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Pressure measurement technique and installation effects on the performance of wafer cone design

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ABSTRACT

The present study explores novel pressure averaging technique for wafer cone flowmeter design and its robustness in the presence of double 90° bend (out-of-plane) and gate valve as a source of upstream flow disturbance. The wafer cone flowmeter is tested in a circular pipe (inside diameter of 101 mm) with water as the working medium for the flow Reynolds number ranging from 1.19×10^5 to 5.82×10^5. Influence of the half cone angle (α) on the coefficient of discharge (C_d) of wafer cone flowmeter is studied with this new pressure averaging technique. Half cone angles considered in this study are 30° and 45° with a constant constriction ratio (β) of 0.75. The upstream static pressure tap is located at 1*D* upstream of the wafer cone. The downstream pressure averaging technique comprises eight circumferential holes of diameter 2 mm on the maximum diameter step of the wafer cone. The pressure taps are communicated through the support strut which serves as a downstream static pressure tap. The disturbance causing elements are individually placed at 1.5*D*, 5.5*D*, 9.5*D* and 13.5*D* upstream to the wafer cone flowmeter. The wafer cone flowmeter is also tested with gate valve opening of 25%, 50% and 75% for all the arrangements considered. The 30° cone is found to be better than 45° cone for the range of Reynolds number covered in the present study. The results show that the 30° wafer cone flowmeter with novel downstream pressure averaging technique is insensitive to the swirl flow created by a double 90° bend (out-of-plane) and requires an upstream length of 9.5*D* with a gate valve as a source of flow disturbance.

1. Introduction

The increase in commodity prices is forcing stringent necessity for accurate fluid flow measurement in various sectors. Process expansion always suffers space constraints. Under these circumstances, fluid flow measurements demand minimum installation lengths. Conical flowmeters are the first choice, capable of bringing down the installation costs owing to their minimum installation length requirements and with desired level of accuracy ($\pm 0.5\%$). Wafer cone flowmeter is a variant of the cone flowmeter which consists of a cone placed inside a pipe with support at the downstream side of the cone instead of upstream side. The wafer cone offers a smooth constriction for the flow as opposed to the conventional cone design and the static pressure measurements are carried out before the flow reaches the support of the cone. This phenomenon gives improved performance for the wafer cone flowmeter. A wafer cone with upstream and downstream wall taps is the most common configuration used in the industry. The present work introduces a novel downstream static pressure averaging technique to improve the performance of wafer cone flowmeter.

Ifft and Mikkelsen [1] experimentally studied the pipe elbow effects on the performance of conventional conical flowmeter. Three β ratios of 0.363, 0.650 and 0.750 were studied. The deviation in coefficient of discharge (C_d) was 0.622% in case of conical flowmeter with a β ratio of 0.75 when a single elbow was placed adjacent to the flowmeter. For conical flowmeters with β ratios of 0.363 and 0.650, the deviation in coefficient of discharge was within 0.5% for disturbances like single and double elbows. However, the deviations observed for orifice meters for the same β ratios were as high as 5%. Prabhu et al. [2] studied the effect of upstream pipe fittings on the performance of conical flowmeter and orifice meter. The upstream disturbances were produced with 90° pipe bends viz. single bend, double in-plane bends and double out-of-plane bends. To minimize the effect of upstream disturbance due to a single bend and double in plane bend on the conical flowmeter, upstream piping of minimum 4*D* is required as opposed to 22*D* required by the orifice meter. It was also observed that the pumping power required with conical flowmeter was 50% less than that of orifice meter. Peters et al. [3] studied the wafer type conical flowmeter under flow disturbances induced by gate valves, pipe elbows and 24° swirl generator with gas and

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Nomenclature

A_1	cross sectional area of the pipe (m^2)
A_2	cross sectional area of the passage at the maximum cone diameter (m^2)
C_d	coefficient of discharge
$\overline{C}_d$	average value of coefficient of discharge
C_{d_expt}	experimental value of coefficient of discharge
C_{di}	a datum in a sample
C_{d_num}	value of coefficient of discharge obtained from numerical simulation
D	internal diameter of the pipe (m)
D_1	maximum cone diameter (m)
Δp	differential pressure drop measured across the flowmeter (Pa)
K	irrecoverable pressure loss coefficient
m_{in}	initial mass of the water in the collecting tank (kg)
m_f	final mass of the water collected in the tank after time 't' (kg)
$\dot{m}_{act}$	actual mass flow rate (kg/s)
$\dot{m}_{th}$	theoretical mass flow rate (kg/s)
N	sample size
P_1	static pressure tap through the cone toward the downstream end of the cone
P_2	static pressure tap on the pipe wall at the maximum diameter of the cone
P_3	static pressure tap on the pipe wall at the downstream end of the cone
Re_D	Reynolds number ($\rho VD/\mu$)
t	time during which the water is collected in the tank (s)
U	uncertainty
V	average velocity of the water flowing through the pipe (m/s)
y^+	dimensionless wall thickness in computational domain

