# FLOW OF FLUIDS 

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## FLUID FLOW

A fluid is a substance that continually deforms (flows) under an applied shearstress.

Fluids are a subset of the phases of matter and include liquids, gases.

Fluid flow may be defined as the flow of substances that do not permanently resist distortion

The subject of fluid flow can be divided into fluid static's and fluid dynamics

## FLUID STATICS

$\emptyset$ Fluid static's deals with the fluids at rest in equilibrium
$\varnothing$ Behavior of liquid at rest
Ø Nature of pressure it exerts and the variation of pressure at different layers
Pressure differences between llayers of liquids


Consider a column of liquid with two openings Which are provided at the wall of the vessel atdifferent height

The rate of flow through these openings are different due to the pressure exerted at the different heights are different

Consider a stationary column the pressure $P$ is acting on the surface of the fluid, column is maintained at constant pressure by applying pressure

The force acting below and above the point 1 are evaluated

Substituting the force with pressure x area of cross section in the above equation

$$
\begin{aligned}
& \text { Force acting on the liquid }=\quad \text { Force on the surface }+\begin{array}{c}
\text { Force excreted by the liquid } \\
\text { Above point } 1
\end{array} \\
& \text { At point } 1
\end{aligned}
$$

Pressure at point $2 \times$ Area $=($ Pressure on the surface area $\times$ surface area)

Pressure at point $1 \times$ Area $=\quad$ (Pressure on the surface area $\times$ surface area) + (mass $\times$ g)
$P_{1} S=P_{2} S+$ height xvolume $x$ density $\times g$

$$
\begin{array}{ccc} 
& + & \mathrm{x}
\end{array} \begin{gathered}
\mathrm{P} \\
=
\end{gathered}
$$

Since surface area is same

$$
P_{1}=P_{s}+h_{1} \rho g
$$

Pressure acting on point 2 may be written as

$$
P_{2}=P_{s}+h_{2} \rho g
$$

Difference in the pressure is --

$$
\begin{aligned}
& P_{2}-P_{1}=g\left(P_{s}+h_{2} \rho\right)-\left(P_{s}+h_{1} \rho\right) g \\
& \Delta P=\left(P_{s}+h_{2} \rho-P_{s}-h_{1} \rho\right) g \\
& \Delta P=\Delta h \rho g \quad[F=\text { Volume. } \rho g]
\end{aligned}
$$

## FLUID DYNAMICS

$\varnothing$ Fluid dynamics deals with the study of fluids in motion

- $\varnothing$ This knowledge is important for liq ments which will change their flow behavior when exposed to differeffow Through pipes
- MIXING

FILLED IN CONTAINER

## Importance

ü Manufacture of dosage forms
ü Handling of drugs foradministration

The flow of fluid through a pipe can be viscous or turbulent and it can be determined by Reynolds number

Reynolds number have no unit

Glass tube is connected to reservoir of water, rate of flow of water is adjusted by a valve,
A reservoir of colored solution is connected to one end of the glass tube with help of nozzle.

Colored solution is introduced into the nozzle as fine stream through jet tube.


Colored liquid
LAMINAR OR VISCOUSFLOW


TURBULENT FLOW

## Turbulent



## Laminar



## Laminar Flow



## Turbulent Flow



## TYPES OF FLOW

è Laminar flow is one in which the fluid particles move in layers or laminar with one layer sliding with other
è There is no exchange of fluid particles from one layer to other
è Avg velocity $=0.5 \mathrm{~V}_{\text {max }}$
è $R e<2000$
è When velocity of the water is increased the thread of the colored water disappears and mass of the water gets uniformly colored
è There is complete mixing of the solution and the flow of the fluid is called as turbulent flow
è Avg velocity $=0.8 \mathrm{~V}_{\text {max }}$
è $R e>4000$

The velocity at which the fluid changesfrom laminar flow to turbulent flow that velocity is called as criticalvelocity

## REYNOLDS NUMBER

In Reynolds experiment the flow conditions are affected by Ø Diameter of pipe ØAverage velocity $\varnothing$ Density of liquid
$\emptyset$ Viscosity of the fluid
This four factors are combined in one way as Reynolds number

