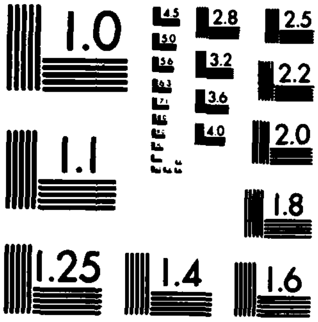
AD-A146 556 THE CONCEPT OF SOLID SOLVENT AS PROCESSING AID(U) 1/1
RENSSELAER POLYTECHNIC INST TROY NY C I CHUNG
20 SEP 84 TR-1 N00014-83-K-0424
UNCLASSIFIED F/G 11/11 NL



COPY RESOLUTION TEST CHART

12

OFFICE OF NAVAL RESEARCH

CONTRACT N00014-83-K-0424

TECHNICAL REPORT NO. 1

THE CONCEPT OF SOLID SOLVENT AS PROCESSING AID

BY

Chan I. Chung
Polymer Science and Engineering Program
Rensselaer Polytechnic Institute
Troy, New York 12180-3590

September 20, 1984

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: 1

2. GOVT ACCESSION NO.: AD-A146556

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): THE CONCEPT OF SOLID SOLVENT AS PROCESSING AID

5. TYPE OF REPORT & PERIOD COVERED: Technical Report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): C.I. Chung

8. CONTRACT OR GRANT NUMBER(s): N00014-83-K-0424

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Rensselaer Polytechnic Institute
Troy, New York 12181

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS:
Chemistry Branch
Office of Naval Research
Arlington, VA 22217

12. REPORT DATE: September 20, 1984

13. NUMBER OF PAGES: 31

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report):
Technical Report Distribution List, GEN & 356B.
For unlimited distribution and public release.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES:
To be submitted to J. Poly. Sci.-Poly. Phy. Ed.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Solid Solvent
Processing Aid
Low molecular weight crystalline material

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The concept of solid solvent entails the use of a low molecular weight crystalline materials (LMC) as a processing aid. A LMC as an ideal solid solvent mixed into a polymer is expected to become a solvent for the polymer at high processing temperatures reducing the melt viscosity and thus enhancing the processability, but to become a non-solvent for the polymer at low use temperatures

(continued on back)

precipitating out of the polymer without adversely affecting the properties of the polymer.

The feasibility of such concept was examined using acetanilide as a potential solid solvent for polystyrene (PS) and Kraton 1101, a block copolymer containing PS blocks. Acetanilide demonstrated the essential features required of a solid solvent supporting the concept of solid solvent. It had a high solubility in PS at high temperatures very effectively reducing the melt viscosity of PS and Kraton 1101, and it precipitated out of PS at low temperatures although it had an undesirably high residual solubility. The concept of solid solvent appears to be a viable one.

THE CONCEPT OF SOLID SOLVENT AS PROCESSING AID

Chan I. Chung
Polymer Science and Engineering Program
Rensselaer Polytechnic Institute
Troy, New York 12180-3590

SYNOPSIS

The concept of solid solvent entails the use of a low molecular weight crystalline materials (LMC) as a processing aid. A LMC as an ideal solid solvent mixed into a polymer is expected to become a solvent for the polymer at high processing temperatures reducing the melt viscosity and thus enhancing the processability, but to become a non-solvent for the polymer at low use temperatures precipitating out of the polymer without adversely affecting the properties of the polymer.

The feasibility of such concept was examined using acetanilide as a potential solid solvent for polystyrene (PS) and Kraton 1101, a block copolymer containing PS blocks. Acetanilide demonstrated the essential features required of a solid solvent supporting the concept of solid solvent. It had a high solubility in PS at high temperatures very effectively reducing the melt viscosity of PS and Kraton 1101, and it precipitated out of PS at low temperatures although it had an undesirably high residual solubility. The concept of solid solvent appears to be a viable one.

INTRODUCTION

One of the most important advantages of polymeric materials over other classes of materials lies in the easiness of processing. Polymers can be quite easily and inexpensively processed into desired shapes. Some polymers, however, possess a high viscosity usually accompanied by a high elasticity at the processing temperatures, causing processing difficulties. Especially, polymer blends and block copolymers with a multiphase structure often exhibit such behavior. A significant reduction of the viscosity at the processing temperatures is desirable to enhance the processability for those polymers.

Solvents (or plasticizers) are very effective in reducing the viscosity of polymers.(1) They can reduce the viscosity by a factor much greater than their weight of volume fractions, but they also adversely affect the properties at the use temperatures resulting in a lower modulus and a lower use temperature range, etc. unless they are removed from the products after processing. Thus, the use of solvents as processing aid is impractical.

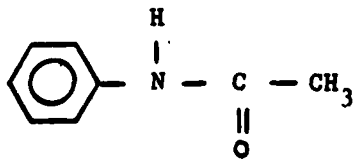
The concept of solid solvent is to use a low molecular weight crystalline materials (LMC) as a processing aid for polymers. A LMC as an ideal solid solvent should become compatible with a polymer and act as a solvent in the liquid state above its melting point, significantly reducing the viscosity of the polymer, but should become incompatible and crystallize out of the polymer as discrete domains below its melting point without adversely affecting the properties of the polymer. A drastic increase in the compatibility between a LMC and a polymer upon melting the LMC can be expected because the entropy of mixing between the liquid LMC without any structural contraint and the polymer is drastically greater than that between the solid LMC with the crystalline structural constraint and the polymer. A higher entropy of mixing results in a lower free energy of mixing, making the mixed state as thermodynamically more stable state when the free energy of mixing eventually becomes negative.(2) Several LMC - polymer systems, which exhibit the essential behavior as postulated in this paper for a solid solvent, have been reported by some investigators in their study of the effects of LMC on the physical properties of polymers.(3-6) Linnig, et.al.(3) found that cyrstalline organic compounds having a β - naphthyl group increased the modulus of various rubbers to a remarkable degree. In particular, 5% of phenyl - β - naphthylamine (PBNA) with a partial solubility in rubber was found to be comparable in its stiffening effect on rubber to about 40 phr of a good reinforcing carbon black. Joseph, et.al.(4) in their study of the reinforcement potential of LMC in glassy polymers found that acetanilide and anthracene were soluble in styrene-acrylonitrile copolymer (SAN) at hgih temperatures above their melting points but they crystallized out of the polymer at temperatures below their melting points into small domains of the order of 10μ in width and length and much smaller dimension in thickness. From dynamic mechanical measurements, they found that LMC gave little reinforcement to glassy polymers and concluded that the elastic moduli of organic crystals were about the same as those of organic polymers in the glassy state. None of these investigators, however, explored the potential of LMC as processing aid. Blyler(7) studied the effect of molding lubricants on the viscosity of ABS. He found that a fatty acid amide at 4 phr could reduce the viscisity of an ABS sample at 200°C and 100 S^{-1} by 30% and that the fatty acid amide crystallized out of the ABS upon cooling. His results strongly supports the concept of solid solvent.

The reduction of viscosity by the use of an appropriate LMC as a solid solvent is expected to be significant for polymers with a single phase structure in the molten state. The reduction of viscosity by a solid solvent for polymers with a multiphase structure in the molten state such as block copolymers will be even greater if the solid solvent not only acts as a solvent for one or more of the phases but also promotes mixing between the phases. It is well known(8) that block copolymers made of incompatible polymers have multiphase structure, each component polymer being separated into its own phase. The multiphase structure leads to unusual physical properties, very different from those of the component polymers. A number of block copolymers is now widely used as thermoplastic elastomers.(9,10) Our study,(11,12) and others(13) have shown that the multiphase structure in block copolymers often persists to high temperatures of processing, well above the glass transition or melting points of the component polymers, causing unusually high melt viscoelasticity and consequent processing difficulty. Phase separation in block copolymers occurs due to thermodynamic incompatibility between the component polymers. As the mobility of polymer segments increases (for example, with increasing temperature or by adding solvent), mote mixing between different polymer segments will occur and eventually a homogeneous phase will be attained. Once the multiphase structure disappears, a normal melt viscoelasticity and greatly improved processability are expected. The use of solid solvent may allow processing of otherwise intractable block copolymers. The concept of solid solvent may also be beneficial to polymers with processing difficulty due to thermal instability such as polyvinyl chloride by permitting a lower processing temperature.

We have been investigating the feasibility of the concept of solid solvent, in particular as applied to block copolymers. This paper reports our preliminary results on the interaction between one particular polymer-solid solvent pair and its extension to one block copolymer.

EXPERIMENTAL

A commercially available block copolymer, Kraton 1101 from Shell Chemical Company, was used as a model block copolymer in our study. Kraton 1101 is a styrene-butadiene-styrene (SBS) block copolymer, and it has the polystyrene (PS) block molecular weight of 11,000 each and the polybutadiene (PB) block molecular weight of 54,000 with 29% PS content according to Pillai, et.al.(14) The microstructure of the PB block is 45% trans 1,4, 40% cis 1,4 and 15% 1,2. The nominal molecular information on Kraton 1101 given by Shell is 102,000 total molecular weight with 31% PS content.(15) We have to work with an uncertain molecular information, but this does not interfere with the goal of our present study. The PS blocks and the PB blocks are incompatible and they separate into their own phases. Kraton 1101 exhibits an elastomeric behavior at the low temperatures of usage resulting from the multiphase structure and a highly viscoelastic melt behavior at the high temperatures of processing. The persistent multiphase structure in the molten state is believed to be responsible for the high melt viscoelasticity. Based on a previous study,(4) acetanilide was chosen as a potential solid solvent for the PS phase in Kraton 1101. Acetanilide purchased from Fisher Scientific Company comes as a flake but it is easily crushed into a fine powder. It has the following chemical structure and Fisher Scientific gives its melting point at 115°C.



