path.

Photographs of the flow out of the I and L shape mixheads and also of test tubes containing the mixture were taken with a standard 35 mm camera (Pentax) and floodlights. The material used was a glycerine–water mixture with a viscosity of 200 cP.

Emulsion Test

The mixing quality of the various mixheads was quantified using a procedure known as the emulsion test.[17,18] In this test, one stream of a glycerine–water mixture (200 cP viscosity) and another stream of a butanediol–polyol (TONE-0305, Union carbide) mixture (200 cP viscosity) were

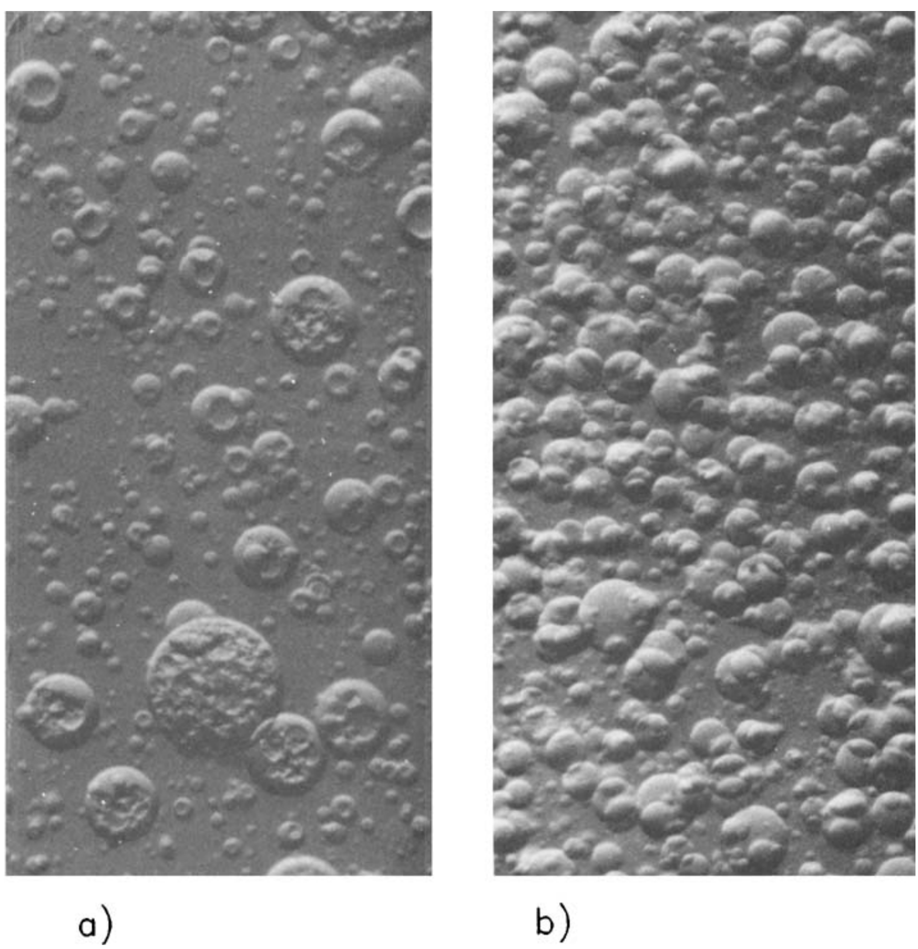
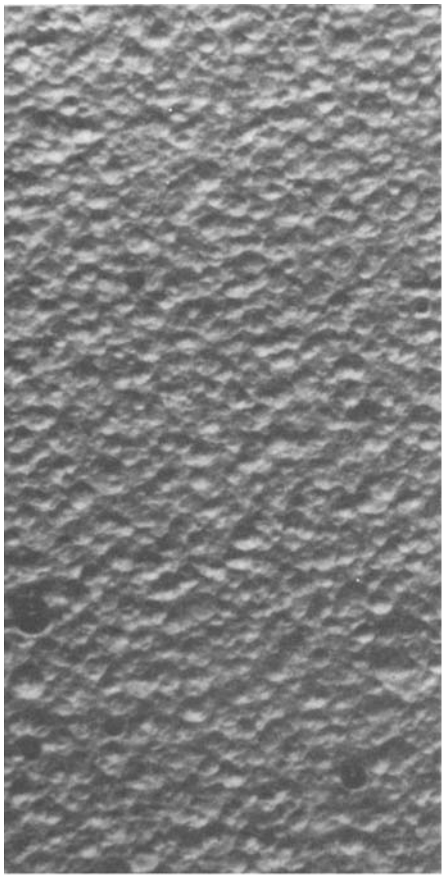


Fig. 5. Photomicrographs at 40× showing dispersed droplet sizes in a glycerine–water, butanediol–polyol emulsion: (a) poor mixing; (b) medium mixing; (c) good mixing.



c)

Fig. 5. (*Continued from the previous page.*)

impingement mixed in equal volumes at different flow rates. The resulting emulsion was centrifuged for 2 min at a high rotation speed. Upon centrifuging, a portion of the butanediol–polyol mixture tended to cream up, while the remainder stayed in emulsion with the glycerine–water mixture. Thus, the amount of separation present in the centrifuged emulsion gave an indication as to the quality of mixing produced by the mixhead.

