Cavitation Parameters

Cavitation is the process of the formation of vapor bubbles in low pressure regions within a flow. One might imagine that vapor bubbles are formed when the pressure in the liquid reaches the vapor pressure, p_V, of the liquid at the operating temperature. While many complicating factors discussed later cause deviations from this hypothesis, nevertheless it is useful to adopt this as a criterion for the purpose of our initial discussion. In practice, it can also provide a crude initial guideline.

The static pressure, p, in any flow is normally nondimensionalized as a pressure coefficient, C_p, defined as

$$C_p = (p - p_1) / \frac{1}{2}\rho U^2 \tag{Mbeb1}$$

where p_1 is some reference static pressure for which we shall use the pump inlet pressure and U is some reference velocity for which we shall use the inlet tip speed, ΩR_{T1}. It is important to note that, for the flow of an incompressible liquid within rigid boundaries, C_p is only a function of the geometry of the boundaries and of the Reynolds number, Re, which, for present purposes, can be defined as $2\Omega R_{T1}^2/\nu$ where ν is the kinematic viscosity of the fluid. It is equally important to note that, in the absence of cavitation, the fluid velocities and the pressure coefficient are *independent* of the level of the pressure. Thus, for example, a change in the inlet pressure, p_1, will simply result in an equal change in all the other pressures, so that C_p is unaffected. It follows that, in any flow with prescribed fluid velocities, geometry and Reynolds number, there will be a particular location at which the pressure, p, is a minimum and that the difference between this minimum pressure, p_{min}, and the inlet pressure, p_1 is given by

$$C_{pmin} = (p_{min} - p_1) / \frac{1}{2}\rho U^2 \tag{Mbeb2}$$

where C_{pmin} is some negative number which is a function only of the geometry of the device (pump) and the Reynolds number. If the value of C_{pmin} could be obtained either experimentally or theoretically, then we could establish the value of the inlet pressure, p_1, at which cavitation would first appear (assuming that this occurs when $p_{min} = p_V$) as p_1 is decreased, namely

$$(p_1)_{\substack{\text{CAVITATION}\\ \text{APPEARANCE}}} = p_V + \frac{1}{2}\rho U^2 \left(-C_{pmin}\right) \tag{Mbeb3}$$

which for a given device, given fluid, and given fluid temperature, would be a function only of the velocity, U.

Traditionally, several special dimensionless parameters are utilized in evaluating the potential for cavitation. Perhaps the most fundamental of these is the cavitation number, σ, defined as

$$\sigma = (p_1 - p_V) / \frac{1}{2}\rho U^2 \tag{Mbeb4}$$

Clearly every flow has a value of σ whether or not cavitation occurs. There is, however, a particular value of σ corresponding to the particular inlet pressure, p_1, at which cavitation first occurs as the pressure is decreased. This is called the cavitation inception number, and is denoted by σ_i:

$$\sigma_i = \left[(p_1)_{\substack{\text{CAVITATION}\\ \text{APPEARANCE}}} - p_V\right] / \frac{1}{2}\rho U^2 \tag{Mbeb5}$$

If cavitation inception occurs when $p_{min} = p_V$, then, combining equations (Mbeb3) and (Mbeb5), it is clear that this criterion corresponds to a cavitation inception number of $\sigma_i = -C_{pmin}$. On the other hand, a departure from this criterion results in values of σ_i different from $-C_{pmin}$.

Several variations in the definition of cavitation number occur in the literature. Often the inlet tip velocity, ΩR_{T1}, is employed as the reference velocity, U, and this version will be used in this monograph unless otherwise stated. Sometimes, however, the relative velocity at the inlet tip, w_{T1}, is used as the reference velocity, U. Usually the magnitudes of w_{T1} and ΩR_{T1} do not differ greatly, and so the differences in the two cavitation numbers are small.

In the context of pumps and turbines, a number of other, surrogate cavitation parameters are frequently used in addition to some special terminology. The $NPSP$ (for net positive suction pressure) is an acronym used for $(p_1^T - p_V)$, where p_1^T is the inlet total pressure given by

$$p_1^T = p_1 + \frac{1}{2}\rho v_1^2 \tag{Mbeb6}$$

For future purposes, note from equations (Mbeb6), (Mbeb4) and (Mbbc5) that

$$\left(p_1^T - p_V\right) = \frac{1}{2}\rho\Omega^2 R_{T1}^2 \left(\sigma + \phi_1^2\right) \tag{Mbeb7}$$

Also, the $NPSE$, or net positive suction energy, is defined as $(p_1^T - p_V)/\rho$, and the $NPSH$, or net positive suction head, is $(p_1^T - p_V)/\rho g$. Furthermore, a nondimensional version of these quantities is defined in a manner similar to the specific speed as

$$S = \Omega Q^{\frac{1}{2}} / (NPSE)^{\frac{3}{4}} \tag{Mbeb8}$$

and is called the "suction specific speed". Like the specific speed, N, the suction specific speed, is a dimensionless number, and should be computed using a consistent set of units, such as Ω in rad/s, Q in ft^3/s and $NPSE$ in ft^2/s^2. Unfortunately, it is traditional U.S. practice to use Ω in rpm, Q in gpm, and to use the $NPSH$ in ft rather than the $NPSE$. As in the case of the specific speed, one may obtain the traditional U.S. evaluation by multiplying the rational suction specific speed used in this monograph by 2734.6.

The suction specific speed is similar in concept to the cavitation number in that it represents a nondimensional version of the inlet or suction pressure. Moreover, there will be a certain critical value of the suction specific speed at which cavitation first appears. This special value is termed the inception suction specific speed, S_i. The reader should note that frequently, when a value of the "suction specific speed" is quoted for a pump, the value being given is some critical value of S that may or may not correspond to S_i. More frequently, it corresponds to S_a, the value at which the degradation in the head rise reaches a certain percentage value (see section (Mbee)).

The suction specific speed, S, may be obtained from the cavitation number, σ, and vice versa, by noting that, from the relations (Mbbc5), (Mbeb4), (Mbeb6), and (Mbeb8), it follows that

$$S = \left[\pi\phi_1 \left(1 - R_{H1}^2/R_{T1}^2\right)\right]^{\frac{1}{2}} / \left[\frac{1}{2}\left(\sigma + \phi_1^2\right)\right]^{\frac{3}{4}} \tag{Mbeb9}$$

We should also make note of a third nondimensional parameter, called Thoma's cavitation factor, σ_{TH}, which is defined as

$$\sigma_{TH} = \left(p_1^T - p_V\right) / \left(p_2^T - p_1^T\right) \tag{Mbeb10}$$

where $(p_2^T - p_1^T)$ is the total pressure rise across the pump. Clearly, this is connected to σ and to S by the relation

$$\sigma_{TH} = \frac{\sigma + \phi_1^2}{\psi} = \left(\frac{N}{S}\right)^{\frac{4}{3}} \tag{Mbeb11}$$

Since cavitation usually occurs at the inlet to a pump, σ_{TH} is not a particularly useful parameter since $(p_2^T - p_1^T)$ is not especially relevant to the phenomenon.