The compatibility between PS and acetanilide was studied first using a commercial PS (PS-1) with a number average molecular weight of 86,700 and a weight average molecular weight of 229,800 and then using a PS fraction (PS-2) with a molecular weight of 10,000 which was comparable to the PS block molecular weight in Kraton 1101.

A Perkin-Elmer differential scanning calorimeter, model DSC-4, equipped with a dedicated microprocessor supplied by LMS, Inc. was used to measure the thermodynamic properties of the samples. The viscosity of the samples was measured using an Instron capillary rheometer (ICR), model 3211.

The polymer samples were broken into small particles, and mixed with the acetanilide power. For the DSC measurements, the mixture was packed into a sealed sample pan and heated from room temperature to about 180°C at 10°C/min measuring the heat flow. The sample was held at the highest temperature for about 20 minutes to allow acetanilide to diffuse into the polymer. The sample was than cooled down to a desired temperature at 10°C/min, and the second heat flow measurement was made on reheating the sample at 10°C/min. At the end of the second heating cycle, the sample was quenched down to a desired temperature by pouring liquid nitrogen at a nominal cooling rate of 320°C/min. The actual cooling rate of the sample inside the sealed pan would be less than the nominal cooling rate. It was hoped to preserve the interaction between the polymer and acetanilide in the molten state into the solid state by quenching. The third heat flow measurement was made on reheating the sample at 10°C/min. Other thermal treatments were given to some samples for a more detailed study. All DSC curves were taken upon heating at 10°C/min unless noted otherwise.

For the ICR measurements, the mixture was extruded at least two times repeatedly at each temperature to insure a complete distribution and diffusion of acetanilide in the polymer. The melt viscosity measured from the second path was substantially lower than that from the first path for the PS-acetanilide mixtures, but the measurements from the second and third paths were about the same.

RESULTS AND DISCUSSION

Figure 1 shows the DSC results of the PS-1 sample. The 1st curve was obtained from the initial heating of the sample as received, the 2nd curve after cooling at 10°C/min, the 3rd curve after quenching and the 4th curve after annealing for about 21 hours at 102°C. The glass transition temperature (T_g) of PS-1 is found to be about 106°C from the 3rd curve. Although the thermal history has a definite influence on the hysterisis of the glass transition with a slower cooling rate causing a greater hysterisis, it has an insignificant effect on the location of the T_g. Figure 2 presents the DSC results of the PS-2 sample. The 1st and 2nd curves were obtained after 10°C/min cooling and quenching, respecitvely. The T_g of PS-2 is found to be about 94°C from both curves. Our measurements of T_g for the PS-1 and PS-2 samples are in an excellent agreement with the previously reported values by other investigators.(16,17) Figure 3 presents the DSC results of acetanilide. Acetanilide shows a sharp melting peak at 116°C, very close to the melting point (T_m) reported by Fisher Scientific, and the thermal history has no effect on the melting behavior as expected for a low molecular weight material. We can conclude from Figures 1-3 that the thermal treatments used in our expeirments will have virtually no effect on the T_g of the PS samples or the T_m of acetanilide. Any change in the T_g of the PS samples or the T_m of acetanilide found for the PS/acetanilide mixtures may be attributed to the interaction between the materials.

Figure 4 presents the DSC results for the PS-1/acetanilide mixture with the acetanilide concentration of 5.97% by weight. The 1st curve taken during the initial heating cycle of the mixture shows that the T_g of PS-1 and the T_m of acetanilide are virtually unaffected by each other. All PS-1/acetanilide mixtures gave a similar result during the initial heating cycle. The T_g of PS-1 in the mixture is found to be 79°C, a large depression of 27°C. The 2nd and 3rd curves show no indication of the acetanilide crystal. The entire amount of acetanilide apparently had dissolved into the polymer during the initial heating cycle and none of the dissolved acetanilide recrystallized out of the polymer during cooling. The dissolved acetanilide could not be recrystallized by annealing.

The DSC results for the PS-1/acetanilide mixture with 18.9% acetanilide are presented in Figure 5. The 1st curve was obtained after cooling the mixture at 10°C/min. Recrystallization of the dissolved acetanilide around 95°C and melting of the crystallized acetanilide with the melting peak at about 112°C are clearly seen. Depression of the T_m of acetanilide by about 4°C is observed. The T_g of PS-1 in the mixture is found to be about 60°C by a repeated experiment using a higher resolution. In order to study the recrystallization mechanism of acetanilide, the mixture was cooled down to different temperatures at 10°C/min and the 2nd - 8th curves were obtained on heating at 10°C/min. The recrystallization mechanism is found to be a classic nucleation and growth of crystals for liquid to solid phase transition in a dense phase.(2) The mixture had to be cooled down to a sufficiently low temperature before the nuclei could grow, with a lower cooling temperature resulting in a higher degree of recrystallization. The 9th curve was obtained after quenching the mixture at the end of the 8th curve. The T_g of PS-1 in the mixture after quenching is found to be about 49°C. It is clear that the entire 18.9% acetanilide dissolves into the polymer at about 180°C and all of acetanilide remains to be dissolved in the polymer upon quenching considering the thermal history and also comparing the areas under the recrystallization and melting peaks. The 10th curve was obtained after annealing the mixture for about 70 hrs at 102°C. It shows the T_g of PS-1 in the mixture at about 71°C and little recrystallization. In another experiment, the T_g of PS-1 in the mixture was found at about 69°C after simply heating the mixture to 102°C at 10°C/min. Apparently, the annealing treatment or even a quick heating to 102°C caused a large fraction of the dissolved acetanilide to recrystallize out of the polymer. The T_g of PS-1 in the mixture increases as the concentration of dissolved acetanilide decreases upon acetanilide recrystallization.

Figure 6 was constructed after a series of annealing experiments to control the amount of dissolved acetanilide. The amount of dissolved acetanilide was determined by quantitatively analysing the DSC curves. The solubility of acetanilide in the PS-1 sample at 102°C is found to be about 8%. Excess acetanilide above 8% dissolved in the polymer can be recrystallized by a simple thermal treatment. Recrystallization of the dissolved solid solvent is an essential requirement for the concept of solid solvent.

Figure 7 presents the DSC results of the PS-2/acetanilide mixture with 10% acetanilide. The 1st and 2nd curves were obtained after cooling at 10°C/min and quenching, respectively. The curves show the T_g of PS-2 in the mixture at about 62°C, a depression of 32°C, and the melting peak of acetanilide at 112°C. The observation of a large acetanilide melting peak without an accompanying recrystallization peak even for the quenched sample is interesting since it indicates acetanilide recrystallization out of PS-2 during cooling unlike for the case of PS-1. The solubility of acetanilide is expected to be greater in PS-2 than in PS-1 since PS-2 has a much lower molecular weight than PS-1. Lower melt viscosity and lower T_g of PS-2 compared with those of PS-1 are believed to have enhanced acetanilide recrystallization in PS-2 during cooling.

The DSC results of Kraton 1101 are presented in Figure 8. The heat flow curve clearly shows the T_g of the PB phase at -95°C. The PS phase gives a broad glass transition and the T_g is not easily seen from the heat flow curve. We found in this particular case that the T_g of the PS phase at about 79°C could be determined easier from the specific heat curve although it required more work of running a sapphire standard. Our values of T_g for the PB and PS phases in Kraton 1101 agree quite well with those reported by others.(16-18) The T_g of the PS phase in Kraton 1101 is much lower than the value expected for the PS phase by itself due to the effects of the soft PB blocks and the interface.

Figure 9 presents the DSC results for the Kraton 1101/acetanilide mixture with 3.1% acetanilide. The T_g of the

PB phase at -95°C was not influenced by acetanilide, but the glass transition of the PS phase became very broad. The T_g of the PS phase in the mixture is approximated to be about 57°C, a depression of about 22°C. Although the absence of any acetanilide melting peak and the unchanged T_g of the PB phase in Figure 9 appear to indicate that all acetanilide was preferentially dissolved into the PS phase, we later found through melt viscosity measurements and solution tests that some acetanilide could stay in the PB phase and cause crosslinking of the PB phase at high temperatures. The extrudate of the mixture at 130°C dissolved in a solvent mixture for Kraton 1101 but the extrudate at 175°C did not dissolve. The effective concentration of acetanilide in the PS phase is unknown, but it should be less than about 10%.

Figures 10 and 11 show the effect of acetanilide on the melt viscosity of the PS-1 sample. It is clearly seen that acetanilide acts as a solvent to PS in the molten state and can greatly reduce the viscosity of polystyrene. 5% acetanilide reduced the viscosity of PS-1 measured at 217°C and 3.5 S^{-1} by as much as 2.16 folds.

Figure 12 shows the effect of 3.3% acetanilide on the melt viscosity of Kraton 1101. Our initial measurements were made at 175°C and 200°C, and we unexpectedly found that acetanilide increased the viscosity of Kraton 1101. Our suspicion of possible chemical reactions between acetanilide and PB was confirmed by solution tests. Kraton 1101 dissolves in a 30/70 mixture of cyclohexane and heptane at room temperature upon stirring. The extrudate of the Kraton 1101/acetanilide mixture extruded at 175°C did not dissolve in the same solvent mixture, but the extrudate extruded at 130°C dissolved. It probably is safe to assume that acetanilide reacts with PB at 175°C crosslinking PB. Kraton 1101 is highly elastic as well as highly viscous even at 200°C. It is highly viscoelastic at 130°C and exhibits flow instabilities similar to a stick-slip phenomenon even at low shear rates. The shear stress goes through a maximum and a minimum almost periodically at a given shear rate. Such fluctuations are indicated in Figure 12. The addition of 3.3% acetanilide reduces the viscosity of Kraton 1101 by about 14% on the average and greatly reduces the stress fluctuation, an indication of reduced melt elasticity. The full potential of acetanilde as a solid solvent for Kraton 1101 could not be evaluated because of the complication caused by chemical reactions between them. However, our experimental results presented here taken together with the results of some previous investigators(3-7) strongly support the concept of solid solvent.

