Pressure Intensity on Conical and Rounded Components in Needle Valves

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ABSTRACT

Flow controlling devices that include needle valves are examined with the pressure variations on the surface. Measurement of pressure intensity is done by providing pressure taps on the surface at regular intervals spirally to cover the area completely, and with use of internal tygon tubes. Pressure force is then integrated on conical surface of needle. Flow in inlet and exit of the channel depends on critical factors such as Reynolds number, is observed and studied. Separation phenomenon is critically examined at entrance of the channels. Avoiding separation, the experiments are carried out by fluctuating some of parameters and modifying the design. Entrance of exit channel and needle tip is modified by rounding of the corners for very high temperature applications to avoid erosions at corners. Local Pressure extremes are plotted using graphs against the cone lift and are recorded. Mainly the factors affecting pressure intensity on the surface are focused and the experimental results are obtained with use of computing software such as Fluent and presented in the paper. Recent uses of these components in additive manufacturing industries, for aerodynamic research have increased the interest and scope for the topic. Experiments are mainly performed on two designs with cone angle 60° and 90° and the results are formulated using graphs varying the relative lift of needle.

Keywords: ***Needle valves, Reynolds Number, Pressure measurements, Separation region.***

1. INTRODUCTION

Various flow control devices are known for adjusting or continuously modulating a fluid flow. If provided with a conical body inserted into various depths inside its entrance, an orifice may serve as a valve. The flow metering conical body with small included angle, made it suitable for precise adjustments for minimal cross sectional areas, and came to be known as "Needle Valves". Needle valve as flow controlling devices with the help of electronic devices as transducer, and using principle of electromagnetism does the excellent job with precision. The flow around needle valves is the extended application of aerodynamics and hydrodynamics. Pressure intensity on surface of such needle valve; be measured accurately with the laboratory models. The electrically driven needle valves (ferromagnetic material) are recently gaining importance, with increasing demand of electromagnetic devices. The needle valves are integral with the jet-generating nozzle, with the fluid leaving the closed cavities at the end of a short exit channel. Such needle valves, with the long history were used in inkjet printing techniques by modulating the fluid flow. A newly emerged phenomenon of near tip separation is observed.

2. FLUID MECHANICS OF NEEDLE VALVE

Needle Valves serving as flow control device basically are the light in weight components with tapered end forming cone shape. Metering Flow of fluid in critical applications need to be fast, which increases the demand of needle valves light components (lower inertia). Fast adjustment of flow valves is achieved by electrically driven mechanism which include transducers and hence principles of ferromagnetism. Metering by needle valves is achieved by relatively moving the needle inside the entrance of exit channel and varying cross sectional area. This is based on two principles of Fluid Mechanics namely Continuity Equation and Bernoulli's Principle. The force on the conical surface is the effect of hydrodynamic forces from the fluid flowing over it. Fig.1 shows a basic model of needle valve and flow across it with relative position of needle in axial direction for controlling the flow.

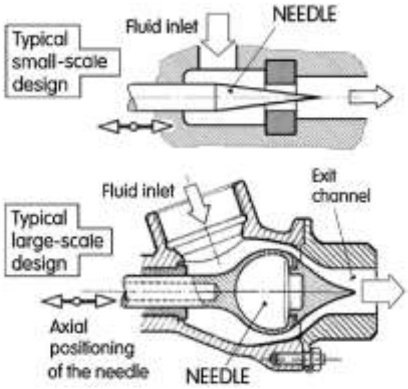

Figure 1: Example of needle valve a small scaled and a large scaled model design.

A simple representation of model of needle valve with the geometric dimensions is specified in the Fig. 2. The conical part which has an included angle β, needle lift z, Length of exit channel l, diameter at exit d. Cone angle for experimentation were chosen as 60◦ and 90◦, which later are turned into rounded parts so as to be used for specified applications of very high temperature fluid flow.

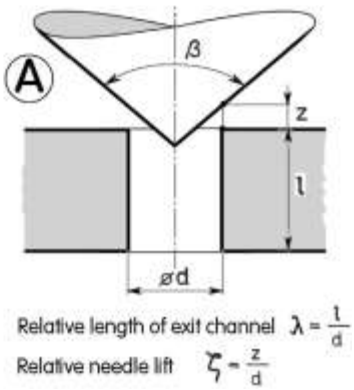

Figure 2: Sharp edge and sharp tip valve.

