

**EFFECTS OF SOME GEOMETRICAL AND
DYNAMICAL PARAMETERS ON THE
FLOW CHARACTERISTICS OF V-CONE
FLOWMETER**

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OCTOBER 2018**

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Submitted

*in fulfilment of the requirements of the degree of Doctor Of Philosophy
to the*



INDIAN INSTITUTE OF TECHNOLOGY DELHI

OCTOBER 2018

CERTIFICATE

This is to certify that the thesis titled "**EFFECTS OF SOME GEOMETRICAL AND DYNAMICAL PARAMETERS ON THE FLOW CHARACTERISTICS OF V-CONE FLOWMETER**" being submitted by **Sheikh Nasiruddin** to the Indian Institute of Technology Delhi for the award of the degree of '**Doctor of Philosophy**' is a record of bonafide research work carried out by him under our guidance and supervision. He has fulfilled the requirements for the submission of this thesis, which in our opinion has reached the requisite standard. The results contained in the thesis have not been submitted in part or full, to any other University or Institute for the award of any degree or diploma.

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ACKNOWLEDGEMENT

I acknowledge my sincere and deep indebtedness to my supervisors Prof. S.N. Singh, Prof. S.V. Veeravalli and Dr. Sriram Hegde for their valuable guidance, keen interest, support and encouragement throughout this work. During the entire course of this work, apart from educative discussions, Prof. S.N. Singh inspired and motivated me with his leadership and guidance in crucial and critical matters.

I shall like to express my gratitude to Dr. Murali Cholemari who spent his valuable time and assisted me in learning PIV.

My sincere thank to all the staff of Gas Dynamics and Fluid Mechanics Laboratory of Applied Mechanics Department for their assistance during this work. I would like convey my special thank to Shri Madan Gopal for his skilful work during fabrication of experimental set-up.

I would like to express my sincere thanks to my friends specially Dr. T. Vijaykumar, Mr Chandrahas, Mr. Lakhvinder Singh, Mr Shrish Shukla for their moral support and fruitful discussions at the moment of difficulty.

I have no words to express my gratitude to my parents, wife and children. Their patience, understanding and loving support made this work possible.

Finally, I would like to spare a thought for myself. At the end of Ph.D., I remember the moments when I thought to achieve this degree was beyond me but now I am glad to say that it was not and enjoyed this inspirational pursuit of knowledge.

Date: October 2018

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ABSTRACT

Various obstruction type flow measuring devices are being used in the industries and V-cone flowmeter is one of them. Many researchers have investigated and evaluated the performance of the V-cone flowmeter but very limited literature is available may be due to commercial use. There are many dynamical and geometrical parameters whose effect on the performance of the V-cone flowmeter may or may not have been investigated but is not available in the open literature. In the current research work, the effect of some of these parameters has been investigated both experimentally and computationally. First, the performance of a V-cone flowmeter with rear support is evaluated experimentally to establish the effect of vertex angle for two specific ' β ' values i.e. 0.62 and 0.72 in the flow range of $3028 \leq Re \leq 81877$. It has been found that for a given vertex angle, coefficient of discharge (C_d) is nearly independent of ' β ' value. For a given ' β ' value the coefficient of discharge decreases with vertex angle. The effect of downstream pressure tap location on the performance of V-cone flowmeter has also been investigated experimentally. The downstream pressure tap between 0.4D and 0.5D distance could be an alternative position for pressure differential to the base pressure generally used. PIV, a non-intrusive tool has been used for measuring velocity and turbulent intensity and visualization of the 2D vector field for the cone configuration of $\beta=0.62$ and vertex angle 30° at the flow Reynolds number of 3028, 6057, 52755 and 74488.