CONCLUSION

The concept of solid solvent has been examined using acetanilide as a potential solid solvent for PS and Kraton 1101. The concept entails using a LMC as a processing aid. An ideal solid solvent mixed into a polymer is expected to become a solvent to the polymer reducing the viscosity of the polymer at high processing temperatures, but to precipitate out of the polymer without adversely affecting the properties of the polymer at low use temperatures.

Acetanilide is found to satisfy the basic requirements of a solid solvent for PS although it certainly is not an ideal solid solvent for PS. Acetanilide has a high solubility in PS at high processing temperatures very effectively reducing the viscosity. It precipitates out of PS at low temperatures following a classic mechanism of crystal nucleation and growth, but it has an undesirably high level of residual solubility. Acetanilide also is found to effectively reduce the viscosity of Kraton 1101. Its full potential as a solid solvent for Kraton 1101 could not be evaulated because of the adverse chemical reactions between acetanilde and the PB segments of Kraton 1101 at high temperatures. Although acetanilide did not behave as an ideal solid solvent for PS and Kraton 1101 in our preliminary study, we believe that it exhibited the essential features of a solid solvent. The concept of solid solvent will be further investigated involving other chemicals and polymers.

ACKNOWLEDGEMENT

The author gratefully acknowledges the support of this research by the Office of Naval Research. Most of the DSC results were taken from the work of Mrs. W. Aycock for her graduate degree.

REFERENCES

1. F.N. Kelley and F. Bueche, J. Polymer Sci., 50, 549 (1961).
2. O. Olabisi, L.M. Robeson and M.T. Shaw, "Polymer-Polymer Miscibility", Academic Press, New York, 1979.
3. F.J. Linnig, E.J. Parks and R.D. Stiehler, Rubber Chem. Tech., 39, 1041 (1966).
4. J.R. Joseph. J.L. Kardos and L.E. Nielsen, J. Applied Polymer Sic., 12, 1151 (1968).
5. J.L. Kardos, W.L. McDonnell and J. Raisoni, J. Macromol. Sci.-Phys., B6(2), 397 (1972).
6. M. Narkis, A. Siegmann, M. Puterman and A.T. DiBenedetto, J. Polymer Sci.-Polymer Phys. Ed., 17, 225 (1979).
7. L.L. Blyler, Jr., Polymer Eng. Sci., 14(11), 807 (1974).
8. G.M. Estes, S.L. Cooper and A.V. Tobolsky, J. Macromol. Sci.-Rev. Macromol. Chem., C4(2), 313 (1970).
9. J.T. Bailey, E.T. Bishop, W.R. Henricks, G. Holden and N.R. Legge, Rubber Age, 98, 69 (October 1966).
10. J.L. Henderson, Plastics Eng., 39(6), 31 (June 1983).
11. C.I. Chung and J.C. Gale, J. Polymer Sci.-Polymer Phys. Ed., 14, 1149 (1976).
12. C.I. Chung, H.L. Griesbach and L. Young, ibid, 18, 1237 (1980).
13. E.V. Gouinlock and R.S. Porter, Polymer Eng. Sci., 17, 534 (1977).
14. P.S. Pillai, D.I. Livingston and J.D. Strang, Rubber Chem. Tech., 45, 241 (1972).
15. W.L. Krudop of Shell Development Company, private communication, September 1984.
16. S. Krause and M. Iskandar in "Multiphase Polymers", Advances in Chemistry Series, No. 176, edited by S. Cooper and G.M. Estes, ACS, 1979.
17. P.M. Toporowski and J.E. Roovers, J. Polymer Sci.-Polymer Chem. Ed., 14, 2233 (1976).
18. G. Kraus, C.W. Childers and J.T. Gruver, J. Appl. Polymer Sci., 11, 1581 (1967).

LIST OF FIGURES

Fig. 1.