3. SEPARATION BUBBLE AT ENTRANCE OF CHANNEL

Model of needle valves were manufactured with specifications as such the included cone angle and relative lift adjusted through external mechanism in applications such as nozzles forming jets. Typical representation of needle valve with the design parameters as relative lift, cone angle exit channel length is shown on Fig. 3.

Particularly a sharp edged needle valve at the exit of a channel with cone angle $\beta=\pi/2$. Separation bubble forming at the entrance of an exit channel observed depends on the geometric parameters and the length of the exit channel. Relative cone lift (ζ) determines the flow through nozzle, maximum the lift minimum the flow.

As observed in these conical needle valves the separation occurs dominantly, increases the losses. These bubbles of separation usually lead to generation of stationary vortex rings dwelling immediately downstream from the entrance edge. These vortex rings tend to carry away the energy utilized in their formation increasing losses in hydrodynamic energy. To avoid such losses the further experiments were carried out to test the rounded components having a smooth curve at the entrance of exit channel or at the tip of the needle.

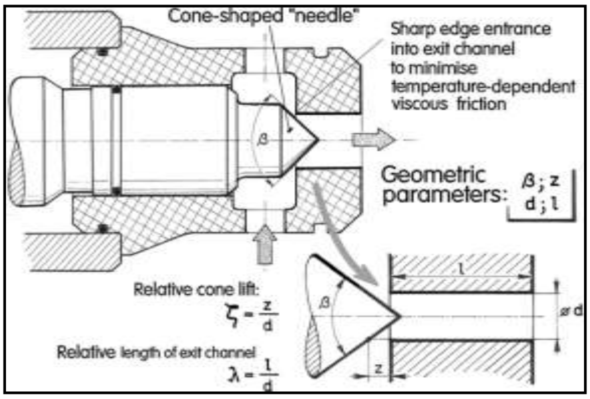

Figure 3: Representation of needle valve with geometric parameters.

The exact separation bubble formation at the exit channel due to the relative lift of the needle is shown in Fig. 4. Two cases with different lengths of exit channel are shown.

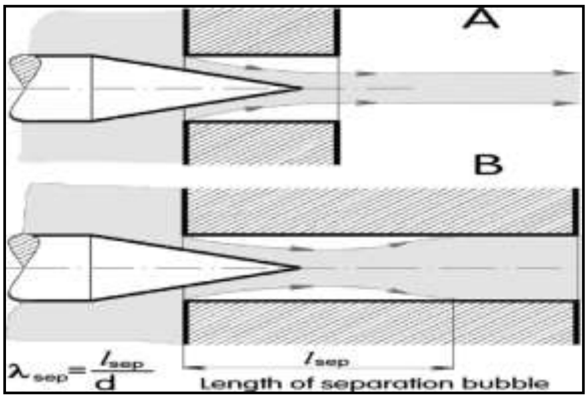

Figure 4: Importance of the relative length of the constant cross-section exit channel.

4. PRESSURE MEASUREMENT (A CASE STUDY)

Experiments are performed on laboratory test model where main aspect of distribution of pressure intensity is focused with varying cone angle and the relative lift of cone. According to the main interest of the paper, only centripetal flow directions are presented. The laboratory model made with the two cone angles i.e. $\beta=\pi/2$ and $\beta=\pi/3$ gave good results for measurement of the parameters at the surface.

4.1 Conical needle with cone angle $\beta=\pi/2$.

An experimental set up was such created to measure the pressure intensity on the conical surface of valve. Conical surface of the valve is provided with spiral holes which are internally connected to manometer through fluid lines called tygon tubes as shown in Fig.5. The fluid flowing along the surface exerts certain pressure on the holes which is sensed by the manometer connected through tygon tubes. Holes are arranged spirally on the surface so that all the area is covered, and the results are to be obtained from every part of the surface. For this laboratory model of needle valves, the geometry was defined by specifying three characteristic parameters namely β, ζ, λ out of which λ, ζ are distances later which are reduced to a dimensionless quantity by relating them to exit channel diameter d. This resulted in three degrees of freedom which already lead to complications for numerical computation of flow with larger values.

