GOVERNMENT POLYTECHNIC BHADRAK

Fluid Mechanics

Fourth Semester

MechanicalEngg.

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FLUIDMECHANICS(TH-03)

SL.NO	CHAPTER	TOPICS	PERIODASPER SYLLABUS	PERIODS ACTUALLY NEEDED	EXPECTED MARKS
01	01	PROPERTIESOF FLUID	08	06	15
02	02	FLUIDPRESSURE AND ITS MEASUREMENT	08	09	15
03	03	HYDROSTATICS	08	06	12
04	04	KINEMATICSOF FLOW	08	08	18
05	05	ORIFICE,NOTCHES& WEIR	08	07	10
06	06	FLOWTHROUGH PIPE	10	06	15
07	07	IMPACTOFJET	10	10	15
		TOTAL	60	52	100

CHAPTER-

01PROPERTIESOFFLUID

INTRODUCTION

Fluidmechanicsisthe branchof engineering science whichdeals withthestudyoffluidsanditspropertiesandforceswhich cause motion of different layer.

FLUID:

Fluidisasubstanceasaliquidor gasi.e.capableofflowing and yields easily through small external pressure.

Ex-water,air,petrol,etc

PROPERTIESOFFLUID:

1) Density/MassDensity

- Density or mass density of a fluid is defined as the ratio of massofafluidto itsvolume. Thusmassperunitvolumeofa fluid is called density.
- Itisdenotedby ρ.

Mathematically:

- Massdensity(ρ)=massoffluid/volumeoffluid
- Units–gm/cm^3,kg/m^3,gm/cc
- Thevalueofdensityof1000kg/m^{3}or1 gm/cm^3
- Densityofwaterismaximumat4˚C

2) SpecificWeightorWeightdensity:

- Specificweightor weightdensityofa fluidofafluidis definedas theratiobetweenweight ofthefluid toits volume.
- Itisdenotedby w.
- Mathematically,

- SpecificWeight=weightofthefluid/volumeofthe fluid

  =(massoffluid×accelerationdueto gravity)/ volume of the fluid

  w =ρ×g
- Units-N/m^3,kgf/m^3,dyne/cm^3
- Weightdensityofwateris9810N/m^3

3) Specificgravity:

- It is defined as the ratio between density or weight densityofafluidto thedensityorweightdensityofa standard fluid.
- Itisalsoknownasrelativedensity.
- ItisdenotedbyS.
- Mathematically,

  specificgravity=(densityorweightdensityofafluid)/ (density or weight density of standard fluid)
- Forgasstandardfluidisair,forliquidstandardfluidiswater.

4) SPECIFICVOLUME:

- Specificvolumeofafluidis defined asthevolumeoccupiedby a unit mass or volume per unit mass of a fluid is called specific volume.
- Specificvolume=volumeoffluid/massoffluid

  =1/(massoffluid/volume)

  =1/ ρ
- Itisreciprocalofdensity.Itisexpressedinm^3/kg

PROBLEM-01

Calculate thespecificgravity,densityandweightdensityofone litre of a liquid which weighs 7N.

Datagiven

.Volume=1litre=0.001m^3

Weight=7N To

be found

Specificgravity(S)=?

Density (ρ)=?

Weightdensity(w)=?

Calculation

1) Specificweight(w)= weight/volume
=7/0.001=7000N/m^3
2) Density(ρ)=weightdensity/accelerationduegravity
=7000/9.81=713.5 kg/m^3

3) Specificgravity(S)=densityofliquid/densityofwater
=713.5/1000=0.713(ans)

PROBLEM-02

Calculate thedensity,specific weightandweightofonelitreof petrol of specific gravity=0.7.

Datagiven

Specificgravity(s)=0.7

Volume=1litre=0.001m^{3}To

be found

Density(ρ)=?

SpecificWeight(w)=?

Weight (w)=?