Figure 5 shows photomicrographs at 40× magnification of the dispersed droplets in emulsions produced by a stirred mixer prior to centrifuging. The poorly mixed sample contains droplets of a much larger size and a broader distribution than the better mixed samples. After centrifuging, the poorly mixed emulsion separates more easily than the better mixed samples. Thus, the total length of emulsion after centrifuging increases as the mixing intensifies. This fact allows calculation of a mixing index MI by dividing the length of emulsion after centrifuging, L, by the total length of the shot, L_0. A schematic of the emulsion test is illustrated in Figure 6.

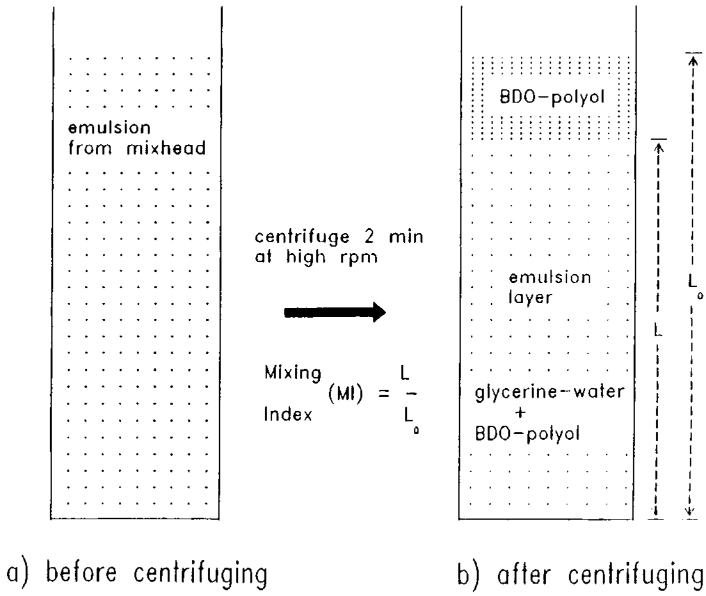


Fig. 6. Schematic diagram of the emulsion test.

Adiabatic Temperature Rise Method

A crosslinking polyurethane/urea was used for the adiabatic temperature rise measurements. A complete formulation of the material system is given in Table I. This system is similar to a basic crosslinked polyurethane except that the chain extender was replaced by a diamine. The A stream consists of a mixture of polyol and diamine with a viscosity around 50 cP at room temperature. The B stream is a mixture of high and low molecular weight diisocyanates and has a viscosity similar to that of the A stream. One-tenth percent (0.1%) by weight of dibutyltin dilaurate catalyst (T12, M & T Chemical) was added to the A stream to produce a reaction with a gelation time of around 10 s at an initial material temperature of 25°C. All materials were degassed overnight at room temperature to prevent foaming in the open mold. The A and B side components were mixed in our mini RIM machine at a

TABLE I
Polyurethane/Urea System Used for the Adiabatic Temperature Rise Measurement

A side	Polyol TONE0305 (Union Carbide)	6.0 parts
	Diamine DETDA diethyltolulenediamine	27.0 parts
	Catalyst T12 (M & T Chemical)	0.1 parts
B side	Diisocyanate 1305 (Dow Chemical)	44.0 parts
	Diisocyanate 143L (Dow Chemical)	22.0 parts

stoichiometric ratio of 1.05 with a 5% excess isocyanate used to insure complete reaction. The flow rate ratio of the A and B components is 1/1.67.

Temperature rise was measured with a 24 gauge, exposed tip J-type thermocouple placed in the center of a styrofoam coffee cup. Material was injected into the cup directly from the mixhead to lessen any aftermixing. Adiabatic temperature vs. time measurements were recorded using a chart recorder (Houston Instruments, Omniscribe D5000). Following the material preparation, the cup samples were cut in half using a band saw to permit cross-sectional viewing.

RESULTS AND DISCUSSION

In the following results, the nozzle Reynolds number is calculated from

$$\mathrm{Re} = 4Q\rho/\pi d\mu \tag{1}$$

where Q is volume flow rate through the nozzle, ρ density, d nozzle diameter, and μ viscosity. Unless otherwise noted, the lower Re of the two streams, that of the polyol–diamine stream, is used.

Flow Visualization

Figure 7 shows the photographs taken for the short L shape mixhead at Re = 200 and 800. At the low Re, the streamlines and the vortex formation of the flow are plainly visible. Three flow regions can be identified on the photographs. Near the impingement point, a turbulent-like chaotic flow is formed. Since mixing occurs in a confined chamber, wall drag effect and viscous dissipation gradually change the flow from a chaotic type to a laminar type. It appears that the 90° bend of the L shape creates a vortex type of flow near the corner when the fluid changes flow direction. In the second chamber, the flow is primarily a laminar flow. Increasing the flow rate (i.e., higher Re) tends to increase the space of the turbulent-like flow region and decrease the space for vortex formation near the corner. Consequently, the flow in the second chamber becomes less laminar and not as stable as the low Re. Compared with results from I shape mixheads, the L shape would cause less spray from the mixhead than the I shape since the 90° bend produces a rapid change of flow from the chaotic mixing region to a more ordered region. However, at high Re, such a transition is not as efficient for the short L shape mixhead.