ISSN: 2321-8169
564 – 571

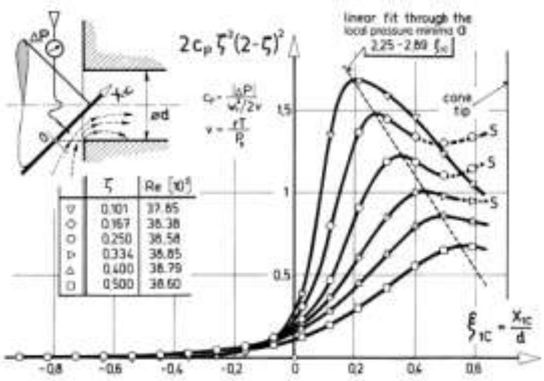

Figure 5: Pressure measurement on conical surface with cone angle 90

Along with the pressure measurement Fig.6 also shows a graph with curves giving pressure intensities varying with relative cone lifts ζ. Introduction of a horizontal factor a* and vertical factor b*, convert the family of curves into a practically single universal curve valid for any liftζ.

$a* = -0.827\ ζ^2 + 1.395\ ζ + 0.061$

$b* = -2.54\ ζ + 1.898$

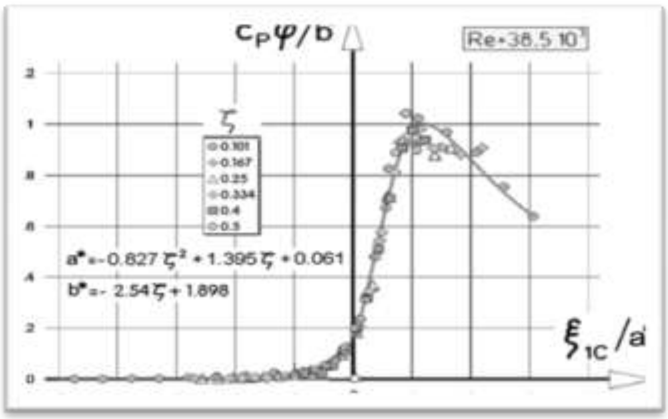

Figure 6: Graph single curve of pressure intensity with varying relative lifts

4.1.1Reynolds number

Reynolds number, a dimensionless number helps to signify the flow is laminar or turbulent; here the fluid flowing over the surface of valves has a effect on pressure force exerted by it on surface. According to the experimental evaluations the effect observed is not affecting as compared to the other factors like area ratio and pressure coefficient.

Re= (Wr*d/ν)

Where, Wr= reference velocity (m/s)

ν = viscosity (m^2/s)

Wr= (4*Ṁ*v/πd^2)

Where, Ṁ=mass flow rate (kg/s)

v=specific volume (m^3/kg)

4.2 Needle valve with rounded components

Rounded components of the valves are purposely manufactured to avoid separation of fluid from surface. The main purpose of rounding of the needle tip and entrance of exit cannel is to avoid their erosion due to very high temperature fluid flowing through it at a high velocity rates. In experimental model of rounded components the new two parameters in addition to the earlier parameters β, λ, ζ, ρ, $ρ_c$. These two parameters are the curve radius of needle tip and the entrance of the exit channel as shown in Fig.8. The set up for rounded components in the nozzle assembly is given in Fig.7.

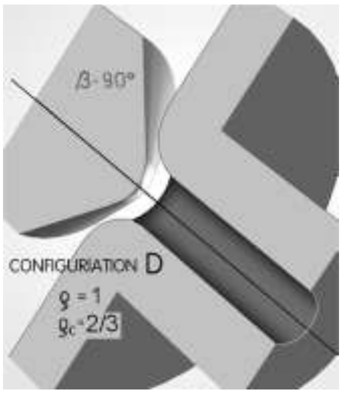

Figure 7: The fully rounded configuration D of needle valves.

Rounding of these components help in preventing the valves from erosion by aggressive hot fluids (molten metal), that endanger the valve by rapid deterioration. Avoiding separation bubble the nozzle corner are kept curved and the pressure intensity is measured through manometer with the help of fluid lines.

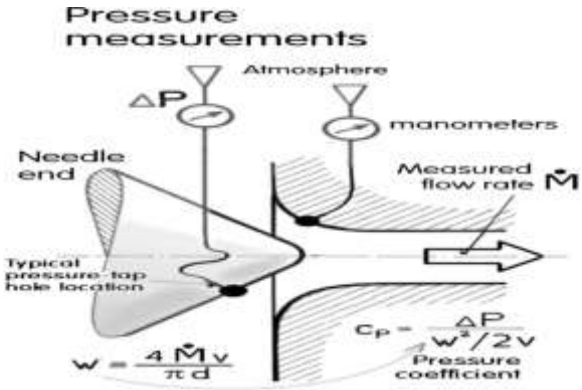

Figure 8: Pressure measurement on needle valve with rounded corners.