<u>Calculation</u>

Weknowspecificgravity=densityofliquid/densityofstandardfluid

Hence density of liquid= sp. Gravity × density of standard fluid

$$=0.7\times1000=700\ kg/m^3$$

Specificweight(w)=density×accelerationduetogravity

$$=700\times9.81=6867 N/m^3$$

Weknowweightdensity=weight/volume

·:weight=weightdensity×volume

$$=6867\times0.001=6.867 N$$

VISCOSITY:

- Viscosity is defined as the property of a fluid which offers resistance tothemovementofonelayeroveranotheradjacent layer.
- When two layer of a fluid a distance dy apart move one another atdifferentvelocities,sayuandu+du asshowninfig.below,the viscosity together with relative velocity causes a shear stress acting between the fluid layers.
- The top layer causes a shear stress on the adjacent bottom layer andthebottomlayercausesashearstressonadjacenttop layer, this shear stress is directly proportional to the rate of change of velocity with respect to y.
- Mathematically, $\tau \propto (du/dy)$

$$\tau = \mu\ (du/dy)$$

where,μ=constantofproportionalityisknownascoefficientof viscosityordynamicviscosity.

(du/dy)=iscalledvelocitygradient orrate ofchangeofvelocity μ=

$\tau/(du/dy)$

units- NS/M^2,$DyneS/Cm^2$,$KgFS/M^2$

One Dyne S/ Cm^2 is called one poise.

1.3KINEMATICVISCOSITY:

Itis theratiobetweendynamic viscosityto thedensityofthe fluid. It is denoted by ν.

Mathematically,

Kinematicviscosity=Dynamicviscosity/Fluidmass density

$$\nu=\mu/\rho$$

units:-m^2/s,cm^2/s

1cm^2/s=1stoke

1.3SURFACETENSION

- It is defined as a tensile force acting on the surface of a liquid incontact withagas orom thesurface betweentwo immiscible liquids such that the contact surface behaves like a stretched membrane.
- It is the property of a fluid by virtue of which its free surfacebehaves likea stretchedmembrane andsupports comparatively heavier object placed over it.
- Units:N/m
- Surfacetensionofliquiddroplet,$P=4\sigma/d$

- Surfacetensionofahollowbubble,P=8σ/d
- Surfacetensionof aliquidjet, P=2σ/d

1.3 CAPILLARITY:

- it is defined as a phenomenon of rise or fall of a liquid surfacein asmalltuberelativetothe adjacent general level of liquid when the tube is held vertically.
- Therisein liquid leveliscalledcapillaryrise,andthefall of liquid level is called capillary fall.
- Capillaryrise, $\Delta h = 4\sigma\cos\theta / d\rho g$
  $\Theta = 0^{\circ}$ in case of water
- Capillaryfall, $\Delta h = 4\sigma\cos\theta / d\rho g$
  $\Theta = 128^{\circ}$ in case of mercury
- Capillaryriseoccurincaseofwaterandcapillaryfall occur in case of mercury.

TYPESOFFLUID

(i) Idealfluid:

Thefluidwhichis incompressibleand noviscosityis called idealfluid.Itisanimaginaryfluidasallexistingfluidshave some viscosity.

(ii) Realfluid:

Afluidthatpossessesviscosityiscalledrealfluid.Inactual practice all the fluids are real fluid.

(iii) <u>**Newtonianfluid:**</u>

Thefluidwhichobeynewtonslawofviscosityiscalled Newtonian fluid.

(iv) <u>**Non-Newtonianfluid:**</u>

SHORTQUESTIONS

1) Definemassdensityandspecificgravity?(2019-S)

- Ans-**Densityormassdensity** ofafluidisdefinedastheratio of mass of a fluid to its volume. Thus mass per unit volume of a fluid is called density.
- Itisdenotedby ρ.

