

# PART 1. Liquid Properties of Liquid Penetrant

Penetrants and their ancillaries must have physical properties that fall within fairly narrow ranges. None are difficult to attain but properties cannot stray very far from optimum. The coverage of these topics is essentially practical. Some physical chemistry is included, particularly relating to capillarity, light absorption and scattering but not enough to require that the reader be a professional physical chemist. Discussions are limited to descriptions of usable processes and how they work. No effort is made to discuss unproved processes or theories.

For readers who have interests in other theories behind the mechanisms of penetration, surface wetting, adsorption and development and other fundamental physical chemistries of liquid penetrant testing, additional readings<sup>1-7</sup> are suggested.

## Penetration

The very name *penetrant* suggests that the ability to penetrate into voids is the major feature of a penetrant. This is no doubt true but it is not a critical feature. Very nearly any liquid will wet a solid surface and penetrate into voids. In fact, it is not easy to find a liquid that will not penetrate. If it wets, it will penetrate; if not, it will not.

Wetting of smooth, chemically clean surfaces has been studied extensively with relationships worked out between surface tension, interfacial tension, wetting contact angle, energy of adhesion. None are very appropriate because many of these quantities are not measurable on the kinds of surfaces that are tested with liquid penetrant. Even a cleaned surface can pick up a molecular monolayer of oil or oxide in a very short time. The slightest taint of oil on a surface can change a surface and cause a penetrant film to become less wet and to pull up into droplets. As a practical matter, this is not too serious. Reapplication of penetrant will usually dissolve this film and allow testing to proceed.

Surface tension can be defined as the force needed to expand (or pull apart) the surface of a liquid. It results from the attraction of all the molecules within the liquid for each other. At the surface, with no more liquid outside, the net force is

toward the liquid's interior, and the surface acts like a skin. It acts to minimize the surface area of the liquid and it requires effort (the surface tension) to stretch this skin.

Contact angle is the measured angle that a drop of liquid makes with a solid surface. If contact angle  $\theta$  is zero,  $\cos \theta = 1$  and the liquid will wet and spread. If the contact angle is 90 degrees or more,  $\cos \theta = 0$  and the liquid will not wet but will remain as a rounded drop. Intermediate contact angles indicate intermediate degrees of wetting. Contact angles can be measured on special sample surfaces with special equipment.

Energy of adhesion is a measure of the strength of attraction of a liquid to a solid surface and is of more theoretical than practical value.

Penetration of a discontinuity is primarily a capillary effect. The forces involved are those associated with capillary action and are called *capillary pressure* or excess surface pressure. This pressure is given by Eq. 1:

$$(1) \quad P = \frac{2\gamma}{R}$$

where  $\gamma$  is the surface tension of the liquid and  $R$  is the radius of curvature of the liquid surface. The effect of this capillary pressure can best be shown by examining the two systems depicted in Figs. 1a and 1b.

In Fig. 1a the liquid wets the capillary and the pressure  $P_1$  is up. In Fig. 1b the liquid does not wet the capillary and the pressure  $P_2$  is down. The ability to wet or not wet determines in which direction the surface will *curve*, whereas the degree of *wetting* determines to what extent the surface will curve. Therefore, the first requirement for penetration is its ability to wet the surface of the discontinuity.

The dimensions of the capillary are also important and the radius of the capillary can be related to the capillary pressure by examining Fig. 1c. It is found that  $R = r/\cos \theta$ , i.e.,  $\cos \theta = r/R$ , where  $r$  is the radius of the tube and  $\theta$  is the angle of contact of the liquid and the tube.

Equation 1 becomes:

$$(2) \quad P = \frac{2\gamma \cos \theta}{r}$$