Figure 8 shows photographs taken at Re = 400 for the long and short L shape mixheads. The flow in the long L shape mixhead can also be divided into three distinct regions. A turbulent-like region near the impingement point is followed by a transition region downstream. Near the 90° bend, the flow becomes laminar and no visible vortex formation can be seen at the given conditions. The flow in the second chamber appears to be a stable laminar flow. Compared with the results from the short L shape mixhead, the long L shape mixhead would cause less spray at the outlet of the mixhead.

The flow patterns inside the mixhead determine the flow out of the mixhead as shown in Figure 9. At Re = 100, the I shape mixhead produces a very spraying, random flow. The short L shape mixhead gives a calmer stream;

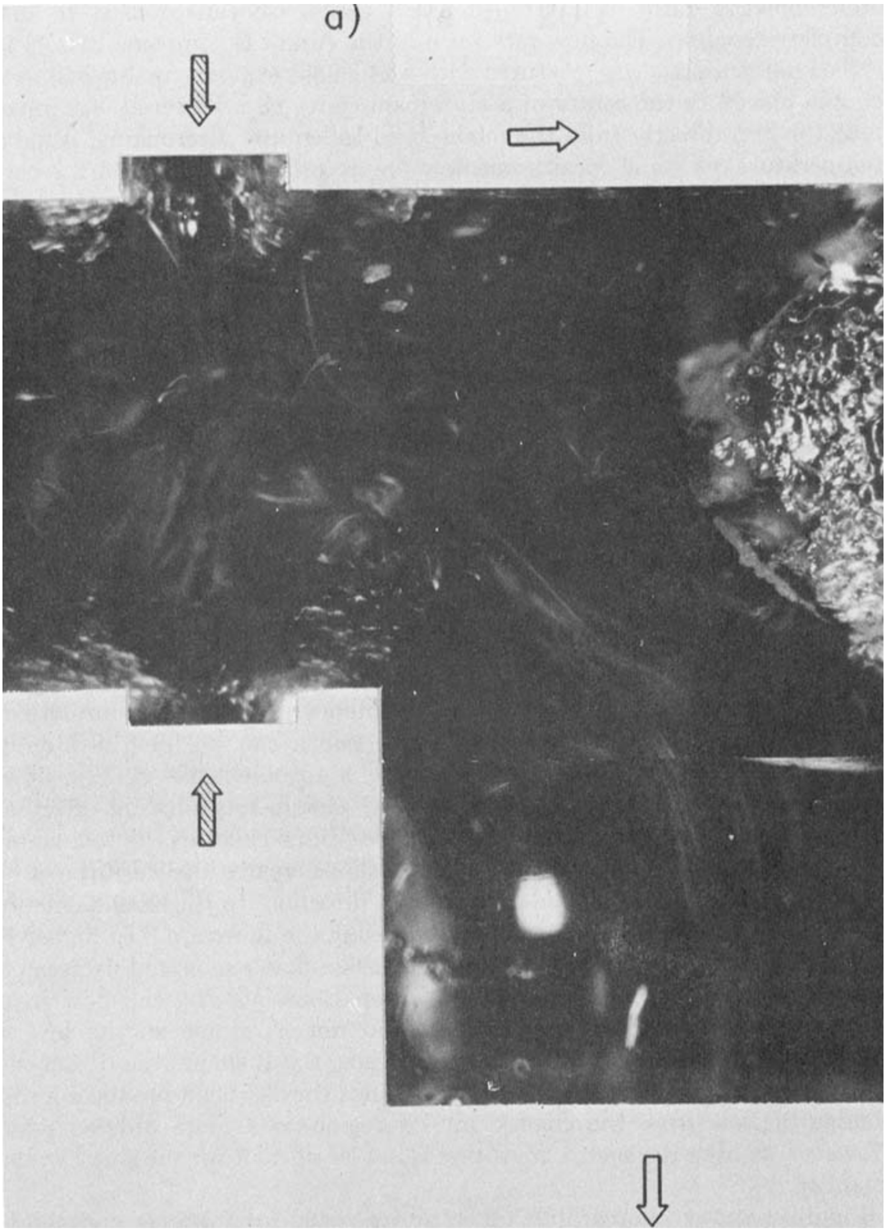


Fig. 7. Flow patterns of impingement mixing in a plexiglass short L shape mixhead for (a) Re = 200 and (b) Re = 800.

however, some twisting of the flow still results. By far, the long L shape mixhead achieves the most quiet, stable, laminar-like flow from the mixhead outlet. At a higher Reynolds number, Re = 200, the same tend is present. The I shape mixhead causes the most chaotic flow; the short L shape mixhead gives a somewhat quieter flow, while the long L shape mixhead produces the best overall quality flow from the outlet.