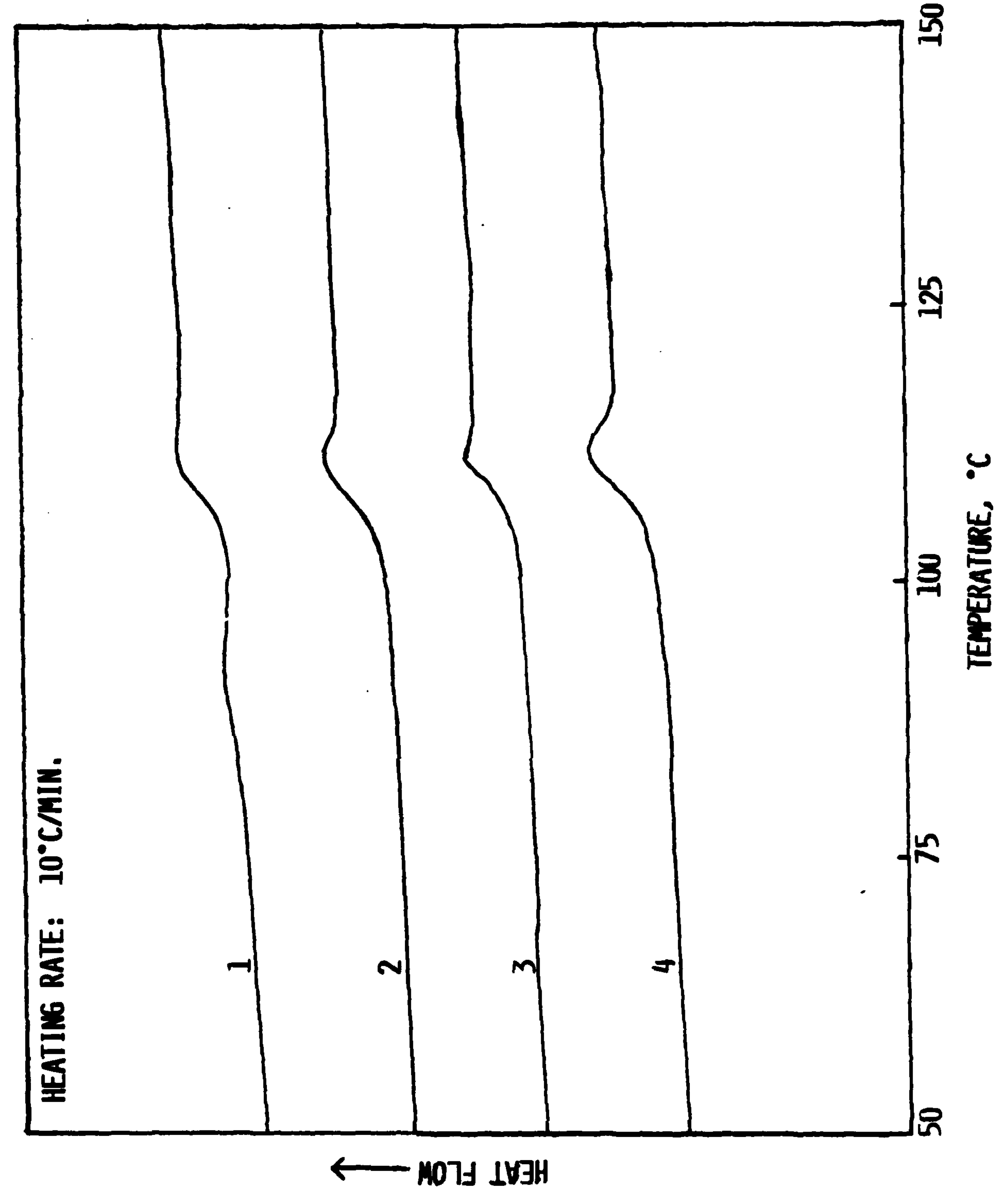

HEATING RATE: 10°C/MIN.
1
2
3
4
HEAT FLOW
50
75
100
125
150
TEMPERATURE, °C

Fig. 2

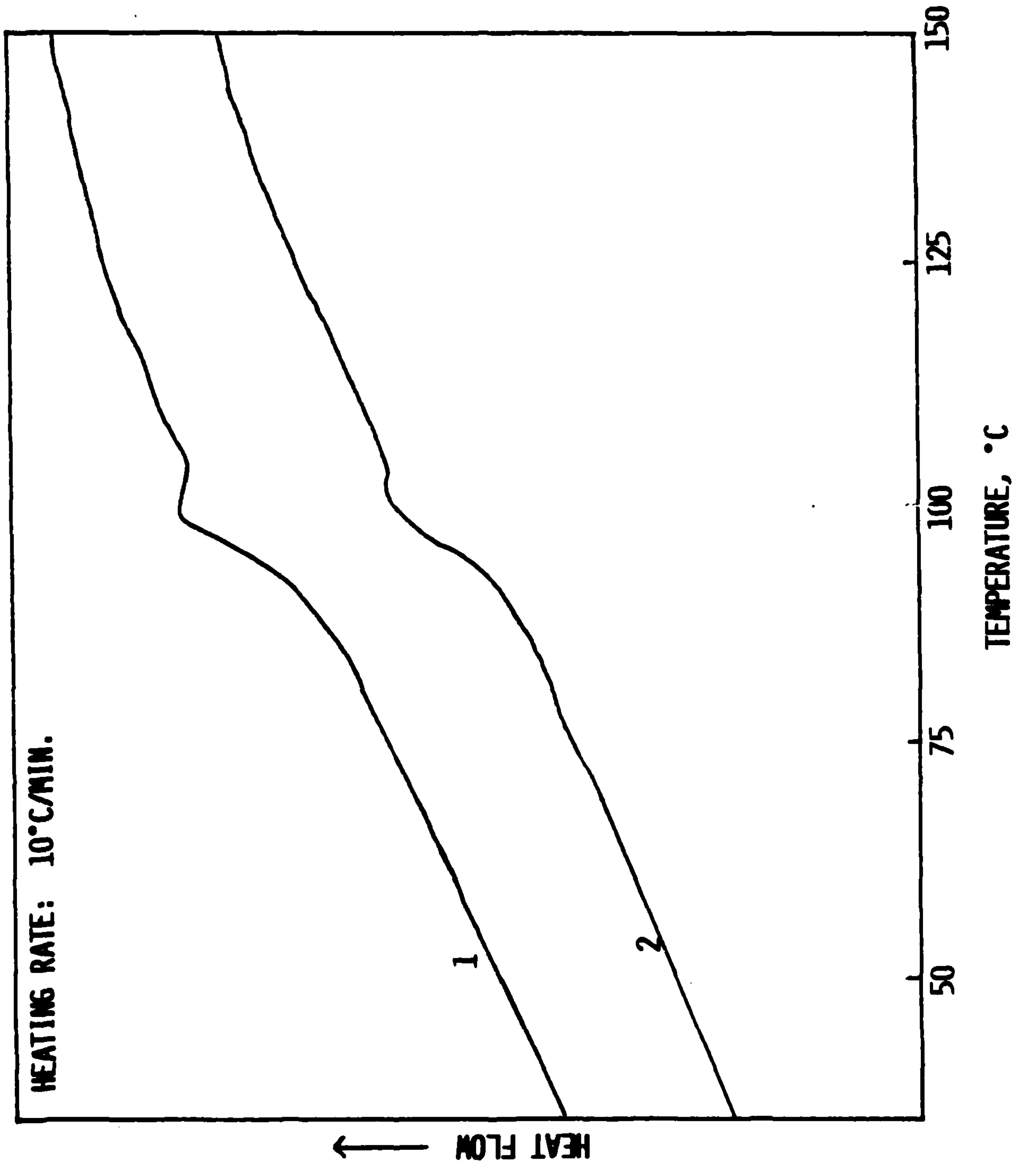

HEATING RATE: 10°C/MIN.
1
2
HEAT FLOW →
50
75
100
125
150
TEMPERATURE, °C

Fig. 3

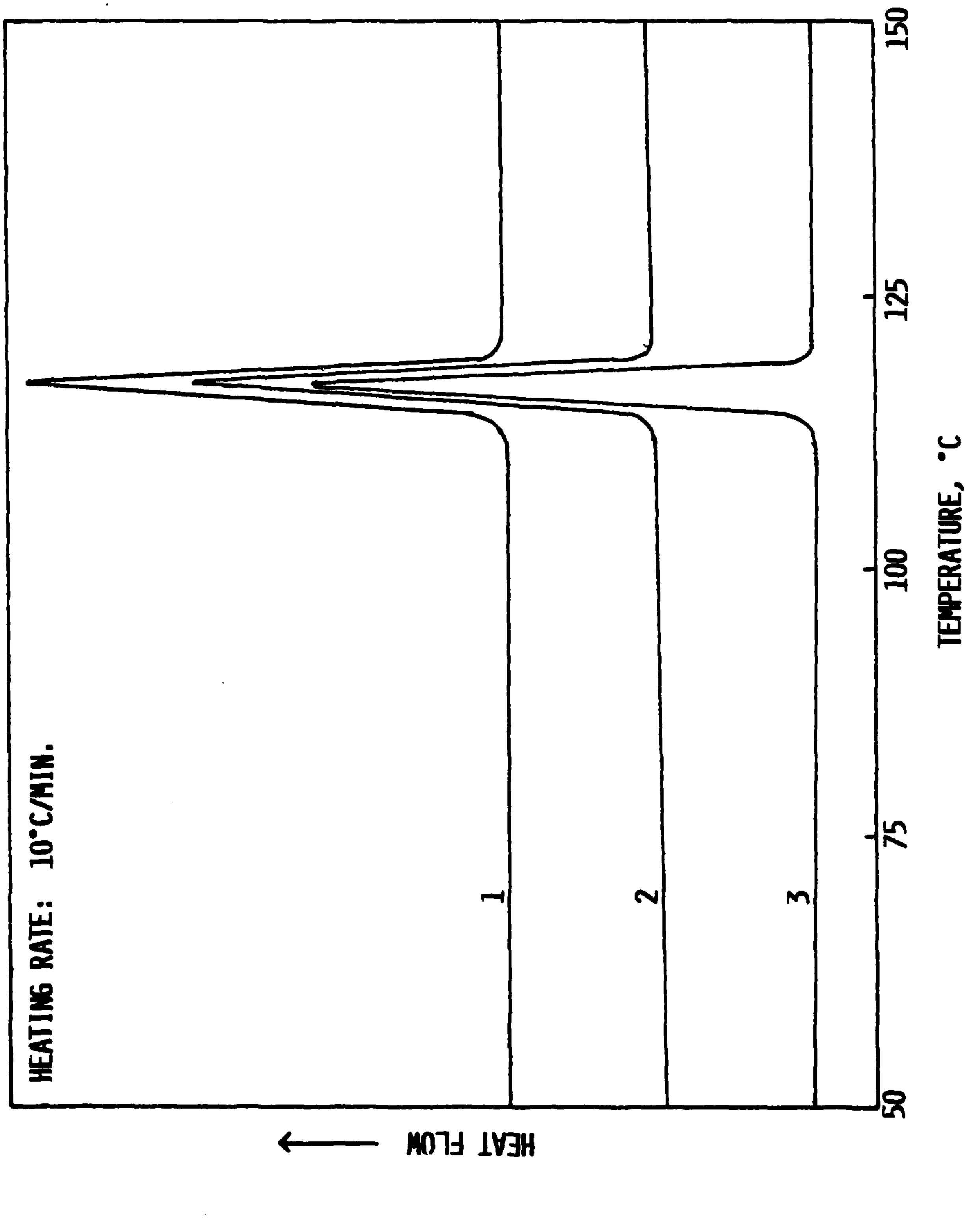

HEATING RATE: 10°C/MIN.
1
2
3
50
75
100
125
150
TEMPERATURE, °C
HEAT FLOW

Fig. 4.

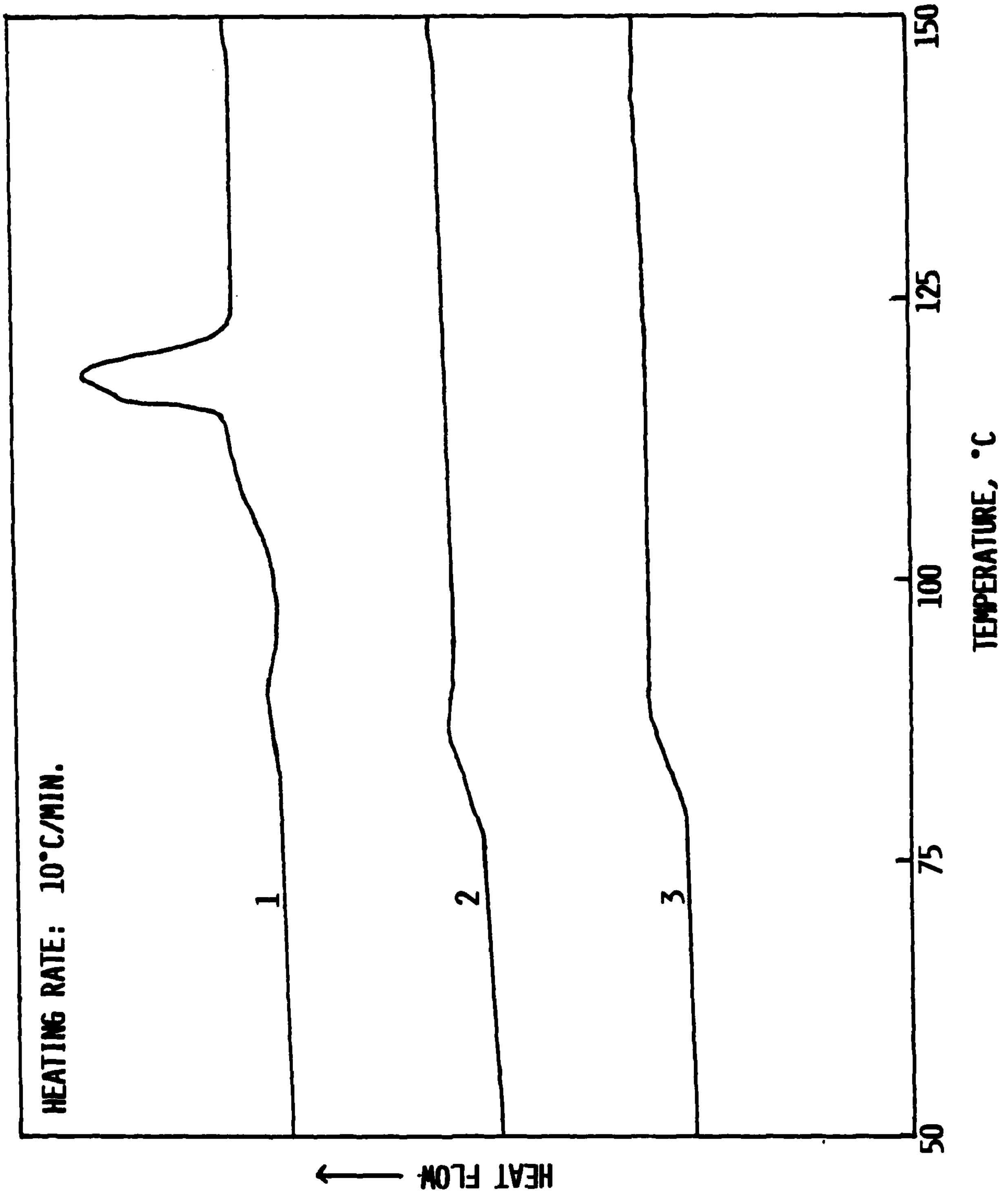

HEATING RATE: 10°C/MIN.
1
2
3
50
75
100
125
150
TEMPERATURE, °C
HEAT FLOW

Fig. 5.