In the concomitant numerical studies, the effect of boundary layer thickness on the performance of V-cone flow meter is studied using the Fluent CFD software. The shear stress transport $k-\omega$ (SST $k-\omega$) turbulence model has been chosen for these numerical simulations after validation. Two V-cone flowmeters with different beta ratios (β) viz., 0.6 and 0.7 with fixed vertex angle (ϕ) of 60° have been studied and analyzed for Reynolds

numbers (Re) ranging from 500 to 5,00,000. The results apparently show that the upstream boundary layer thickness has very little effect on the performance of the flowmeter. In real situation, to have uniform velocity profile at 5D upstream is impractical. A thorough study has been carried out to establish the effect of vertex angle for three cone configurations namely without support (ideal condition) and with front and rear support on the performance of V-Cone flowmeter for a fixed beta ratio (β) of 0.6. The vertex angle has been optimized on the basis of coefficient of discharge (C_d) and the amount of predicted uncertainty (U_{C_d}) in measurements within the range of Reynolds numbers investigated (Re) 10^3 to 10^6 . It is revealed that vertex angle of 75° is the appropriate vertex angle as it provides consistent results over the wide range of Reynolds number starting from laminar flow. The results also show that front support has negligible effect whereas rear support has significant effect on the performance of the flowmeter. The effect of cone vertex tip radius is seen to be negligible. The location of downstream pressure tapping point has also been studied and it is seen that 0.4D location gives consistent results.

The effect of providing a curved surface (the radius of curvature (R)) at the base of the cone element has been investigated by considering radii of curvature of 20 mm (hemispherical, $R/d= 0.5$), 22 mm ($R/d= 0.55$) 25 mm ($R/d= 0.625$) and 27.62 mm ($R/d= 0.6905$) in order to gradually reduce the arc length while keeping the chord length constant. In addition a semi-elliptical based cone with 20 mm semi-major axis and 10 mm semi-minor axis has also been investigated. The study shows that introducing curve surface of R/d ratio=0.55 at the base of the cone increases the mean C_d value by 8 % without significant changes in the accuracy of the flowmeter.

The effect of lateral and angular off-set of the cone axis in the horizontal and vertical planes on the performance of the V-cone flowmeter has also been studied. It is observed that

angular off-set of the cone axis either in the vertical or horizontal plane has insignificant effect but the lateral off-set has significant effect. The deviations are of the order of 3%.

The selected turbulence model has been used to predict the performance of the rear supported V-cone flowmeter and it is seen that the predictions match reasonably well with in-house experimental data. In addition, higher value of discharge coefficient is obtained with rear supported V-cone flowmeter. Discharge coefficient (C_d) increases linearly with Reynolds number in the lower range unlike the oscillating nature seen with front or without supported V-cone flowmeter except for vertex angle of 75° .

सार

उद्योगों में विभिन्न अवरोध प्रकार प्रवाह मापने वाले उपकरणों का उपयोग किया जा रहा है और वी-शंकु प्रवाह मीटर उनमें से एक है। कई शोधकर्ताओं ने वी-शंकु प्रवाह मीटर के प्रदर्शन की जांच और मूल्यांकन किया है लेकिन वाणिज्यिक उपयोग के कारण बहुत सीमित साहित्य उपलब्ध हो सकता है। कई गतिशील और ज्यामितीय पैरामीटर हैं जिनके प्रभाव वी-शंकु प्रवाह मीटर के प्रदर्शन पर असर पड़ सकता है या नहीं, लेकिन खुले साहित्य में उपलब्ध नहीं है। वर्तमान शोध कार्य में, इनमें से कुछ मानकों का प्रभाव प्रयोगात्मक और कम्प्यूटेशनल दोनों की जांच की गई है। सबसे पहले, पीछे समर्थन के साथ वी-शंकु प्रवाह मीटर का प्रदर्शन प्रयोगात्मक रूप से $3028 \leq Re \leq 81877$ की प्रवाह सीमा में दो विशिष्ट ' β ' मानों यानी 0.62 और 0.72 के लिए वर्टेक्स कोण के प्रभाव को स्थापित करने के लिए प्रयोग किया जाता है। यह पाया गया है कि दिए गए कशेरुक कोण के लिए, निर्वहन (सीडी) का गुणांक ' β ' मान से लगभग स्वतंत्र है। दिए गए ' β ' मान के लिए निर्वहन का गुणांक वर्टेक्स कोण के साथ घटता है। वी-शंकु प्रवाह मीटर के प्रदर्शन पर डाउनस्ट्रीम दबाव टैप स्थान का प्रभाव भी प्रयोगात्मक रूप से जांच किया गया है। 0.4 डी और 0.5 डी दूरी के बीच डाउनस्ट्रीम दबाव टैप आम तौर पर उपयोग किए जाने वाले बेस दबाव के दबाव के लिए एक वैकल्पिक स्थिति हो सकती है। पीआईवी, एक गैर-घुसपैठ उपकरण का उपयोग वेग और अशांत तीव्रता को मापने और $\beta = 0.62$ के शंकु विन्यास के लिए 2 डी वेक्टर फ़ील्ड के विज़ुअलाइज़ेशन और 3028, 6057, 52755 और 74488 के प्रवाह रेनॉल्ड्स संख्या पर वर्टेक्स कोण 30 डिग्री के माप के लिए किया गया है।