5. COMPLEXITY OF PRESSURE FIELDS

5.1 Local extremes

The existence of the local pressure extremes along the co-ordinate X axis is defined, and for three example flow cases presented in Fig. 10.These local extreme points are observed due to the phenomenon called concentric collision of flow with azimuthally directions. Experiments with various cone lifts are carried out to obtain variation in pressure fields across the flow. Local extreme point ‘a’ has relatively low pressure due to separation phenomenon with the path lines, whereas at local pressure point ‘b’ there occurs a collision of fluid at tip.

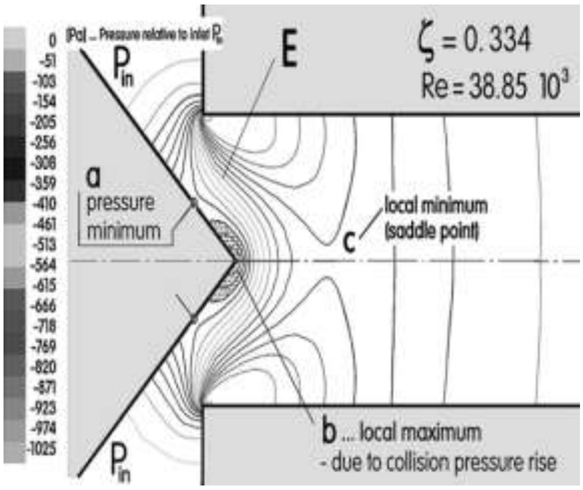

Figure 9: Pressure fields at extreme points in flow.

In accordance with Continuity equation based on keeping discharge constant overall the flow local extreme point ‘c’ (saddle point) has minimum pressure with increasing area of cross section in exit channel. Graphs of pressure difference plotted against relative cone lift are illustrated in the Fig.10. As illustrated from graphs pressure at point ‘b’ is seen maximum due to collision of fluid.

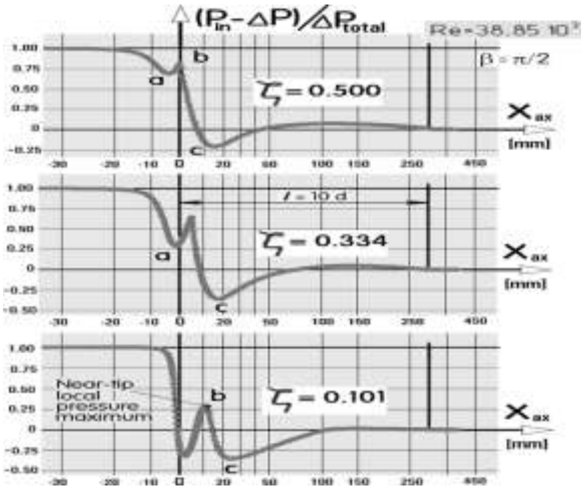

Figure 10: Variation of the pressure distributions along the axis X axis with changes of relative cone lift.

$\Delta P = Pin - P$

Interesting are the variations of the relative importance of these local pressure extremes with varied axial position of the needle. The local minimum ‘a’ near the entrance into the exit channel , as well as the local pressure maximum ‘b’ at the needle tip, become more prominent as the valve is closed.

5.2 Pressure coefficient (Cp)

The measured and evaluated pressure differences depend roughly on the square of the flow rate, its values obtained at different needle lifts vary so much that their direct comparison in diagrams would be difficult and not particularly convincing. It’s dependence on the friction losses in the part of the flow field not strictly belonging to the valve.

$Cp = \Delta P / (Wr^2 / 2v)$

Where, v [m3/kg] is the specific volume, for gas as the fluid evaluated

$v = rT / Pb$

Wr [m/s] is reference velocity evaluated as the bulk velocity in the exit.

5.3 Area Ratio (Φ)

The evaluated pressure depends roughly on its square and therefore on the square of available cross section areas. Thus for the data processing it is the necessary first step to evaluate the dependence of the area ratio on the lift.

$\Phi=2\zeta\sin(\beta/2)(2-\zeta\sin\beta)$

Where, Φ=Area ratio

ζ=relative cone lift

β=cone angle

6. DATA ACQUISITION

According to the main interest in the case of the needle valve integrated into jet-generating nozzles, only the centripetal flow direction results are here presented. The internal layout of the $\beta=\pi/3$ cone, with Tygon tubes for pressure transfer from the taps into the manometer shown in Fig.11.