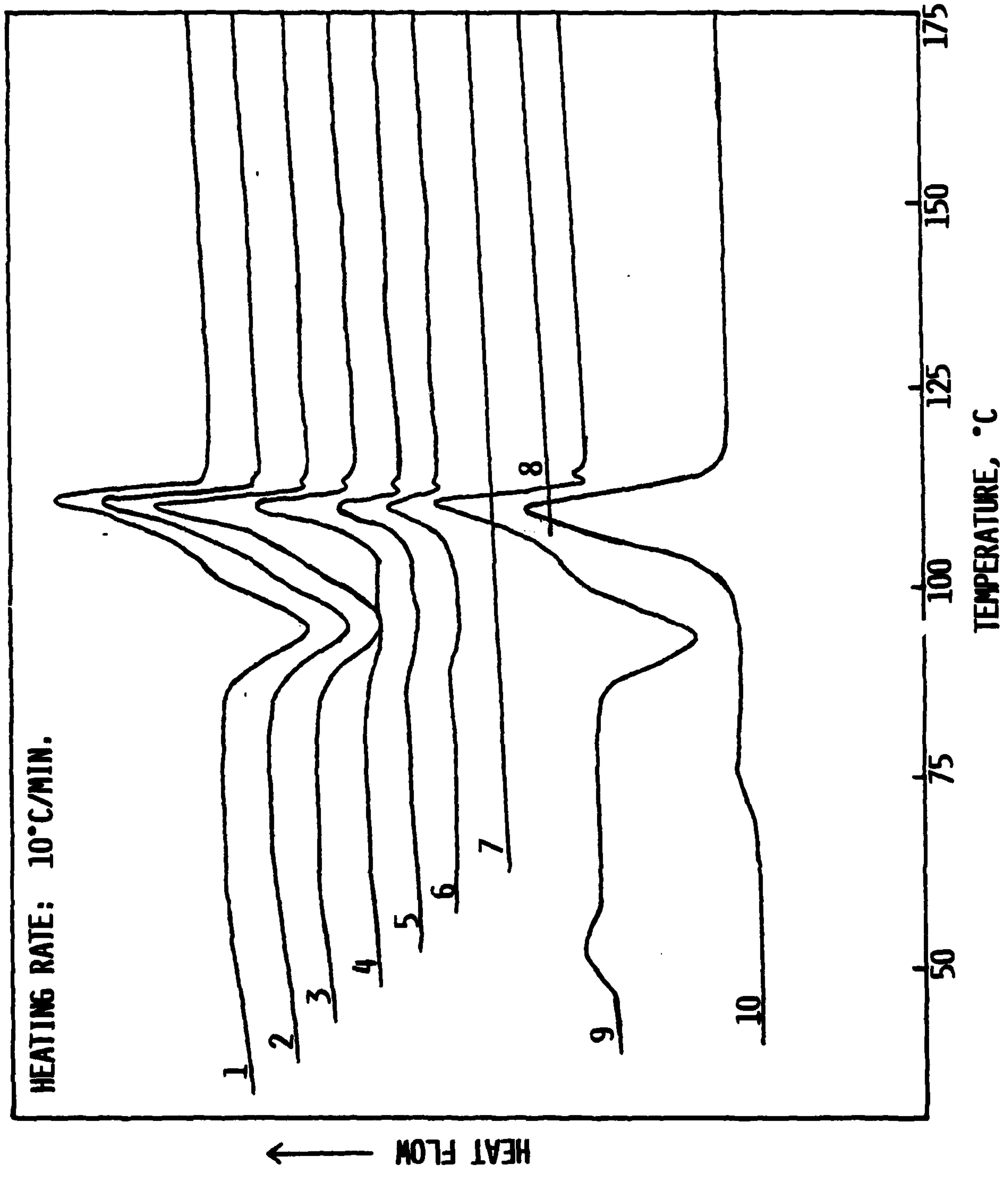

HEATING RATE: 10°C/MIN.
1
2
3
4
5
6
7
8
9
10
50
75
100
125
150
175
TEMPERATURE, °C
HEAT FLOW

Fig. 6.

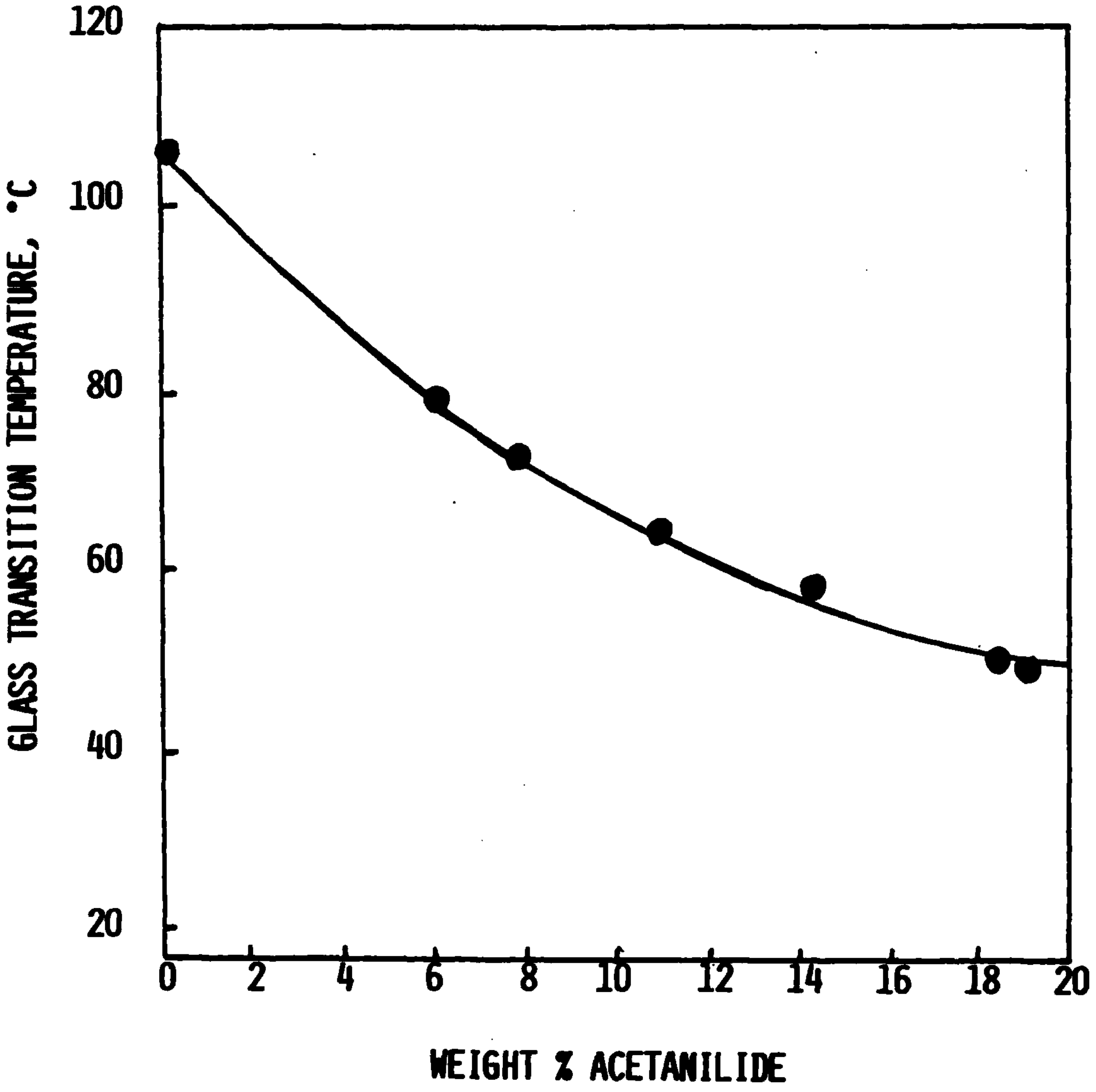

GLASS TRANSITION TEMPERATURE, °C
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
WEIGHT % ACETANILIDE

Fig. 7.

