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Short note

OrificeMeter: An ActiveX component to determine fluid flow in a pipeline ☆

Mahendra P. Verma *

Geotermia, Instituto de Investigaciones Electricas, Av. Reforma 113, Col. Palmira, Apdo. 1-475, Cuernavaca 62490, Mor., México

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1. Introduction

In geothermal systems, fluid flow is measured with an orifice meter. The theoretical formula for an orifice meter is derived on the basis of continuity and Bernoulli equations. The Bernoulli equation is valid for incompressible fluids; therefore, the application of the theoretical formula for orifice meters provides reasonable results for the determination of liquid flow.

The International Organization for Standardization (ISO) included some empirical parameters in the theoretical formula. The modification was based on an extensive study of the comparison of experimentally measured and theoretically calculated values of fluid flow (ISO, 2003). Thus the empirical formula (ISO-5167-2) is useful for both liquid and gas (vapor) flow. The technical details and restrictions for the construction of an orifice meter are also described in the ISO-5167-2 manual. In the geothermal industry, the orifice meter with D and $D/2$ tapings is used for steam flow measurement. Here the fluid flow calculation procedure is discussed on the assumption that the construction of the orifice meter was in accordance with the ISO-5167-2 specifications.

The fluid flow calculation procedure is an iterative process, which requires the thermodynamic properties of the flowing fluid (steam or liquid water). Verma (2003) wrote an ActiveX component, *SteamTables* to calculate the thermodynamic properties of pure water based on the International Association for the Properties of Water and Steam (IAPWS-95) formulation considering temperature and pressure as independent variables.

In this article an ActiveX component, *OrificeMeter* is developed to measure the steam flow in a pipeline with an orifice meter. The algorithm is based on the ISO-5167-2 formulation and it uses the *SteamTables* for the thermodynamic properties of steam at a given pressure and temperature. It also calculates the thermodynamic properties along the separation boundary (i.e. the sublimation, saturation or critical isochor curve) considering temperature or pressure as an independent variable.

2. Basic theory

An orifice meter consists of a flat circular plate with an axial concentric circular hole, called the orifice (Fig. 1). A brief summary of the theory of an orifice is presented here (see for details, Modi and Seth, 2000). By applying the Bernoulli equation the following is obtained

$$\frac{p_1}{\rho g}+\frac{v_1^2}{2g}+z_1=\frac{p_2}{\rho g}+\frac{v_2^2}{2g}+z_2$$

or

$$\left(\frac{p_1}{\rho g}+z_1\right)-\left(\frac{p_2}{\rho g}+z_2\right)\equiv h=\frac{v_2^2}{2g}-\frac{v_1^2}{2g} \quad (1)$$

☆ Code available from server at http://www.iamg.org/CGEditor/index.htm

* Tel.: +52 777 362 3811x7317; fax: +52 777 363 3804.
E-mail address: mahendra@iie.org.mx

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Nomenclature

$A\left[=\left(\frac{19{,}000\beta}{ReD}\right)^{0.8}\right]$ (dimensionless)
A_0 sectional area of the aperture of orifice plate (m^2)
A_1 sectional area at the upstream tapping (m^2)
A_2 sectional area of the jet at the downstream tapping (m^2)
C, C_c, C_d, C_{vel} coefficients of discharge of the orifice with different factors of multiplier (dimensionless). See text for their definition.
D internal diameter of pipe (m)
d aperture of orifice plate (m)
g acceleration due to gravity (m/s^2)
h pressure head (m)
l_1 upstream pressure tapping spacing from the upstream face (m)
$L_1(=l_1/D)$ quotient of the distance of the upstream tapping from upstream face of the place and the pipe diameter (dimensionless)
l_2 downstream pressure tapping spacing from the downstream face (m)
$L_2(=l_2/D)$ quotient of the distance of the downstream tapping from downstream face of the plate and the pipe diameter (dimensionless)
$M_2[=2L_2/(1-\beta)]$ (dimensionless)
p_1 pressure at the upstream tapping (Pa)
p_2 pressure at the downstream tapping (Pa)
$\Delta p(=p_1-p_2)$ pressure difference (Pa)
Q_M mass flow rate passing through the orifice plate (kg/s)
$ReD\left[=\frac{\rho v_1 D}{\mu}=\frac{4Q_M}{\pi\mu D}\right]$ Reynolds number at the upstream pressure tapping (dimensionless)
T temperature at the upstream tapping (K)
t_p plate thickness (m)
v_1 fluid velocity at the upstream tapping (m/s)
v_2 fluid velocity at the downstream tapping (m/s)
z_1 elevation of upstream pressure tapping (m)
z_2 elevation of downstream pressure tapping (m)
$\beta(=d/D)$ diameter ratio (dimensionless)
ρ density of inflowing fluid (kg/m^3)
μ dynamic viscosity of the inflowing fluid (Pa s)
ε expansibility factor (dimensionless)
κ isentropic exponent (dimensionless). It is considered here as the ratio of the specific heat capacity at constant pressure to the specific heat capacity at constant volume.