संगत संख्यात्मक अध्ययनों में, वी-शंकु प्रवाह मीटर के प्रदर्शन पर सीमा परत मोटाई के प्रभाव का अध्ययन फ्लुएंट सीएफडी सॉफ्टवेयर का उपयोग करके किया जाता है। सत्यापन के बाद इन संख्यात्मक सिमुलेशन के लिए कतरनी तनाव परिवहन के- ω (एसएसटी के- ω) अशांति मॉडल चुना गया है। अलग-अलग बीटा अनुपात (β) के साथ दो वी-शंकु प्रवाहमापक, 0.6 डिग्री और 0.7 के साथ 60 डिग्री के फिक्स्ड वर्टेक्स कोण (ϕ) के साथ अध्ययन किया गया है और 500 से 5,00,000 तक के रेनॉल्ड्स नंबर (रे) के लिए विश्लेषण किया गया है। परिणाम स्पष्ट रूप से दिखाते हैं कि अपस्ट्रीम सीमा परत मोटाई प्रवाह प्रवाह के प्रदर्शन पर बहुत कम प्रभाव डालती है। वास्तविक स्थिति में, 5 डी अपस्ट्रीम पर एक समान वेग प्रोफाइल होने के लिए अव्यवहारिक है। तीन शंकु विन्यासों के लिए कशेरुक कोण के प्रभाव को स्थापित करने के लिए एक पूर्ण अध्ययन किया गया है अर्थात् समर्थन के बिना (आदर्श स्थिति) और 0.6 के एक निश्चित बीटा अनुपात (β) के लिए वी-कॉन फ्लोमीटर के प्रदर्शन पर आगे और पीछे समर्थन के साथ। कशेरुक कोण को गुणांक (सीडी) के गुणांक (अनुमानित अनिश्चितता (यूसीडी) के आधार पर ऑप्टिमाइज़ किया गया है, जो रेनॉल्ड्स संख्याओं की जांच (रे) 103 से 106 की सीमा के भीतर माप में है। यह पता चला है कि 75 डिग्री के चरम कोण उचित वर्टेक्स कोण

है क्योंकि यह लैमिनार प्रवाह से शुरू होने वाले रेनॉल्ड्स संख्या की विस्तृत श्रृंखला पर लगातार परिणाम प्रदान करता है। नतीजे यह भी दिखाते हैं कि सामने के समर्थन में नगण्य प्रभाव पड़ता है जबकि पिछले समर्थन प्रवाह प्रवाह के प्रदर्शन पर महत्वपूर्ण प्रभाव डालता है। शंकु वर्टेक्स टिप त्रिज्या का प्रभाव नगण्य माना जाता है। डाउनस्ट्रीम प्रेशर टैपिंग पॉइंट का स्थान भी अध्ययन किया गया है और यह देखा जाता है कि 0.4 डी स्थान लगातार परिणाम देता है।