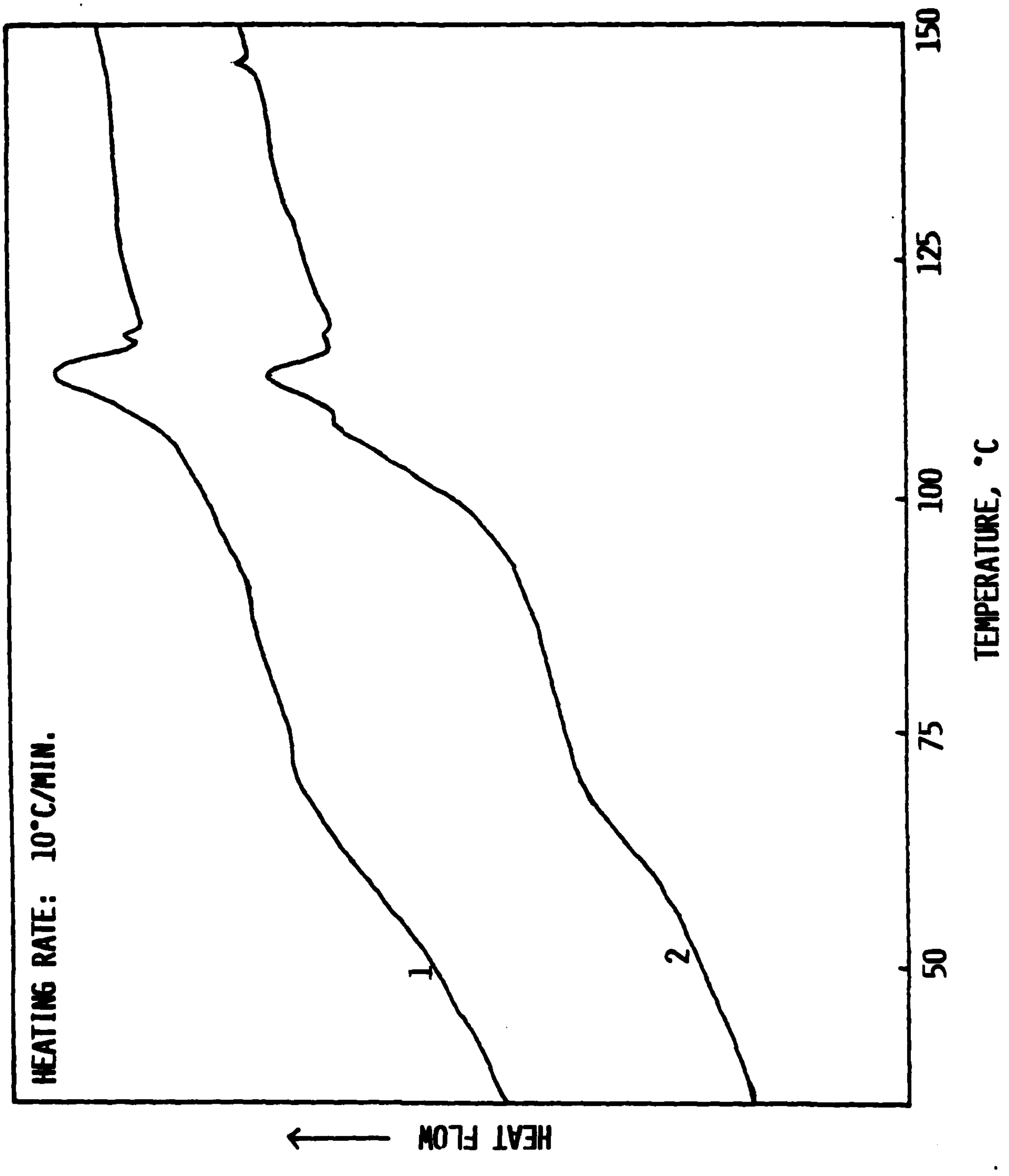

HEATING RATE: 10°C/MIN.
1
2
50
75
100
125
150
TEMPERATURE, °C
HEAT FLOW

Fig. 8.

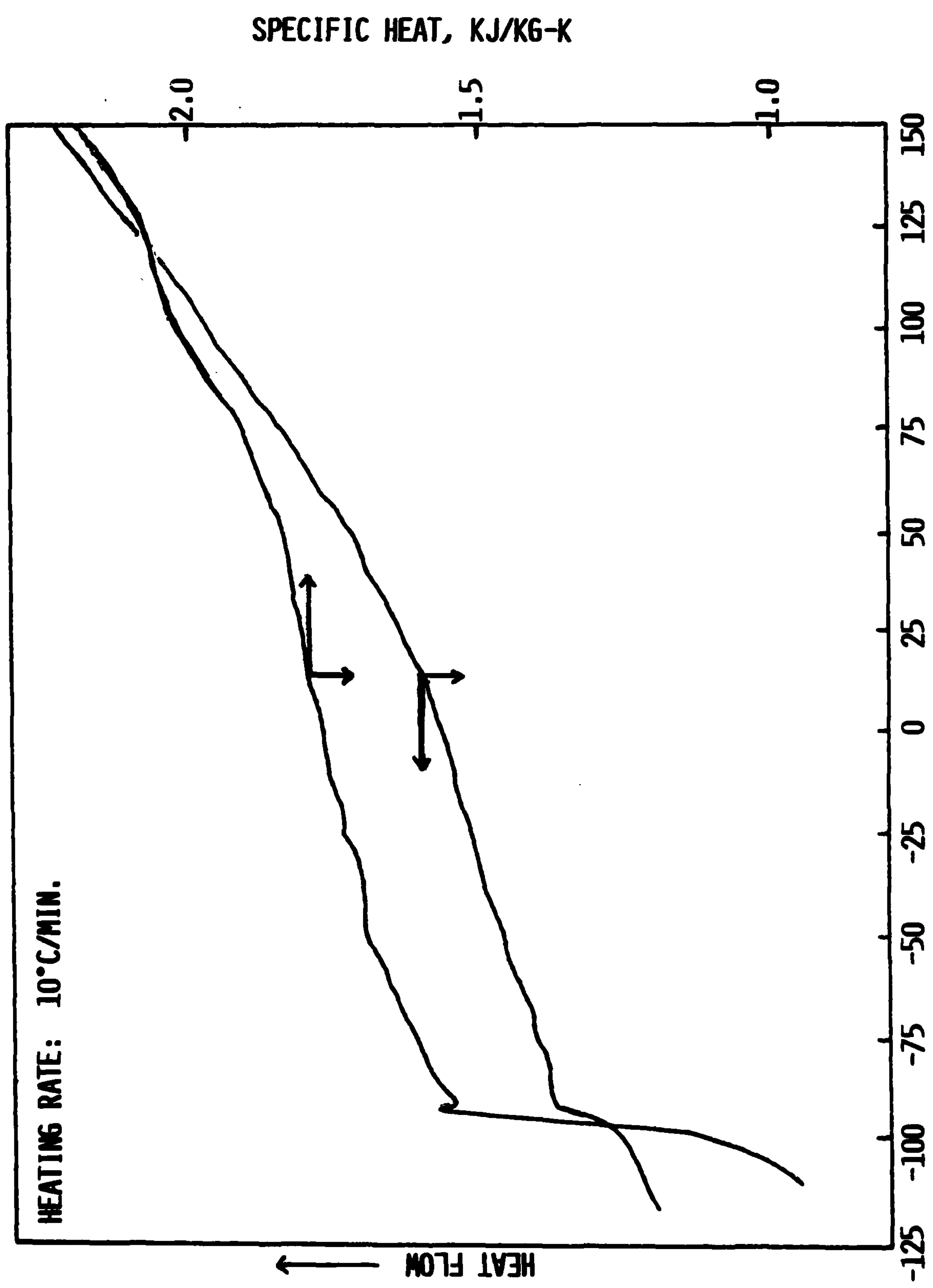

SPECIFIC HEAT, KJ/KG-K
2.0
1.5
1.0
HEATING RATE: 10°C/MIN.
HEAT FLOW
TEMPERATURE, °C
-125
-100
-75
-50
-25
0
25
50
75
100
125
150

Fig. 9.