Ø Inertial forces are due to mass and the velocity of the fluid particles trying to diffuse the fluid particles
Ø viscous force if the frictional force due to the viscosity of the fluid which make the motion of the fluid in parallel.
$\neg$ At low velocities the inertial forces are less when compared to the frictional forces
$\neg$ Resulting flow will be viscous in nature
$\neg$ Other hand when inertial forces are predominant the fluid layers break up due to the increase in velocity hence turbulent flow takes place.
$\neg$ If $\mathrm{Re}<2000$ the flow I said to be laminar
$\neg$ If $\operatorname{Re}>4000$ the flow is said to be turbulent
$\neg$ If Re lies between 2000 to 4000 the flow change between laminar to turbulent

## APPLICATIONS

Ø Reynolds number is used to predict the nature of the flow
$\varnothing$ Stocks law equation is modified to include Reynolds number to study the rate of sedimentation in suspension

When velocity is plotted against the distance from the wall following conclusions can be drawn
$\varnothing$ The flow of fluid in the middle of the pipe is faster then the fluid near to the wall
$\varnothing$ At the actual surface of the pipe - wall the velocity of the fluid is zero

Pipe wall


$\mathrm{U} / \mathrm{U}_{\text {max }}$

## BERNOULLI'S THEOREM

When the principals of the law of energy is applied to the flow of the fluids the resulting equation is a Bernoulli's theorem
$\varnothing$ Consider a pump working under isothermal conditions between points $A$ and $B$
$\varnothing$ Bernoulli's theorem statement, "In a steady state the total energy per unit mass consists of pressure, kinetic and potential energies are constant"

Kinetic energy $=u^{2} / 2 \mathrm{~g}$

Pressure energy $=P_{a} / \rho_{A} g$


At point a one kilogram of liquid is assumed to be entering at point a,

$$
\text { Pressure energy }=\mathrm{P}_{\mathrm{a}} / \mathrm{g} \rho_{\mathrm{A}}
$$

Where $\mathrm{P}_{\mathrm{a}}=$ Pressure at point a

$$
\mathrm{g}=\text { Acceleration due to gravity }
$$

$\rho_{A}=$ Density of the liquid
Potential energy of a body is defined as the energy possessed by the body by the virtue of itsposition

$$
\text { Potential energy }=X_{A}
$$

Kinetic energy of a body is defined as the energy possessed by the body by virtue of its motion,

$$
\text { kinetic energy }=U_{\mathrm{A}_{2}} / 2 \mathrm{~g}
$$

Total energy at point $\mathrm{A}=$ Pressure energy + Potential energy $+\mathrm{K} . \mathrm{E}$

Total energy at point $\mathrm{A}=\mathrm{P}_{\mathrm{a}} \mathrm{V}+\mathrm{X}_{\mathrm{A}}+\mathrm{U}_{\mathrm{A}} / 2 \mathrm{~g}$

According to the Bernoulli's theorem the total energy at point
A is constant
Lotal ennergy at point $\left.\mathrm{A}=\mathrm{P}_{\mathrm{A}} \mathrm{V}+\mathrm{X}_{\mathrm{A}}+\underset{2}{\left(\mathrm{U}_{\mathrm{A}}\right.} \quad / 2 \mathrm{~g}\right)=$

After the system reaches the steady state, whenever one kilogram of liquid enters at point $A$, another one kilogram of liquid leaves at point $B$

$$
\text { Total energy at point } B=P_{B} V+X_{B}+U_{B} 2 / 2 g
$$

$$
\begin{aligned}
& P_{A} V+X_{A}+\left(U_{A}^{2} / 2 g\right)+\text { Energy added by the pump } \\
& =P_{B} V+X_{B}+\left(U_{B_{2}} / 2 g\right)
\end{aligned}
$$

V is specic volume andit is reciprocal of density.
Theoretically all kinds of the energies involved in fluid flow should be accounted, pump has added certain amount of energy.

During the transport some energy is converted to heat due to frictional Forces

Energy loss due to friction in the line = F Energy added by pump = W

$$
P_{a} / \rho_{A}+X_{A}+U_{A}^{2} / 2 g-F+W=P_{B} / \rho_{\mathrm{U}_{B_{2}}}+X_{B}+
$$

This equation is called as Bernoulli's equation

## ENERGY LOSS

According to the law of conversation of energy, energy balance have to be properly calculated fluids experiences energy losses in several ways while flowing through pipes, they are

Ø Frictional losses
$\varnothing$ Losses in the fitting
Ø Enlargement losses
Ø Contraction losses

## Application of <br> BERNOULLI'S THEOREM

- $\varnothing$ Used in the measurement of rate of fluid flow using flowmeters
- $\varnothing$ It applied in the working of the centrifugal pump, in this kinetic energy is converted in topressure.