Greek symbols

$\Delta\overline{\varpi}$	irrecoverable pressure drop due to the placement of cone in the flow path (Pa)
α	half Cone angle (deg.)
β	constriction ratio of the conical flowmeter ($\sqrt{((D^2-{D_1}^2)/D^2)}$)
μ	dynamic viscosity of the water (Pa s)
ρ	density of the water (kg/m^3)
σ	standard deviation

water media. Standard testing (no disturbance) with 100 mm cone of β ratios of 0.45 and 0.65 showed results within $\pm 1\%$ for both the media viz. high pressure gas (26–30.4 bar) and water (0.827 bar). Upstream length requirements for wafer V-cone flowmeter were 0D for double bend (out-of-plane), 3.1D for gate valve and 0D for 24° swirl generator for 4 in. cone with β ratio of 0.45. However, the dimensions of the cones are not disclosed.

Singh et al. [4] experimentally studied the performance of conical flowmeter in the presence of upstream disturbance caused by a gate valve. Constriction ratios (β) considered in their study were 0.64 and 0.77. They found that C_d increases with increasing closure of valve. The coefficient of discharge of the conical flowmeter is unaffected if an upstream pipe length of 10D or more is provided between the valve and the conical flowmeter. Singh et al. [5] numerically studied the effects of half cone angle (30°, 40°and 50°) and upstream swirl (swirl angles of 10°, 20° and 30°) on coefficient of discharge of conical flowmeter for β=0.5, 0.64 and 0.70. They found that value of C_d decreases marginally with increasing cone angle and the conical flowmeter having 30° half cone angle has the value of discharge coefficient with minimum scatter of 0.06% standard deviation. Influence of the swirl is reported only for a conical flowmeter with a half cone angle of 40° and a β ratio of 0.64. Percentage change in the coefficient of discharge with swirl angle of 10° was 1.22% whereas for 20° and 30° swirl, the change was 2.56% and 2.90% respectively. This phenomenon was attributed to the fact that the presence of swirl affects both the pressure field and the structure of wake behind the cone. Swirl sets up a radial pressure gradient which increased the downstream pressure thereby reducing the pressure difference across the cone. This resulted in a slight increase in the value of discharge compared to the fully developed flow situation. Singh et al. [6] numerically studied the influence of upstream disturbances (single elbow, double elbows in-plane and double elbows out-of plane) on the coefficient of discharge of conical flowmeter. The deviations in the discharge coefficient due to asymmetric flow caused by the elbow fittings were rather small (2%). In addition, the percentage variation in the computed values of the discharge coefficients over a wide range of Reynolds numbers was also small (< 1%). Sapra et al. [7] made an attempt to standardize cone flowmeter design with systematic studies on various beta ratio (0.4, 0.5, 0.6, 0.7 and 0.8) cones. A maximum deviation of 3% in discharge coefficient is observed of beta ratio of 0.5 with 50% and 25% gate valve openings.

The majority of the literature regarding conical flowmeter has contributed to the influence of cone angle and β ratio on the performance of conical flowmeter. The downstream pressure tap location is the other major design parameter which is seldom addressed in the literature. The downstream pressure tap plays a vital role under swirling flow situations with induced radial pressure gradients. The aim of the present work is to address the sensitivity of the downstream pressure tap location on the performance of wafer cone flowmeter under fully developed and disturbed flow condition. In this connection, a novel pressure averaging technique is compared with conventional pressure tap locations. Two wafer cones with half cone angles (α) of 30° and 45° with a constant constriction ratio (β) of the 0.75 are studied. Two downstream static pressure tap locations covered in the present study are

- an averaging pressure tap communicated through the cone support measuring the static pressure at the maximum diameter of the cone; and
- a wall tap downstream of the cone.

An undisturbed pipe length of 54D is provided before the wafer cone flowmeter to ensure fully developed flow condition. The flowmeter is placed at different upstream distances from a double 90° bend (out-of-plane) and gate valve. This is essentially to study the influence of disturbed flow on the coefficient of discharge compared to fully developed flow condition.

2. Experimental setup

The construction of a wafer cone flowmeter and the locations of static pressure taps are shown in Fig. 1. The static pressure tap