The pressures for the trials at 120 F and 140 F for a 20-ipm stem speed were little different, yet for each of the three lubrication systems, the higher temperatures consistently gave lower pressures than were obtained at room temperature. The pressure differences in each case were not large, about 2 to 3 percent, but appear to be statistically significant.

It is believed that these small pressure reductions were due entirely to a reduction in viscosity of the castor oil at the higher temperature. However, the marginal benefits of working with castor oil at 120-140 F did not warrant a further study of the technique.

It is well to point out that the practice of preheating castor oil did not change the temperature of the "active" manganin coil sufficiently to have a significant effect on fluid-pressure measurements. This is evident from the essentially identical fluid pressures obtained at both 120 and 140 F given at the top of Table XV. Yet, Figure 18 shows that the reduction in the resistivity of manganin is as great between 80 F and 120 F as it is between 120 and 140 F. These results suggest that the coil itself was not heated much above room temperature, probably because of inadequate time available during the extrusion stroke and the fact that the fluid was cooled to some extent by the cold tooling.

Extrusion at 400 and 500 F

In the hydrostatic extrusion of AISI 4340 steel at 500 F, the variables investigated included fluids, lubricants, and extrusion ratio. In addition, some trials were made at 400 F (shown separately in Table XI) because the fluid used (silicate ester) had a flash point at 470 F. In all of these trials, the fluid, billet, die, and container were at the same temperature. Details of the heating, stem-seal arrangements, and fluid-pressure measurements are given in the section on equipment and procedure.

Effect of Fluid. The following fluids were evaluated to determine their relative merits from the standpoint of extrusion pressure reduction and operational performance at temperature:

(1) Polyphenyl ether
(2) Tricresyl phosphate
(3) Triaryl phosphate
(4) Chlorinated diphenyl
(5) Silicate ester.

Before these fluids could be evaluated, however, preliminary trials were necessary to select an effective billet lubricant. The polyphenyl ether (PPE) fluid was selected because of its reportedly good high-temperature stability. Based on these trials, a "best" billet lubricant was selected (L31, fluorocarbon telomer), and the other fluids were evaluated. Data listed in Table XVI summarize the results obtained with the various fluids.

At a ratio of 4:1, the data suggest that the silicate ester (SE) fluid requires the least pressure. This is particularly significant, since the extrusion temperature (400 F) in this case was lower than in the other trials. However, at an extrusion ratio of 5:1 there appears to be only a marginal difference between the pressures for SE and PPE. (PPE fluid, at a ratio of 4:1, required the highest pressures.) Such results at higher ratios are not unexpected, however, because of the more severe conditions at the billet-die interface.

TABLE XVI. EFFECT OF FLUID ON PRESSURES FOR WARM HYDROSTATIC EXTRUSION OF AISI 4340 STEEL

Trial	Extrusion Ratio	Extrusion Temperature, F	Fluid(a)	Type of Stem Seal(b)	Extrusion Pressure, 1000 psi				Extruded Surface Finish, microinch, rms	
					Breakthrough		Runout			
					Stem	Fluid	Stem	Fluid	Transverse	Longitudinal
394	4.0	500	PPE	1t	198	196	197	194	26	27
410	4.0	500	TCP	2t	200	187	200	185	28	34
411	4.0	500	TAP	2t	202	192	201	191	50	57
412	4.0	500	CBP	2t	196	186	191	181	31	30
413	4.0	400	SE	2t	189	182	189	180	41	35
418	5.0	500	PPE	2t	243	213	233	206	45	45
420	5.0	500	PPE	2t	230	200	222	197	31	29
422	5.0	400	SE	2t	223	196	214	193	30	25

(a) PPE – Polyphenyl ether
TCP – Tricresyl phosphate
TAP – Triaryl phosphate
CBP – Chlorinated biphenyl
SE – Silicate ester

(b) 1t = one PTFE O-ring used on stem seal; 2t = PTFE O-rings used on stem seal.

Apart from their effects on pressure requirements, it is worthy of note that all of the fluids evaluated performed satisfactorily as pressure media in the 400 to 500 F range. The finishes obtained with each fluid ranged from good to excellent but with triaryl phosphate (Trial 411) some slight scoring was observed.

Effect of Lubricants. A good measure of the effectiveness of the lubricants is given by:

(1) The difference between fluid breakthrough pressure and the corresponding runout pressure for individual trials

(2) The occurrence of stick-slip evident from the pressure curve

(3) Surface finish of the extruded product.

An evaluation of several lubricants on this basis is contained in Table XVII.

With the exception of L33 (55 wt percent MoS_2 and 6 wt percent graphite in sodium silicate), all of the lubricants used at 500 F for AISI 4340 steel and with PPE as the fluid can be rated as good to excellent. Three of the lubricants, L31, L34, and L38, gave outstanding results. For these lubricants, low breakthrough-pressure peaks and uniform or decreasing runout pressures were achieved. In addition, the surface finish of the extrusions was exceptionally good in all three cases. However, the other lubricants are considered satisfactory except where criterion such as surface finish is unusually demanding.

Apparently, good lubrication of AISI 4340 in hydrostatic extrusion at 500 F is readily accomplished. Choice of the lubrication system for a production operation appears to depend on economic factors and availability.