## Chapter 2

- Measurement of flow-
- Classification of flow meters,
- venturimeter,
- orificemeter,
- pitot tube,
- rotameter
- current flow meters
- Pressure measurement-
- Classification of manometers,
- simple manometer/
- U tube manometer andmodifications (Differential/inclined),
- Bourdon gauge


## MANOMETERS

Manometers are the devices used for measuring the pressure difference

Different type of manometers are there they are
1)Simple manometer
2)Differential manometer
3)Inclined manometer

## SIMPLE MANOMETER

Ø This manometer is the most commonly used one

Ø It consists of a glass U shaped tube filled with a liquid A- of density $\rho_{\mathrm{A}} \mathrm{kg} / m e t e r$ cube and above A the arms are filled with liquid $B$ of density $\rho_{B}$
$\varnothing$ The liquid $A$ and $B$ are immiscible and the interference can be seen clearly

Ø If two different pressures are applied on the two arms the meniscus of the one liquid will be higher than the other

$\varnothing$

## $\varnothing$ The pressure at point 2 can be written as <br> $$
=P_{1}+(m+R) \rho_{B} g
$$

since $\Delta P=\Delta h \rho g$ $(m+R)=$ distance from 3 to 5


Pressure at $3=P_{1}+(m+R) \rho_{B} g$

Pressure at 4 is less than pressure at point 3 by $R \rho_{A} g$
Pressure at 5 is still less than pressure a point 4 by $\mathrm{m} \rho_{\text {в }}$

This can be summariseas
$P_{1}+(m+R) \rho_{B} g-R \rho_{A} g-m \rho_{B} g=P_{2}$
$\Delta P=P_{1}-P_{2}=R\left(\rho_{A^{-}} \rho_{B}\right) g$

- Pressure difference can be determined by measuring R
- Manometers are use inmeasuring flow of fluid.


## DIFFERENTIAL MANOMETERS

Ø These manometers are suitable for measurement of small pressure differences

Ø It is also known as two - Fluid U- tube manometer
Ø It contains two immiscible liquids $A$ and $B$ having nearly same densities

Ø The U tube contains of enlarged chambers on both limbs,

Ø Using the principle of simple manometer the pressure differences can be writtenas
$\Delta P=P_{1}-P_{2}=R\left(\rho_{c}-\rho_{A}\right) g$


$$
\begin{array}{ll}
1 & P_{1} \\
2 & P_{1}+a \rho_{B} g / g_{c} \\
3 & P_{1}+a \rho_{B} g / g_{c}+b \rho_{A} g / g_{c} \\
4 & P_{1}+a \rho_{B} g / g_{c}+b \rho_{A} g / g_{c} \\
5 & P_{1}+a \rho_{B} g / g_{c}+b \rho_{A} g / g_{c}-R \rho_{C} g / g_{c} \\
6 & P_{1}+a \rho_{B} g / g_{c}+b \rho_{A} g / g_{c}-R \rho_{C} g / g_{c}-d \rho_{A} g / g_{c} \\
7 & P_{1}+a \rho_{B} g / g_{c}+b \rho_{A} g / g_{c}-R \rho_{C C} g / g_{c}-d \rho_{A} g / g_{c}-a \rho_{B} g / g_{c}=P_{2}
\end{array}
$$

The last equation may be simplified to

$$
P_{1}-P_{2}=(d-b) \rho_{A} \frac{g}{g_{c}}+R \rho_{C} \frac{g}{g_{c}}
$$

but since $b-d=R$, or $d-b=-R$,

$$
\Delta P=P_{1}-P_{2}=R\left(\rho_{C}-\rho_{A}\right) \frac{g}{g_{c}}
$$

$$
\Delta P=P_{1}-P_{2}=R\left(\rho_{c}-\rho_{A}\right) g
$$

Hence smaller the difference between $\rho_{c}$ and $\rho_{A}$ larger will be $R$

## INCLINED TUBE MANOMETERS

Many applications require accurate measurement of low pressure such as drafts and very low differentials, primarily in air and gas installations.
In these applications the manometer is arranged with the indicating tube inclined,

This enables the measurement of small pressure changes with increased accuracy.

$$
P_{1}-P_{2}=g R\left(\rho_{A}-\rho_{B}\right) \sin \alpha
$$

## Inclined Manometer

- To measure small pressure differences need to magnify $R_{m}$ some way.