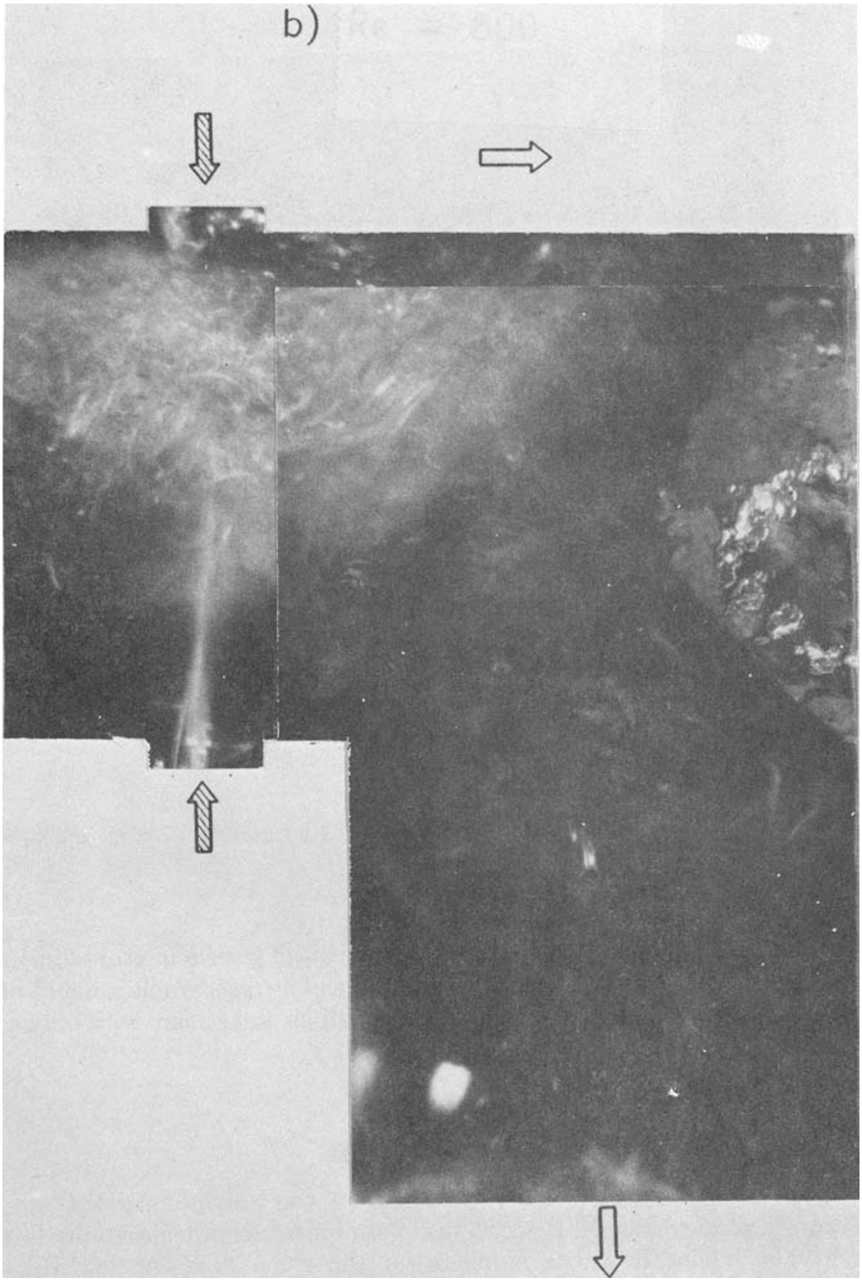


Fig. 7. (*Continued from the previous page.*)

Air bubble entrapment is also readily apparent in the mixture. At low Re (i.e., Re < 100), all mixheads give mixtures relatively free of air bubbles. However, at a higher Re of 200, the mixture from the I shape mixhead becomes cloudy with entrapped air bubbles, the mixture from the short L shape mixhead contains a few bubbles, while the product from the long L shape mixhead still remains relatively free of any air entrapment. This trend

