LIQUID SPRAY AND SPRAY NOZZLES

Nozzle flow rate

In order to calculate the discharge flow rate from a given nozzle the Bernoulli law shall be used, which says that the energy of a liquid flow remains unchanged over all the sections of the flow. Friction and turbulence losses are neglected, which is reasonable for our purposes if the calculation is performed over two sections not too far away from each other.

The energy of a given liquid flow crossing a given pipe section is composed of three parts, namely:

\[ P \quad \text{Pressure energy of liquid particle per volume unit} \]
\[ \frac{1}{2} \rho V^2 \quad \text{Kinetic energy of liquid particle per volume unit} \]
\[ \rho g Z \quad \text{Potential Energy of liquid particle per volume unit} \]

Where \( \rho \) = density of liquid, \( g \) = gravitational acceleration, \( Z \) = height respect to one plane of reference, \( V \) = liquid velocity

The Bernoulli law can be written as follows

\[ P + \frac{1}{2} \rho V^2 + \rho g Z = E \]

Therefore, if we consider two sections of the same pipe, section A and section B, we can write that the flow energy remains constant in the form:

\[ P_A + \frac{1}{2} \rho V_A^2 + \rho g Z_A = P_B + \frac{1}{2} \rho V_B^2 + \rho g Z_B \]

If we finally consider that the two above sections are taken immediately before and immediately after the nozzle outlet orifice, being:

\[ \begin{aligned}
Z_A &= Z_B \\
P_B &= 0 \\
V_A &= 0
\end{aligned} \quad (P_i \text{ is a differential pressure referred at the atmosphere pressure})
\]

we shall come to the formula:

\[ P_A - \frac{1}{2} \rho V_B^2 \Rightarrow V_B = \sqrt{\frac{2}{\rho} \cdot P_A} \Rightarrow V = C \cdot \sqrt{P} \]

When we define a new constant, \( k \), to include the value of the nozzle orifice outlet area \( A \), then we come to the following equation which says that for a nozzle spraying into a room at ambient pressure, the exiting flow is proportional to the feed line pressure.

\[ Q = A \cdot V \Rightarrow Q = A \times C \times \sqrt{P} \Rightarrow Q = K \cdot \sqrt{P} \]

Considering now two different pressure values for the same nozzle, since \( k \) is a constant quantity, we can write that:

\[ K = \frac{Q}{\sqrt{P}} \Rightarrow \frac{Q_1}{\sqrt{P_1}} = \frac{Q_2}{\sqrt{P_2}} \Rightarrow \frac{Q_1}{Q_2} = \sqrt{\frac{P_1}{P_2}} \]

and derive from the above an equation that makes it possible to calculate the nozzle flow value at any given pressure value, once the flow value at another pressure value is known:

\[ Q_2 = Q_1 \cdot \sqrt{\frac{P_2}{P_1}} \]
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The Equation (5) has been obtained after having simplified the real problem, neglecting several factors like for example:
• In most of the practical application cases the flow is turbulent and not laminar.
• Friction losses tend to strongly increase with liquid velocity.
• Depending upon the type of nozzle, a different percentage of the available energy is used to break up the jet and give the desired spray pattern and spray angle.

For the above reason equation (5) gives reliable results if used in a limited pressure range around the pressure value where the flow rate is known, with this pressure range depending upon the type of nozzle.
Our experience has shown that one can expect the error in the calculated value to be lower than +/- 5% for pressure values ranging from 1/3 to 3 times the reference value.

As an example, a nozzle rated for 10 lpm at 3 bars would have, according to equation (5) the following flow values:
a 1 bar 5.77 lpm
a 9 bar 17.3 lpm
in real conditions it can be expected the flow rate values, to be:
as high as 6.1 lpm a 1 bar
as low as 16.2 lpm a 9 bar
Above considerations are to be used as a guideline only, because of the many factors influencing real operations which have not been considered here, for example liquid, temperature, viscosity and density.

Possible percentage deviation from theoretical flow rate values.

Also, above mentioned percentage errors have to be understood for nozzles using part of the flow energy to produce wide angle spray patterns.
Lower values can be expected for narrow angle nozzles, impact nozzles, and straight jet nozzles.
Laboratory tests and diagrams showing real flow rate values for each nozzles are used in practice when a precise result must be available.

Nozzle discharge coefficient

With reference to equation (4), if we consider the pressure value to be equal to 1, (P = 1 bar), the flow rate of the nozzle becomes:
\[ Q = K \cdot \sqrt{P} = K \cdot \sqrt{1} = K \]

\text{NOZZLE CAPACITY FOR } P=1 \text{ bar}

K is a parameter widely used in the fire fighting industry.

In some instances reference is made to the nozzle discharge coefficient or shortly to the nozzle coefficient to indicate the nozzle flow rate for a unitary pressure.
Of course, for a given pressure value \( P_n \), the flow value will be

\[ Q_n = K \sqrt{P_n} \]

\text{CAPACITY AT A GIVEN PRESSURE VALUE WHEN } K \text{ KNOWN}