$\sin \alpha=R / R_{i}$
$R=R_{i} \sin \alpha$

$$
P_{a}-P_{b}=g R_{1}\left(\rho_{a}-\rho_{b}\right) \sin \alpha
$$

## MEASUREMENT OF

## RATE OF FLOW OF FLUIDS

Methods of measurement are
Ø Direct weighing or measuring
ØHydrodynamic methods
ü Orifice meter
ü Venturi meter
ü Pitot meter
ü Rotameter
ØDirect displacement meter
ØDisc meters
Ø Current meter

## DIRECT WEIGHING OR

The liquid flowitg4 (brblushia ©ipe is collected for specific period at any point and weighed or measured, and the rate of flow can be determined.

Gases can not be determined by this method

## ORIFICE METER

- $\varnothing$ Orifice meter is a thin plate containing a narrow and sharp aperture.
- $\varnothing$ When a fluid stream is allowed to pass through a narrow constriction the velocity of the fluid increase compared to up stream


The orifice meter measures pressure e.g. at point $a$ and $b$ determines the flow rate.

## CONSTRUCTION

$\varnothing$ It is consider to be a thin plate containing a sharp aperture through which fluid flows

Ø Normally it is placed between long straight pipes
$\varnothing$ For present discussion plate is introduced into pipe and manometer is connected at points $A$ and $B$

## Working

ü When fluid is allowed to pass through the orifice the velocity of the fluid at point $B$ increase, as a result at point $A$ pressure will be increased.
ü Difference in the pressure is measured by manometer
ü Bernoulli's equation is applied to point $A$ and point $B$ for experimental conditions

## Contd...

Total energy at point $\mathrm{A}=$ Pressure energy + Potential energy + K. E

Total energy at point $A=P_{a} V+X_{A}+U_{A_{2}} / 2 g$

## Bernaulis eqn...

$P_{a} / \rho_{A}+X_{A}+U_{A_{2}} / 2 g-F+W=P_{B} / \rho_{B}+X_{B}+U_{B_{2}} / 2 g$

- Pipeline is horizantal $A$ and $B$ are at same position

Therefore $X_{A}=X_{B}$

- Suppose friction losses areneglisible $\mathrm{F}=0$
- As liquid is incompressible so density remain same, Therefore $\rho_{A}=\rho_{B}=\rho$
- No work is done on liquid therefore w = 0

After applying assumptions Bernaulis eqn...
$P_{A} / \rho_{A}+X_{A}+U_{A_{2}} / 2 g-F+W=P_{B} / \rho_{B}+X_{B}+U_{B_{2}} / 2 g$

Change to---

$$
\begin{aligned}
& \mathrm{P}_{\mathrm{A}} / \rho+\mathrm{U}_{\mathrm{A}_{2}} / 2 \mathrm{~g}=\mathrm{P}_{\mathrm{B}} / \rho+\mathrm{U}_{\mathrm{B}_{2}} / 2 \mathrm{~g} \\
& \mathrm{U}_{\mathrm{A}_{2}} / 2 \mathrm{~g}-\mathrm{U}_{\mathrm{B}_{2}} / 2 \mathrm{~g}=\mathrm{P}_{\mathrm{B}} / \rho-\mathrm{P}_{\mathrm{A}} / \rho
\end{aligned}
$$

Multiply both sides by -2 g
$U_{B}{ }^{2}-U_{A_{2}}=2 g \cdot P_{A} / \rho-2 g \cdot P_{B} / \rho$
$\sqrt{U_{B}^{2}}{ }^{2} U_{A_{2}}=\sqrt{ } 2 g / \rho \cdot\left(P_{A}-P_{B}\right)$
$\sqrt{U_{B_{2}}}-U_{A_{2}}=\sqrt{ } 2 g \Delta H \quad \ldots \ldots$. as

$$
\left(P_{A}-P_{B}\right) / \rho=\Delta H
$$

$\sqrt{ } \mathrm{U}_{\mathrm{B}_{2}}-\mathrm{U}_{\mathrm{A}_{2}}=\sqrt{ } 2 \mathrm{~g} \Delta \mathrm{H}$
diameter of venacontracta is not known practically
There arte friction losses Therefore above equation is modifiedto--
$\sqrt{U_{0_{2}}}-U_{A_{2}}=C_{0} \sqrt{ } 2 \mathrm{~g} . \Delta \mathrm{H}$
If the diameter of orifice is $1 / 5$ th of the diameter of pipe then $U_{A_{2}}$ is