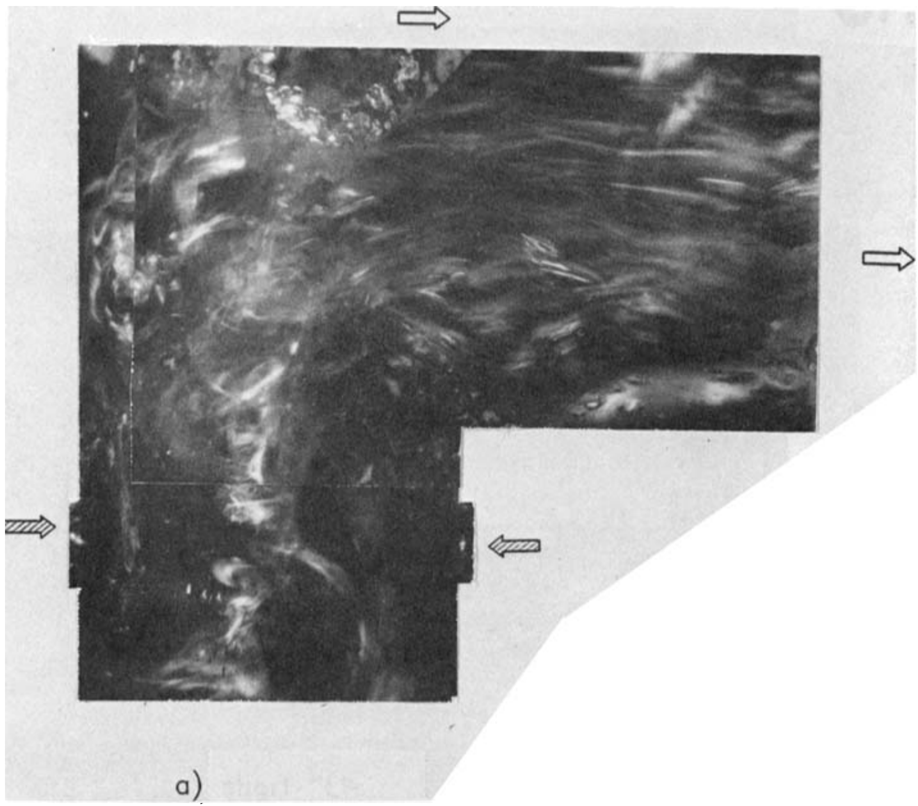


Fig. 8. Flow patterns of impingement mixing at Re = 400 for (a) short L shape and (b) long L shape mixheads.

continues at a Re = 250 where the I shape mixhead gives a mixture filled with air bubbles, the short L shape mixhead produces a considerable amount of air entrapment, and the long L shape mixhead still gives a stream with only a few bubbles.

Emulsion Test

Figure 10 shows a plot of MI vs. log Re for the I shape mixhead and the medium L shape mixhead. It seems that both mixheads provide similar mixing quality at higher Reynolds numbers for the given fluid. At low Re (i.e., Re < 100), the L shape mixhead does appear to give a slightly better mixing. The additional mixing in the L shape mixhead may be provided by the increased back pressure in the mixing chamber and the vortex formation provided by the 90° bend. The downward trend in the mixing indices for the I shape mixhead from Re = 250 to Re = 300 seems to indicate that a critical Re has been reached. Above this critical Re, the mixing quality may become worse. This is because that there is little back pressure in the I shape mixhead, and the material residence time in the mixing chamber is quite short at high flow rates. Consequently, the material is expelled before there is much