The orifice meter is aligned horizontally; therefore $z_1=z_2$ and $h=(\Delta p/\rho g)$. From Eq. (1) the velocity at Section 2 can be written as

$$v_2=\sqrt{2gh+v_1^2} \tag{2}$$

Since in the derivation of the above expression the energy losses due to friction are not considered, the actual velocity at Section 2 is obtained by multiplying with a factor C_{vel} as

$$v_2=C_{vel}\sqrt{2gh+v_1^2} \tag{3}$$

According to the continuity equation, the actual discharge, Q_M through the pipe is

$$Q_M=A_1v_1=A_2v_2 \tag{4}$$

The density of flowing fluid is considered the same at both Sections 1 and 2 around the orifice plate. This is an approximation for the validation of the Bernoulli theorem. If we consider the different fluid density at the sections, the derivation of the theoretical formula for an orifice meter will become very complicated and will be of little practical use. This is the reason why the ISO formulation considers only the inflowing fluid density as presented later.

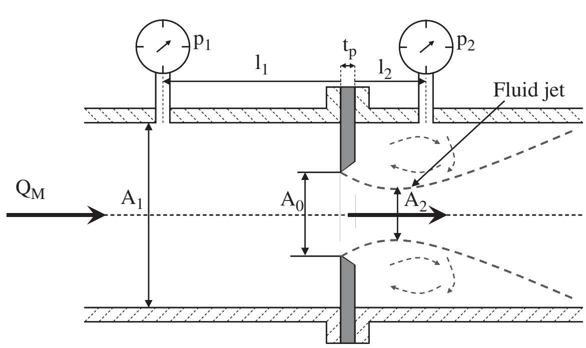

Fig. 1. Schematic diagram of an orifice meter with D and $D/2$ tapping (modified after Modi and Seth, 2000). To the left of the orifice plate, flow of steam occurs in the whole pipeline but to the right there is fluid (steam) jet shown by dashed curves. Turbulence due to jet is shown by dashed curve arrows. A_1, $A_{0,}$ and A_2 represent the area of pipeline, aperture of orifice plate, and tminimum area of fluid jet, respectively.

The area of the jet (A_2) at Section 2 is related to the area of the orifice A_0 by the following expression

$$A_2=C_cA_0 \tag{5}$$

Introducing the value of A_2 in Eq. (4) results in

$$v_1=v_2C_c\frac{A_0}{A_1} \tag{6}$$

Substituting the value of v_1 in Eq. (3) leads to

$$v_2=C_{vel}\sqrt{2gh+v_2^2C_c^2\frac{A_0^2}{A_1^2}} \tag{7}$$

From Eq. (4) and considering $C_cC_{vel}=C_d$, the mass flow rate can be stated as

$$Q_M=\frac{C_dA_0\sqrt{2gh}}{\sqrt{\{1-C_d^2(A_0^2/A_1^2)\}}} \tag{8}$$

The above expression is further simplified by introducing another coefficient C, which is expressed as

$$C=C_d\sqrt{\frac{1-\left(\frac{A_0}{A_1}\right)^2}{1-C_d^2\left(\frac{A_0}{A_1}\right)^2}}.$$

so that the mass flow rate through the orifice plate is

$$Q_M=C\frac{A_0A_1\sqrt{2gh}}{\sqrt{(A_1^2-A_0^2)}}=C\frac{\pi d^2/4\sqrt{2gh}}{\sqrt{\left(1-\left(\frac{d}{D}\right)^4\right)}} \tag{9}$$

In the derivation of the above equation various approximations (validation of Bernoulli theorem, no energy losses, etc.) are considered. Therefore, there is generally not a good agreement between the calculated and measured values of Q_M.

The ISO developed an empirical relation ISO-5167-2 based the theoretical and the experimentally measured values of Q_M. Thus