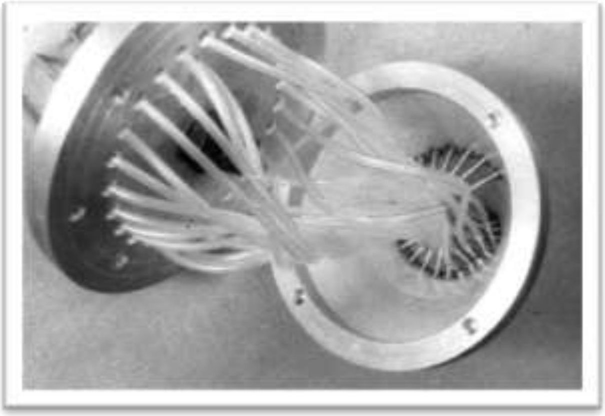

Figure 11: Internal layout of needle with tygon tubes

Measurements were made with air entering in from the outside atmosphere and flowing past the conical surface of the needle into the exit channel. From there the air then passed into a large settling chamber and from there through an orifice flow meter (replaced by a rotameter for very small flow rates).Pressure tap holes drilled in the brass inserts. They were distributed along spirals to avoid influencing a downstream tap by an upstream one (and also to obtain smaller axial distance between the taps than if they were in a straight row).

7. PRESSURE FORCE ON THE CONICAL SURFACE OF NEEDLE

There are two basic components of the axial force: apart from the pressure force there is also the axial component of surface skin friction. It may be said that in general the friction force at reasonably large Reynolds numbers, needle large included angles β and the consequent short axial lengths is very small and in many cases may be neglected altogether. Fig.12. gives the description of pressure forces on conical surface.

Infinitesimal Area,

$dA= 2\pi rdr$

Infinitesimal pressure forces,

$dF= 2\pi(1-\cos\beta/1+\cos\beta)P\ dx$

Where, P =the local value of pressure

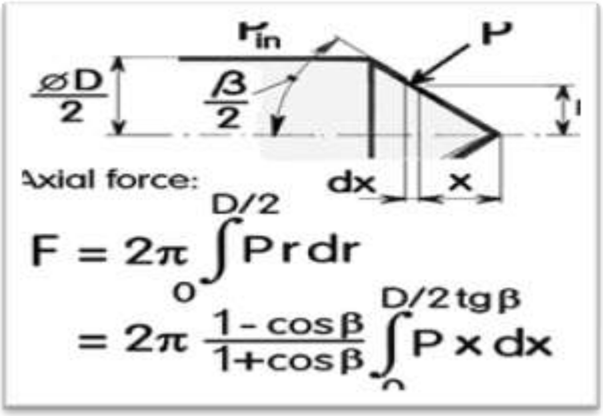

Figure 12: Pressure Force on Surface

. 8. APLLICATIONS

The flow control by the needle remained in some rather special of the drop delivery applications such as- Additive manufacture of ceramics, Deposition of bio molecules, Manufacturing textiles, 3Dprinting and associated techniques. In the above listed applications, the needle valves are integral with the jet-generating nozzle, with the fluid leaving the closed cavities at the end of a more or less short exit channel.

9. CONCLUSIONS

Needle Valves as flow controlling devices has a long history of uses but was not considered as important subject since presence of alternative techniques. Recently the topic has gained enough curiosity because of the increasing applications in field of additive manufacturing and the aerodynamic research. The main aim was to carry out the experiments to measure pressure intensity on the surface of valves and channels with rounded corners peculiarly avoiding phenomenon of separation. Experimental models were designed mainly on the parameter called cone angle, $\beta=90^{\circ}$ and $\beta=60^{\circ}$. Factors affecting the flow and pressure difference including Reynolds number are studied through experimental process satisfying theory and concepts. Graphs provide exclusive information about cone lift and pressure difference at extreme points.

10. ACKNOWLEDGEMENTS

We the students are very grateful to our institute for encouraging us for such an exciting work. A big thank you to ICIIIME organized by department of mechanical engineering, SKNCOE, Pune for providing us this platform, Faculty members of department for being co-operative towards our side and being helpful. With the coordination of teachers and colleagues we are up to this paper, thanks to them.

11. REFFERENCES

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