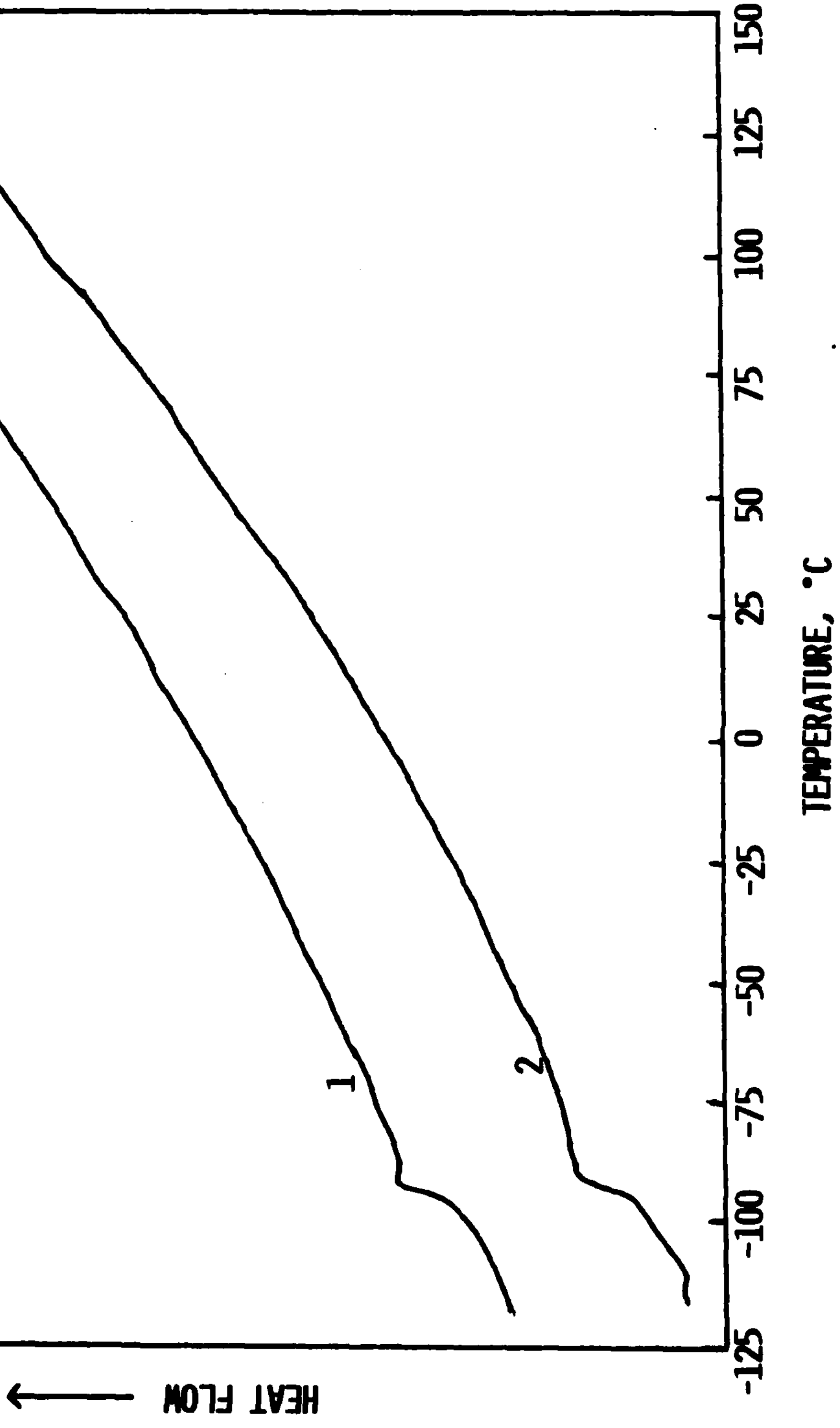

HEATING RATE: 10°C/MIN.
1
2
-125
-100
-75
-50
-25
0
25
50
75
100
125
150
TEMPERATURE, °C
HEAT FLOW

Fig. 10.

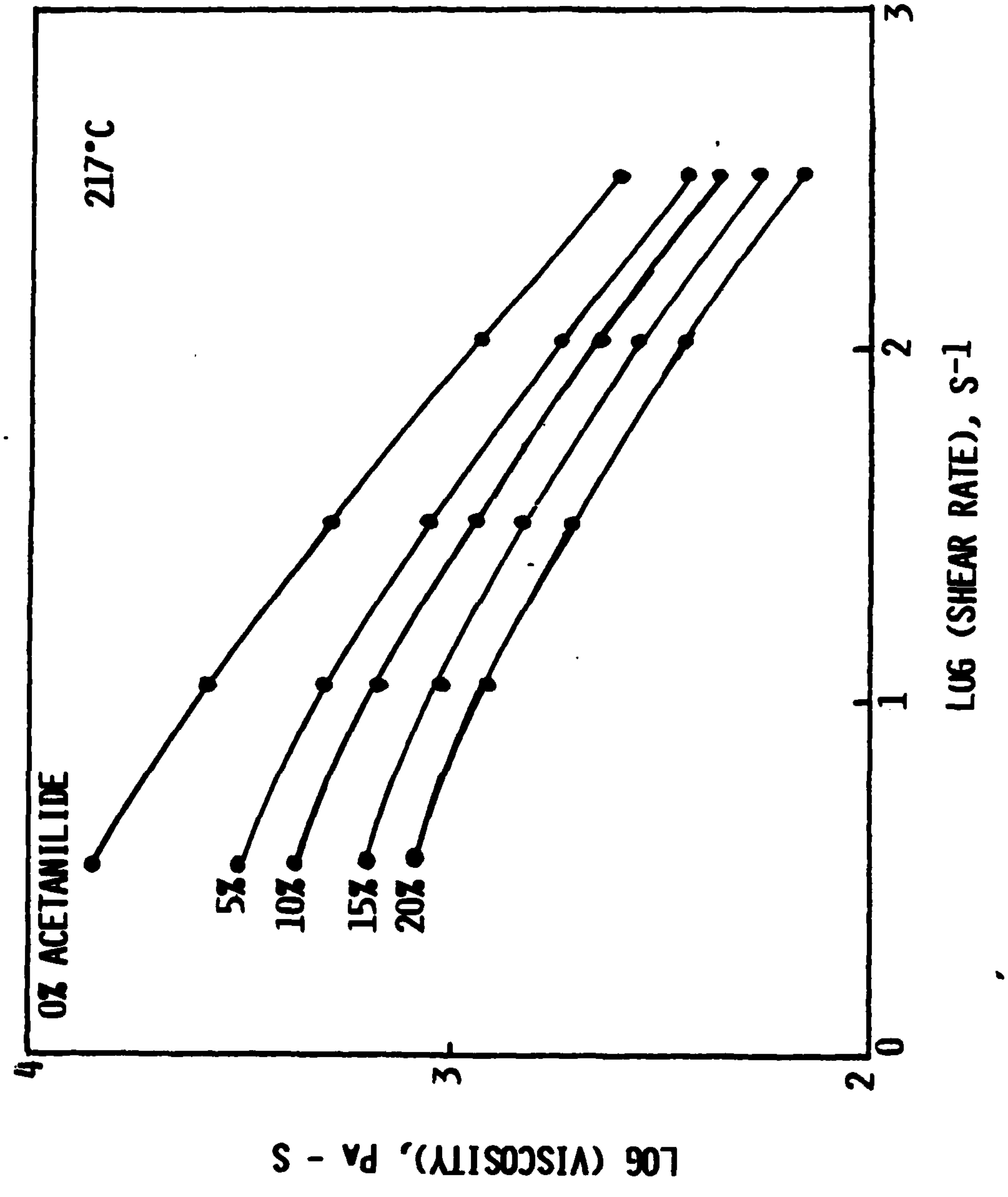

217°C
0% ACETANILIDE
5%
10%
15%
20%
0
1
2
3
LOG (SHEAR RATE), S-1
4
3
2
LOG (VISCOSITY), Pa - S

Fig. 11.

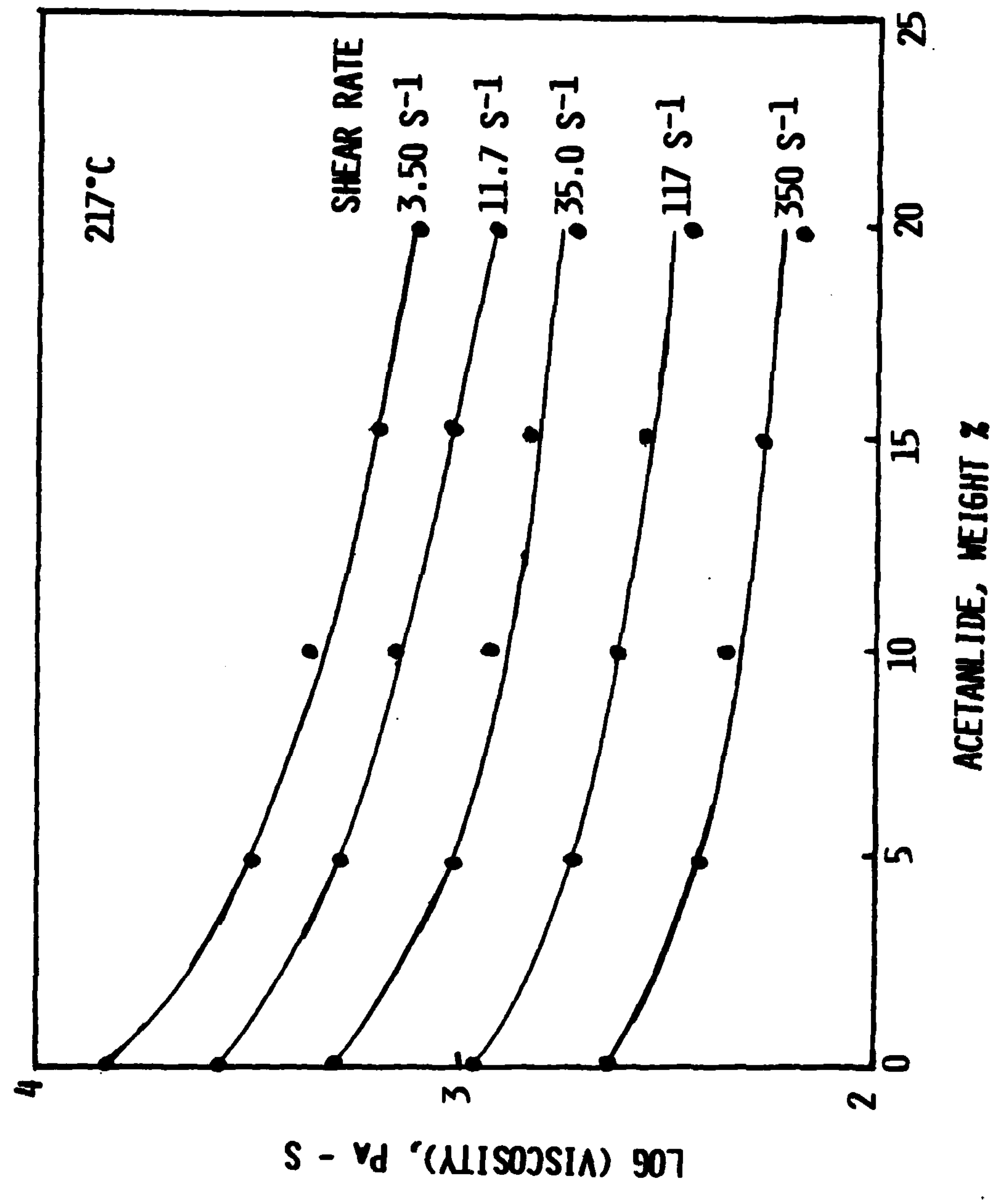
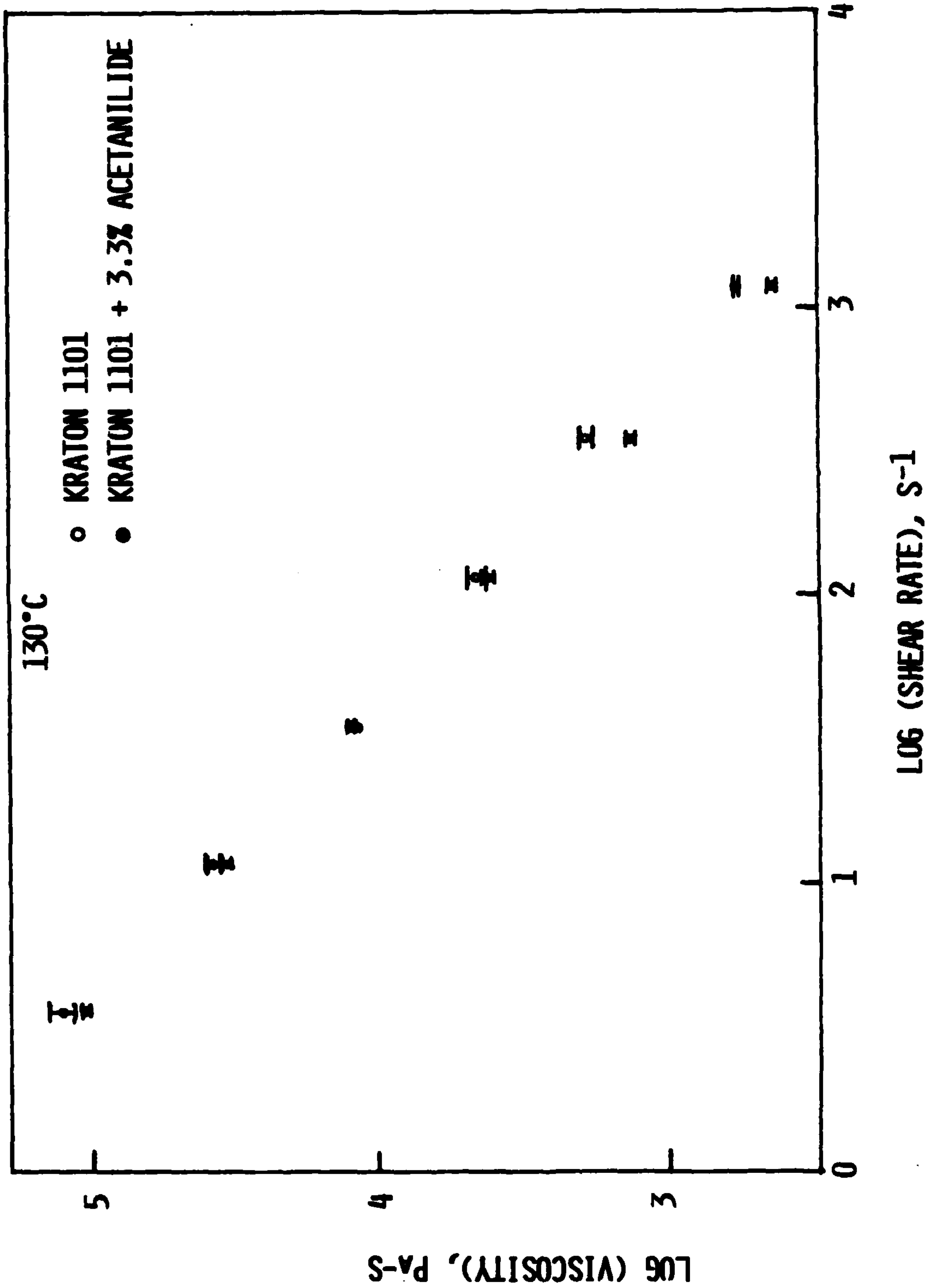