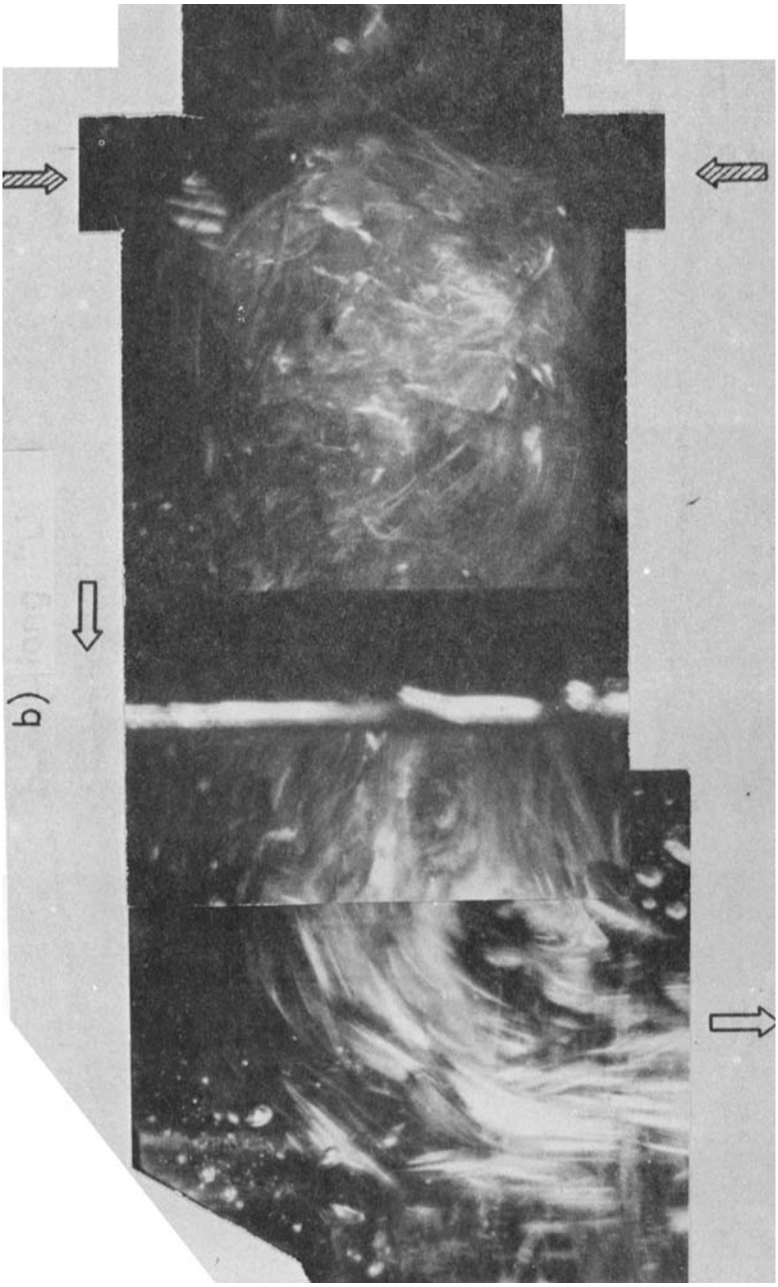


Fig. 8. *(Continued from the previous page.)*

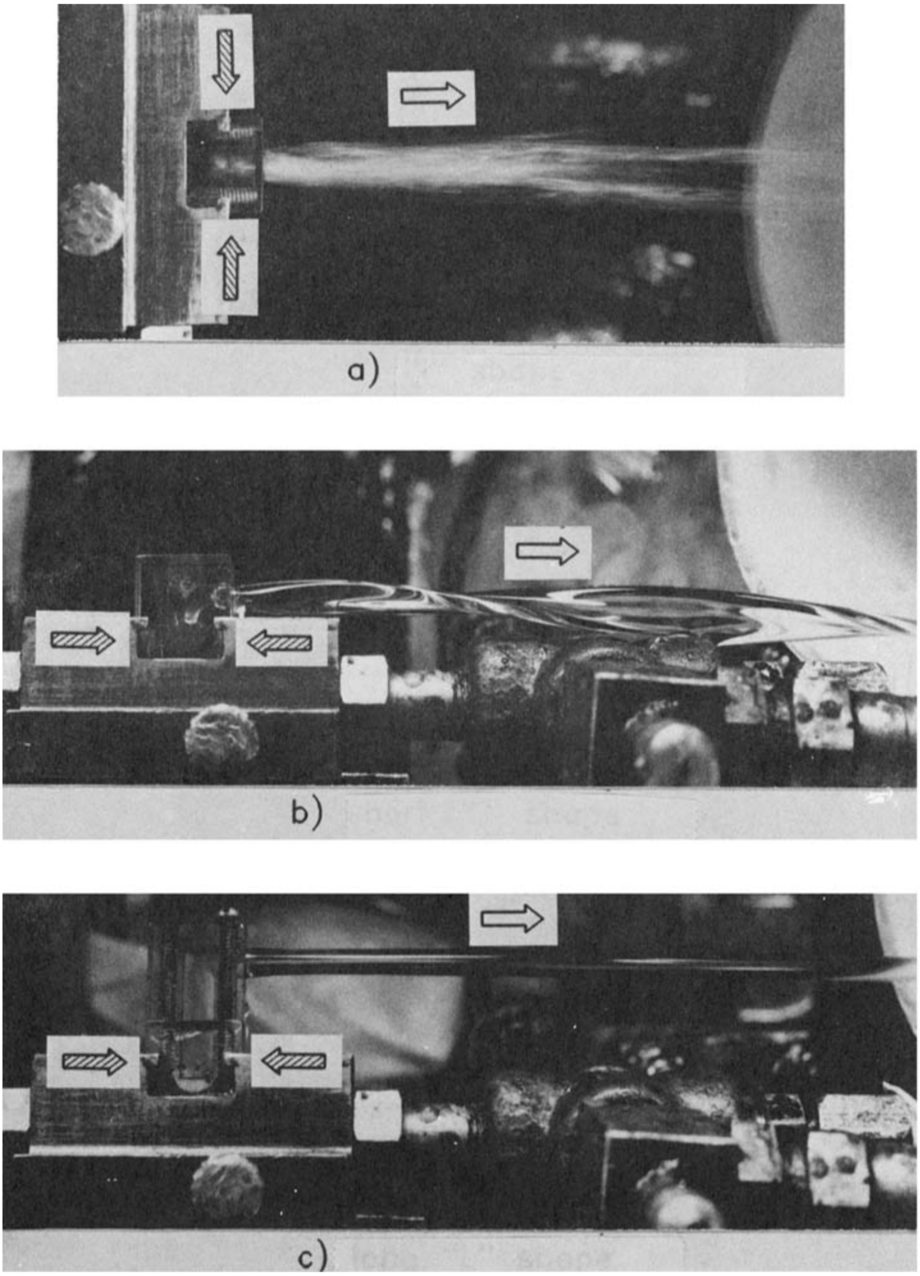


Fig. 9. Flow from the mixhead outlet of a glycerine–water mixture at Re = 100 for (a) I shape, (b) short L shape, and (c) long L shape mixheads.

intimate contact between the impinging streams. The L shape mixhead shows a monotonical improvement of mixing quality with increasing Re.

In Figure 11(a), the mixing indices for the short, medium, and long L shape mixheads are plotted vs. various Re. Overall, the long L shape mixhead does appear to give a slightly better mixing than either the short or the medium L