शंकु तत्व के आधार पर घुमावदार सतह (वक्रता (आर) का त्रिज्या) प्रदान करने का प्रभाव 20 मिमी (हेमीस्फेरिकल, आर / डी = 0.5), 22 मिमी (आर / डी) के वक्रता के त्रिज्या पर विचार करके जांच की गई है। = 0.55) तार लंबाई को स्थिर रखते हुए 25 मिमी (आर / डी = 0.625) और 27.62 मिमी (आर / डी = 0.6905) क्रमशः चाप लंबाई को कम करने के लिए। इसके अलावा 20 मिमी अर्ध-प्रमुख धुरी और 10 मिमी सेमी-नाबालिग धुरी के साथ अर्ध-अंडाकार आधारित शंकु की भी जांच की गई है। अध्ययन से पता चलता है कि शंकु के आधार पर आर / डी अनुपात = 0.55 की वक्र सतह शुरू करने से फ्लोमीटर की शुद्धता में महत्वपूर्ण परिवर्तन किए बिना औसत सीडी मान 8% बढ़ जाता है।

वी-शंकु प्रवाह मीटर के प्रदर्शन पर क्षैतिज और ऊर्ध्वाधर विमानों में शंकु अक्ष के पार्श्व और कोणीय ऑफ-सेट का प्रभाव भी अध्ययन किया गया है। यह देखा गया है कि शंकु अक्ष के कोणीय ऑफ-सेट या तो ऊर्ध्वाधर या क्षैतिज विमान में महत्वहीन प्रभाव पड़ता है लेकिन पार्श्व ऑफ-सेट का महत्वपूर्ण प्रभाव होता है। विचलन 3% के आदेश के हैं।

चयनित अशांति मॉडल का उपयोग पीछे समर्थित वी-शंकु प्रवाह मीटर के प्रदर्शन की भविष्यवाणी करने के लिए किया गया है और यह देखा जाता है कि भविष्यवाणियां घर के प्रयोगात्मक डेटा के साथ उचित रूप से अच्छी तरह मेल खाते हैं। इसके अलावा, पीछे समर्थित वी-शंकु प्रवाह मीटर के साथ निर्वहन गुणांक का उच्च मूल्य प्राप्त किया जाता है। निर्वहन गुणांक (सीडी) निचले स्तर में रेनॉल्ड्स संख्या के साथ रैखिक रूप से बढ़ता है, जो 75 डिग्री के चरम कोण को छोड़कर सामने या बिना समर्थित वी-शंकु प्रवाह मीटर के साथ दिखाई देने वाली प्रकृति प्रकृति के विपरीत होता है।

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NOMENCLATURE

D	Inner diameter of the circular pipe (mm)
R	Radius of curvature (mm)
d	Maximum diameter of cone element (mm)
P_1	Upstream pressure (Pa)
P_2	Downstream pressure (Pa)
ΔP	Differential pressure = $P_1 - P_2$ (Pa)
Re	Reynolds number
C_d	Coefficient of discharge
S_m	Source term
F_i	Body force per unit volume
\dot{m}	Mass flow rate (kg/s)
g_i	Gravitational acceleration (m/s^2)
k	Turbulent kinetic energy (m^2/s^2)
φ	Vertex angle ($^\circ$)
β	Equivalent diameter ratio = $\sqrt{1 - \frac{d^2}{D^2}}$
ρ	Density of working fluid (kg/m^3)
ω	Specific turbulence dissipation rate (1/s)
ε	Turbulence dissipation rate (m^2/s^3)
k_s	Roughness height (mm)
\bar{u}	Mean velocity (m/s)
μ	Dynamic viscosity of the working fluid (Pa.s)
μ_t	Turbulence viscosity (Pa.s)
τ_{ij}	Stress tensor (Pa)

δ_{ij}	Kronecker delta
\tilde{G}_k	Generation of kinetic energy (k)
G_ω	Generation of vorticity (ω)
Γ_k	Effective diffusivity of k
Γ_ω	Effective diffusivity of ω
Y_k	Dissipation of k due to turbulence
Y_ω	Dissipation of ω due to turbulence
S_k, S_ω	User defined source terms for k and ω equation
D_ω	Cross-diffusion term.
f	Friction factor
u_*	Friction velocity = $\sqrt{\frac{\tau_w}{\rho}}$
y_p	Half-height of first cell from the wall (mm)

Subscripts

i, j, k	Tensorial notations
k	Quantities related to turbulent kinetic energy
ω	Quantities related to dissipation rate
w	Wall