There may be selected applications, however, where the advantages of the pure hydrostatic extrusion process may be offset by its somewhat lower production rate capabilities compared to conventional extrusion (or other competitive processes). The lower production rates result from the extra cycle time required to handling and pressurizing the sizable volumes of hydrostatic fluid normally used in this technique.

However, suppose a significant portion of a company's products requires the use of only plain round billets of a given diameter. Then the question that arises is "can the pure hydrostatic extrusion process be simplified for plain round billets to be even more efficient and competitive with conventional extrusion?"

To answer this, one has to reexamine the precise role of the hydrostatic fluid. For plain round billets, the main function of using a fluid is to eliminate or minimize container friction and reduce die friction. Then why not limit the effect of the fluid to only this aspect for this particular application?

In view of this, another question is "what is the minimum thickness of a fluid film under pressure between the billet and container that would essentially eliminate container friction?" Theoretically, the fluid film need only be thick enough to avoid asperity contact and still be of low enough shear strength to minimize container friction. Then why not use the very minimum of hydrostatic fluid in that region?

With this in mind, the Hydrafilm extrusion process was conceived which extends the capabilities of the pure hydrostatic process. In so doing, the many benefits of hydrostatic extrusion can now be obtained for a greater number of products.

## THE HYDRAFILM EXTRUSION PROCESS

A schematic of one approach to the Hydrafilm extrusion process is shown in Figure 3. The key features of the process include the following:

(1) Hydrostatic fluid minimized. This is minimized in two locations:

(a) Between billet and container. The radial clearance can be less than 0.010 inch. By comparison to normal practice in pure hydrostatic extrusion, this is a thin film. However, by definition in lubrication terminology, it is a thick-film. For this reason, we refer to the process technically as "thick-film" hydrostatic extrusion.

(b) Between billet and stem. Only enough fluid is used to allow enough fluid pressurization to prevent or minimize billet upsetting and, if necessary, to achieve the proper thick-film viscosity to minimize friction. The fluid "head" above the billet need only be slight since it does not take much stem stroke to pressurize the very small amount of fluid between the billet and container. For some applications, no fluid "head" at all may be required.

(2) Stem contacts billet. Allowing the stem to contact the billet prior to and during extrusion not only permits further minimization of the hydrostatic fluid, but more importantly, largely avoids the potential problems of stick-slip and billet motion control.

In pure hydrostatic extrusion, stick-slip (rapidly intermittent billet motion) can occur on occasion with poor or marginal lubrication. This problem, due largely to the high elasticity or compressibility of the fluid under pressure, increases in severity with the ratio of fluid/billet volume.

For example, with poor lubrication, the pressure developed in the fluid prior to billet extrusion can far exceed that required once extrusion breakthrough is achieved. The excess energy stored in the fluid is suddenly released by extremely rapid extrusion of the billet until the fluid pressure drops to the "minimum" or runout level normally required for extrusion with reasonably good lubrication.

By the stem contacting the billet in the Hydrafilm process, there is little or no opportunity for stick-slip to occur, except perhaps at extremely slow ram speeds. Moreover, the possibility of unintentional complete billet extrusion is essentially eliminated.

(3) Billets precoated with hydrostatic medium. Because we have now minimized the amount of hydrostatic medium used, this allows a very significant simplification of the hydrostatic process. With production presses currently offered to industry, a large portion of billet extrusion cycle time is lost to fluid handling, i.e., fluid injection, fluid compression and decompression, and fluid removal. With the Hydrafilm process, the billets can be precoated with the hydrostatic medium which may be in the form of waxes, greases, or viscous fluids. By precoating, the billet cycle time, and thus production rates, can now closely approach or equal that achieved in conventional extrusion.

If the hydrostatic medium used as a precoat is too viscous under pressure, then the tooling (container, die, mandrel) can be warmed slightly (in the order of 100-200 F for some media) to lower the medium viscosity precisely where it is needed -- right at the tooling surfaces. In this approach, close technical control over a lubrication system is being exercised in order to maximize its capability or effectiveness for a given application.

(4) Separate billet lubricants may be used. As mentioned earlier, separate billet lubricants independent of the hydrostatic medium are sometimes necessary or desirable, depending on the billet material and the severity of the extrusion conditions.