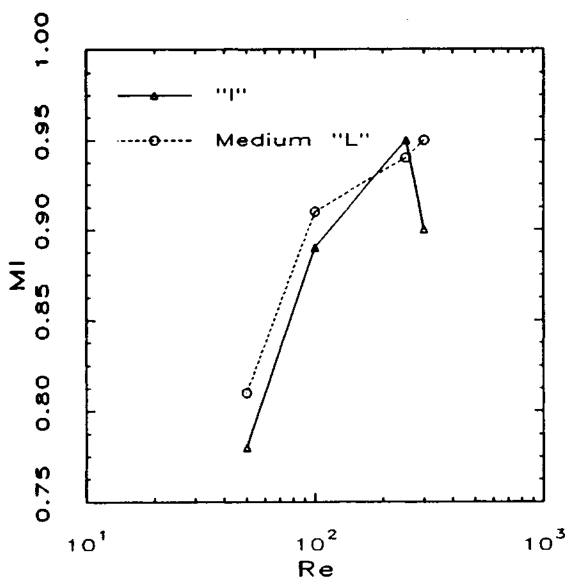
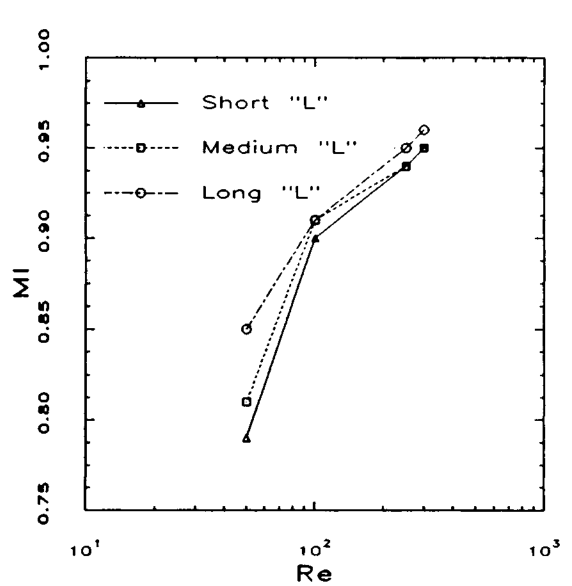
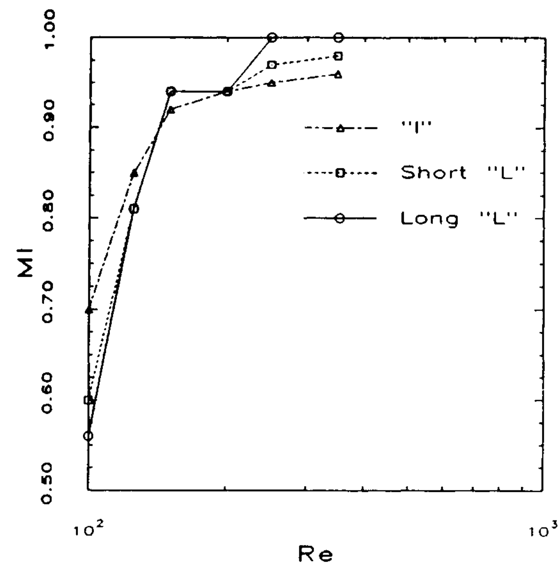


Fig. 10. MI vs. log Re for the I (—△—) and medium L (--○--) shapε mixheads. Viscosity is 200 cP.



(a)

Fig. 11(a). MI vs. log Re for the short (—△—), medium (--□--), and long (—-—○—-—) L shape mixheads. Viscosity is 200 cP.



(b)

Fig. 11(b). MI vs. log Re for the I (——△——), short L (- -□- -), and long L (—○—) shape mixheads. Viscosity is 150 cP.

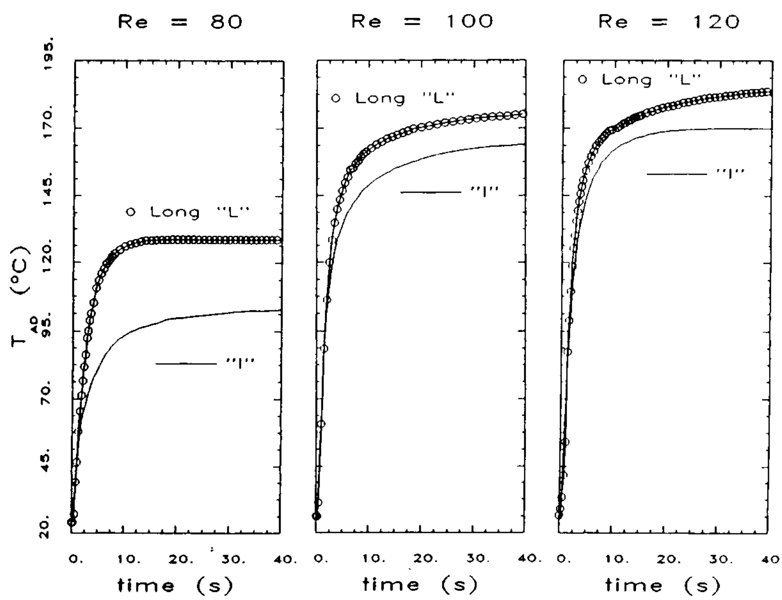


Fig. 12. Adiabatic temperature rise vs. time for the I (—) and long L (○) shape mixheads at Re = 80, 100, and 120.

