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NONISOTHERMAL RETARDATION OF ELASTIC FLUIDS

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It is shown that nonisothermy during the retardation of a polymer fluid after extension can result in diminution in specimen reduction.

The nonisothermal effect under consideration is characteristic for elastic fluids. After homogeneous isothermal extension [1] of the cylindrical specimen of elastic fluid to a length l and diameter d ($l \gg d$), the stress can drop instantaneously to zero and afford the possibility of reducing the specimen in time because of the elastic energy accumulated during extension (retardation process). There is no stress in the inertialess approximation for this process. The time of specimen reduction is $t_1 \sim \theta_2$. Here θ_2 is the retardation time, which is a constant of the fluid. As the temperature changes, $\theta_2 \approx \exp(E/RT)$ for an elastic polymeric fluid. Under isothermal conditions, when the temperature during retardation is identical as during extension, the retardation process will be homogeneous. If the temperature of the environment changes by a jump,* say, after extension, then the retardation process will not be homogeneous if the specimen heating time is $t_2 \sim d^2/\xi \sim \theta_2$. In this case, tangential stresses, say, will occur during retardation because of the variable temperature along the specimen radius and the dependence $\theta_2(T)$. Hence, part of the elastic energy will be expended in relaxing the nonzero stresses, and specimen reduction will consequently diminish as compared to the isothermal case. A theoretical consideration of the problem of nonisothermal retardation because of its inhomogeneity is complex even in linear rheology. The effect discussed above is found experimentally in this paper.

The experiment was performed on a polyisobutylene P-20 melt with the greatest Newtonian viscosity $\eta = 1.3 \cdot 10^6$ Pa·sec, relaxation time $\theta_1 \sim 4 \cdot 10^2$ sec, and retardation time $\theta_2 \approx 80$ sec. This polymer had been investigated earlier under homogeneous extension and retardation in [2, 3]. Preliminary extension of the cylindrical specimen was carried out in the constant strain rate mode at T = 22 and 70°C. The extension and retardation were performed in a water bath to compensate for the specimen weight and thermostatting. To accomplish the retardation the extended specimen was cut by knives. The retardation process was performed at both the extension temperatures (isothermal case) and at 22°C after extension at 70°C (nonisothermal case). In the latter case, not more than 5 sec elapsed in the last case in the cutting and transferring of the specimen from one bath (70°C) to the other (22°C). The specimen diameter changed from ≈1.5 to ≈ 3 mm in the retardation. The time for the temperature change after the changeover was $t_2 \sim d^2/\xi \sim 10^2$ sec. The change in specimen length l_r with time was observed visually on a ruler during retardation.

The dependences of l_r/l on the time t obtained during retardation in the isothermal case for 22 and 70°C are presented in Fig. 1 (points 1, 2, respectively), and for specimen transferral from 70 to 22°C in the nonisothermal case. In all three cases the specimen was

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*At a lower temperature the specimen is in the running state.

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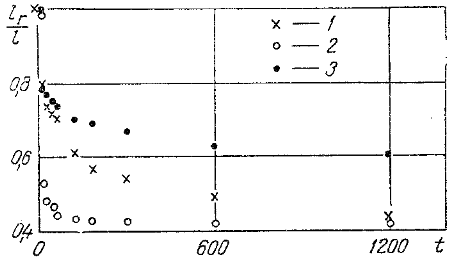

Fig. 1. Dependence of l_r/l on time t (sec) for retardation after homogeneous extension to $\sigma = 1.3\cdot10$ Pa, $\alpha = 2.6$. Retardation under isothermal conditions at 22 and 70°C corresponds to the points 1, 2 and under nonisothermal conditions (transferral from 70 to 22°C) to point 3.

stretched to a stress of $\sigma = 1.3\cdot10^5$ Pa and the elastic strain $\alpha = 2.6$.* Here, as is shown in [3], for the progress of the retardation process it is not important in what extension regime σ and α are achieved. It is seen from the figure that in the nonisothermal case, the ultimate length l_r is greater than in the isothermal case, i.e., nonisothermy results in a diminution in specimen reduction. Let us also note that the isothermal curves can be superposed (but not with the nonisothermal) according to the principle of temperature—time superposition (see e.g., [3]).

It was shown in [2] that the swelling of a polymer fluid at the exit from a capillary can simulate the retardation process. Upon extruding a polymer fluid from a capillary, its swelling can be greater in the isothermal case than in the nonisothermal case. In the latter case, the temperature within is the capillary temperature and outside is different.

In conclusion, let us emphasize that the polymer is in the running state in all the temperatures considered above. If the temperature is lowered to the vitrification or crystallization temperature, the specimen will be reduced less during retardation under nonisothermal conditions and because of solidification.

NOTATION

l, d, length and diameter to which the specimen is stretched before the beginning of retardation; l_r, length of the specimen being reduced during retardation; α, elastic strain; t_1, time of specimen reduction during retardation; t_2, time of temperature equilibration in the specimen; θ_1, θ_2, relaxation and retardation times; η, viscosity; ξ, thermal diffusivity factor; T, temperature; E, activation energy of the viscous flow; R, universal gas constant.

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*The elastic strain is $\alpha = \lim_{t\to\infty} l/l_r(t)$ for homogeneous retardation [1].