## neglisible

The velocity of the fluid at thin constriction may be written as

$$
U_{0}=C_{0} V_{2 g \Delta H}
$$

$\Delta \mathrm{H}=$ Difference in pressure head, can be measured by manometer
$C_{0}=$ constant coeff of orifice (friction losses)
$\mathrm{U}_{0}=$ velocity of fluid at the point of orifice meter

- §Velocity at either of the point $A$ and $B$ can bemeasured
- §Volume of liquid flowing per hourcan be determined by knowing area of cross section


## VENTURI METER

- When fluid is allowed to pass through narrow venturi throat then velocity of fluid increases and pressure decreases
- Difference in upstream and downstream pressure head canbe measured by using Manometer
- $U_{v}=C_{v} \sqrt{ } 2 g . \Delta H$


## VENTURI METER



## Why Venturi meter if Orifice meter is

- Main disadnadintage arof orifice meter is power loss due to sudden contraction with consequent eddies on other side of orifice plate
- We can minimize power loss by gradual contraction of pipe
- Ventury meter consist of twotapperd (conical section) inserted in pipeline
- Friction losses and eddies can be minimized by this arrangement.


## Velocity head increased Pressure head decreased



## DISADVANTAGES

$\varnothing$ Expensive
Ø Need technical export
$\varnothing$ Not flexible it ispermanent
Advantages
$\varnothing$ For permanent installations
$\emptyset$ Power lossis less
Ø Headloss is negligible

## Differences Between Orifice Meter and Venturi Metercof at $\mathbf{w}$

| Orifice meter | Venturi meter |
| :--- | :--- |
| (1) Cheap | Expensive |
| (2) Easy to install | Fabrication is highly technical |
| (3) Construction can be made | It should be purchased from the |
|  | Heme instrument dealer |
| (4) Head losses are more | Howses are insignificant |
| (5) Power losses are more particularly | on fluid that is carried for long |
|  |  |
| coefficient of discharge is high |  |
| (6) Normally used for testing purposes, | Used in on-line installation |
| for example, steam lines etc., |  |
| (7) Greater flexibility | Not flexible, permanent |
| (8) Reading of the orifice meter | The reading of venturi meter is |
| is larger under identical | comparatively smaller under |
| conditions |  |

- According to Bernoulli's therom

Total energy at any point =
Pressure energy + Potential energy + K. E $\mathrm{U}_{0}=\mathrm{C}_{0} \sqrt{ } 2 \mathrm{~g} \Delta \mathrm{H} \quad \ldots . . . \Delta \Delta \mathrm{H}=$ Difference in pressure head
$\Delta H=U^{2} / 2 \mathrm{~g} \quad \ldots \ldots . . \mathrm{U}=$ Velocity at point of incertion
菏


Constructio
Ø It is also known as insertion meter
Ø The size of the sensing element is small compared to the flow channel
Ø One tube is perpendicular to the flow direction and the other is parallel to the flow
$\varnothing$ Two tubes are connected to the manometer

$$
2 g \Delta H_{p}=U^{2}
$$

- Pitot tube is used to measure the velocity head of flow.
- Parallel tube (to Upstream) measure velocity head + pressure head
- Perpendicular tube (downstream) measure only pressure head
- Difference of head between twotubes gives velocity head $\Delta \mathrm{H}$.
- Working of pitot tube video

Differences between venturi- orifice and Pitot tube

- Orifice and venturi meter measure average velocity of whole stream of fluid
- More pressure drop • Less pressure drop


## ROTAMETER




## PRINCIPLE

$\varnothing$ In this device a stream of water enters Transparent tapered tube and strikes the moving plummet
Ø During fluid flow plummet rise or fall
$\varnothing$ As a result, annular space (area) between plummet and tapperd tube may increase ordecrease, depending on variation of flow rate.
$\varnothing$ Head across annulus is equal to weight of plummet.

## Construction

Ø It consists of vertically tapered and transparent tube generally made of glass in which a plummet is centrally placed with guiding wire.
$\varnothing$ Linear scale is etched on glass
$\varnothing$ During the flow the plummet rise due to variation in flow
$\varnothing$ The upper edge of the plummet is used as an index to note the reading
$\varnothing$ As the flow is upward through the tapered tube the plummet rises and falls depend on the flow rate
Ø Greater the flow rate higher the rise of plummet.

- To measure flow rate of gas as well as liquid
- Easy to use and allow direct visual inspection