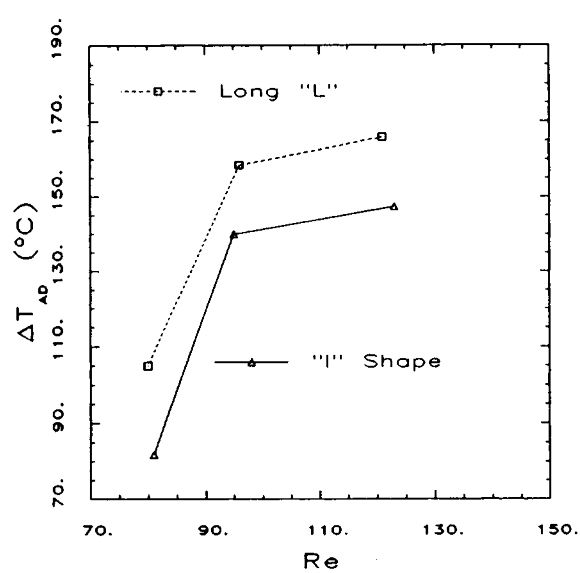


Fig. 13. ΔT_{AD} vs. Re for the I (—△—) and long L (- -□- -) shape mixheads.

shape mixhead. The effect of viscosity on mixing was considered by lowering the viscosities of both the glycerine–water side and the butanediol–polyol side to 150 cP [Fig. 11(b)]. Again the long L shape mixhead gives a better mixing than the short L shape mixhead, especially at the Reynolds numbers more representative of commercial processing conditions (i.e., $150 < \text{Re} < 250$).

Adiabatic Temperature Rise Method

The data from the adiabatic temperature rise measurements are given in Figure 12 as plots of adiabatic temperature (T_{AD}) vs. time at Re = 80, 100, and 120 for the I shape and long L shape mixheads. In all three cases, the long L shape mixhead produces the higher absolute temperature and also the faster reaction rate. Adiabatic temperature rise (ΔT_{AD}) vs. Re for those two mixheads is given in Figure 13. This plot shows that the ΔT_{AD} for both mixheads has a similar dependence upon Re, but that, for a given Re, the long L shape mixhead results in a higher reaction exotherm (i.e., better mixing) than the I shape mixhead.

Cross sections of the mixed polyurethane/urea samples show results similar to those from the adiabatic temperature rise measurements. Namely, samples from both mixheads show a strong dependence on mixing in that those mixed at low Reynolds numbers (i.e., Re = 80) show signs of poor mixing and unreacted monomers, while those samples mixed at higher Reynolds number (i.e., Re = 100, 120) show a more homogeneous structure. However, the samples molded at Re = 100 appear to be of a better quality than those mixed at Re = 120. This is mainly due to the increased bubble entrapment caused by the random, turbulent stream from the mixheads. Generally, the samples from the long L shape mixhead appear better mixed than the samples from the I shape mixhead, which is also in agreement with other experimental results.

CONCLUDING REMARKS

In this work, we have shown that the L shape mixheads give better mixing than the conventional I shape mixhead in both reactive and nonreactive tests. The L shape mixheads also provide a much more laminar-like flow from the outlet than the I shape mixhead which is important for mold filling. Comparing the long and short L shape mixheads, it is found that the long L shape mixhead is slightly better than the short L shape mixhead in both the mixing and the flow quieting aspects.

The L shape mixhead is currently used industrially in foam blowing processes. The flow quieting and spray controlling features of the L shape mixhead make it particularly suitable for these open mold operations. It, however, may also be very valuable for processing low viscosity resins in the increasingly popular structural RIM process.

We hope that the mixing studies of the L shape mixhead presented here provide some insight into the design of desirable mixheads for various applications in the RIM process.

The authors would like to thank Dr. Taylan Altan, Director of the NSF-sponsored Engineering Research Center at the Ohio State University for his support of this work. This work was also partially supported by the OSU Polymer Engineering Research Program which is sponsored by General Motors, Union Carbide, GenCorp, and Owens-Corning Fiberglas.

References

1. G. Menges, *Kunststoff-Rundshau*, **10**, 435 (1973).
2. S. C. Malguarnera and N. P. Suh, *Polym. Eng. Sci.*, **17**, 111 (1977).
3. L. J. Lee, J. M. Ottino, W. E. Ranz, and C. W. Macosko, *Polym. Eng. Sci.*, **20**, 868 (1980).
4. C. L. Tucker and N. P. Suh, *Polym. Eng. Sci.*, **20**, 875 (1980).
5. L. T. Nguyen and N. P. Suh, *Polym. Eng. Sci.*, **26**, 843 (1986).
6. D. J. Scandell, C. W. Mascosko, and W. E. Ranz, *Polym. Proc. Eng.*, **3**, 57 (1987).
7. P. Kolodziej, C. W. Mascosko, and W. E. Ranz, *Polym. Eng. Sci.*, **22**, 288 (1982).
8. M. Nelson and L. J. Lee, *J. Appl. Polym. Sci.*, in press.
9. K. Schluter, U.S. Pat. 3,975,128 (1976).
10. D. Muhl, U.S. Pat. 4,115,299 (1978).
11. F. Schneider, U.S. Pat. 4,175,874 (1979).
12. C. Florentini, U.S. Pat. 4,332,335 (1982).
13. Y. M. Lee and L. J. Lee, *Polym. Proc. Eng.*, **6**(1), 91 (1988).
14. F. M. Sweeney, *Introduction to Reaction Injection Molding*, Technomic, Lancaster, PA, 1987.
15. L. J. Lee, *Rubber Chem. Technol.*, **53**, 542 (1980).
16. D. Nelson, *Plast. Eng.*, **29** (Nov.), (1987).
17. F. Schneider, Krauss-Maffei Corp., private communication, 1987.
18. M. Begemann, thesis, I.K.V., Aachen Technical University, 1985.

Received March 3, 1988
Accepted May 10, 1988