217°C
SHEAR RATE
3.50 S-1
11.7 S-1
35.0 S-1
117 S-1
350 S-1
4
3
2
LOG (VISCOSITY), PA - S
0
5
10
15
20
25
ACETANILIDE, WEIGHT %

Fig. 12.


130°C
○ KRATON 1101
● KRATON 1101 + 3.3% ACETANILIDE
0
1
2
3
4
LOG (SHEAR RATE), S-1
3
4
5
LOG (VISCOSITY), PA-S

TECHNICAL REPORT DISTRIBUTION LIST, GEN

	No. Copies		No. Copies
Office of Naval Research Attn: Code 413 800 N. Quincy Street Arlington, Virginia 22217	2	Naval Ocean Systems Center Attn: Technical Library San Diego, California 92152	1
ONR Pasadena Detachment Attn: Dr. R. J. Marcus 1030 East Green Street Pasadena, California 91106	1	Naval Weapons Center Attn: Dr. A. B. Amster Chemistry Division China Lake, California 93555	1
Commander, Naval Air Systems Command Attn: Code 310C (H. Rosenwasser) Washington, D.C. 20360	1	Scientific Advisor Commandant of the Marine Corps Code RD-1 Washington, D.C. 20380	1
Naval Civil Engineering Laboratory Attn: Dr. R. W. Drisko Port Hueneme, California 93401	1	Dean William Tolles Naval Postgraduate School Monterey, California 93940	1
Superintendent Chemistry Division, Code 6100 Naval Research Laboratory Washington, D.C. 20375	1	U.S. Army Research Office Attn: CRD-AA-IP P.O. Box 12211 Research Triangle Park, NC 27709	1
Defense Technical Information Center Building 5, Cameron Station Alexandria, Virginia 22314	12	Mr. Vincent Schaper DTNSRDC Code 2830 Annapolis, Maryland 21402	1
DTNSRDC Attn: Dr. G. Bosmajian Applied Chemistry Division Annapolis, Maryland 21401	1	Mr. John Boyle Materials Branch Naval Ship Engineering Center Philadelphia, Pennsylvania 19112	1
Naval Ocean Systems Center Attn: Dr. S. Yamamoto Marine Sciences Division San Diego, California 91232	1	Mr. A. M. Anzalone Administrative Librarian PLASTEC/ARRADCOM Bldg 3401 Dover, New Jersey 07801	1

DL/413/83/01
356B/413-2

TECHNICAL REPORT DISTRIBUTION LIST, 356B

Dr. C. L. Schilling
Union Carbide Corporation
Chemical and Plastics
Tarrytown Technical Center
Tarrytown, New York

Dr. A. G. MacDiarmid
Department of Chemistry
University of Pennsylvania
Philadelphia, Pensylvania 19174

Dr. E. Fischer, Code 2853
Naval Ship Research and
Development Center
Annapolis, Maryland 21402

Dr. H. Allcock
Department of Chemistry
Pennsylvania State University
University Park, Pennsylvania 16802

Dr. M. Kenney
Department of Chemistry
Case Western University
Cleveland, Ohio 44106

Dr. R. Lenz
Department of Chemistry
University of Massachusetts
Amherst, Massachusetts 01002

Dr. M. David Curtis
Department of Chemistry
University of Michigan
Ann Arbor, Michigan 48105

NASA-Lewis Research Center
Attn: Dr. T. T. Serafini, MS 49-1
21000 Brookpark Road
Cleveland, Ohio 44135

Dr. J. Griffith
Naval Research Laboratory
Chemistry Section, Code 6120
Washington, D.C. 20375

Professor G. Wnek
Department of Materials Science
and Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Dr. R. Soulen
Contract Research Department
Pennwalt Corporation
900 First Avenue
King of Prussia, Pennsylvania 19406

Dr. G. Goodman
Globe-Union Incorporated
5757 North Green Bay Avenue
Milwaukee, Wisconsin 53201

Dr. Martin H. Kaufman
Code 38506
Naval Weapons Center
China Lake, California 93555

Dr. C. Allen
Department of Chemistry
University of Vermont
Burlington, Vermont 05401

Professor R. Drago
Department of Chemistry
University of Florida
Gainesville, Florida 32611

Dr. D. L. Venezky
Code 6130
Naval Research Laboratory
Washington, D.C. 20375

Professor T. Katz
Department of Chemistry
Columbia University
New York, New York 10027

Professor James Chien
Department of Chemistry
University of Massachusetts
Amherst, Massachusetts 01002

Professor J. Salamone
Department of Chemistry
University of Lowell
Lowell, Massachusetts 01854

Dr. S. Cooper
Department of Chemistry
University of Wisconsin
750 University Avenue
Madison, Wisconsin 53706

TECHNICAL REPORT DISTRIBUTION LIST, 356B

Professor D. Grubb
Department of Materials Science
and Engineering
Cornell University
Ithaca, New York 14853

Professor T. Marks
Department of Chemistry
Northwestern University
Evanston, Illinois 60201

Professor C. Chung
Department of Materials Engineering
Rensselaer Polytechnic Institute
Troy, New York 12181

Professor Malcolm B. Polk
Department of Chemistry
Atlanta University
Atlanta, Georgia 30314

Dr. D. B. Cotts
SRI International
333 Ravenswood Avenue
Menlo Park, California 94205

Dr. Kurt Baum
Fluorochem, Inc.
680 S. Ayon Avenue
Azuza, California 91702

CAPT. J.J. Auborn, USNR
AT&T Bell Laboratories
Room 6F-211
600 Mountain Avenue
Murray Hill, New Jersey 07974

Professor H. Hall
Department of Chemistry
University of Arizona
Tucson, Arizona 85721

Professor G. Whitesides
Department of Chemistry
Harvard University
Cambridge, Massachusetts 02138

Professor H. Ishida
Department of Macromolecular Science
Case Western University
Cleveland, Ohio 44106

Dr. K. Paciorek
Ultrasystems, Inc.
P.O. Box 19605
Irvine, California 92715

Professor D. Seyferth
Department of Chemistry
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

Dr. G. Bryan Street
IBM Research Laboratory, K32/281
San Jose, California 95193

END

FILMED

11-84

DTIC