Mathematically:

- Massdensity(ρ)=massoffluid/volumeoffluid
- Units–gm/cm^3,kg/m^3,gm/cc

Specificgravity

- It is defined as the ratio between density or weight density ofafluidtothedensityorweightdensityofa standardfluid.
- Itisalsoknownasrelativedensity.
- ItisdenotedbyS.
- Mathematically,

specificgravity=(densityorweightdensityofafluid)/(density or weight density of standard fluid)

2) Definespecificweightandspecificvolume?(2019-S)

Ans-Specific weight or weight density of a fluid of a fluid is definedastheratiobetweenweightofthefluid toits volume. It is denoted by w.

Mathematically,

SpecificWeight=weightofthefluid/volumeofthefluid

=(massoffluid×accelerationdueto gravity)/ volume of the fluid

w =ρ×g

- Units-N/m^3,kgf/m^3,dyne/cm^3

Specificvolume ofafluidisdefined asthevolumeoccupiedbya unit mass or volume per unit mass of a fluid is called specific volume.

- Specificvolume=volumeoffluid/massoffluid

=1/(massoffluid/volume)

=1/ ρ

- Itisreciprocalofdensity.Itisexpressedinm^3/kg

3) Definespecificgravityandstateitsunits?(2019-S)

- It is defined as the ratio between density or weight densityofafluidto thedensityorweightdensityofa standard fluid.
- Itisalsoknownasrelativedensity.
- ItisdenotedbyS.
- Ithasnounit.

- Mathematically,

  specificgravity=(densityorweightdensityofafluid)/ (density or weight density of standard fluid)

4) Whatiskinematicviscosityandstatesitsunits?(2019-S)

Ans-it is defined as the ratio between density or weight densityofafluidto thedensityorweightdensityofastandard fluid.

- Itisalsoknownasrelativedensity.
- ItisdenotedbyS.
- Mathematically,

  specificgravity=(densityorweightdensityofafluid)/ (density or weight density of standard fluid)

LONG QUESTIONS

1)Avolumeof5m^{3}ofcertain fluidweight20KN.Determine specific gravity, mass density and specific weight of the liquid? (2018-S)

CHAPTER-02

FLUIDPRESSUREANDITSMEASUREMENT

INTRODUCTION

- When a fluid contained in a vessel it exerts force on each side and bottom of the vessel. This force per unit area of a fluid is called fluid pressure or simply pressure.
- Thusforceperunitarea ofafluidiscalledfluidpressure.
- Instrumentusedformeasurementofpressureisbarometer.
- Units-N/M^2,N/CM^2,Dyne/CM^2,pascal,KPa,etc
- Itsbiggerunitisbar

  Ibar=10^{5}N/M^{2}or10^{5}Pascal

  Pressureatapointofheighthfromfreesurfaceofliquid –

  P=ρgh

  h=P/ρg,whereP/ρgiscalledpressurehead

PASCAL'SLAW:

Itstatesthatthepressureorintensityofpressureatapointin a static fluid is equal in all direction.

$P_X=P_Y=P_Z$

Where P_X= pressure fluid in X direction

P_Y=pressurefluidinYdirection

P_z=pressurefluidinZ direction

Atmosphericpressure,Absolute,GaugeandVacuum Pressure

- Usually,pressureonafluidisexpressedintwodifferentwaysby assuming two different datums in two different systems.

- Inonesystem,theabsolutezeroorcompletevacuumisadopted as the datum where as in other system, the pressure above the atmospheric pressure is considered.

Atmosphericpressure(P_{atm})

Thepressureexertedbytheenvelopeofairsurroundingthe earth's surface is known as atmospheric pressure.

$P_{atm}=w_{hg}h$

Wherew_{hg}=weightdensityorspecificweightoffluid h= height of the fluid in barometric tube.

AbsolutePressure(P_{ab})

The pressure which is measured with reference to absolute vacuum pressure or zero pressure is called absolute pressure.

GaugePressure(P_{ga})

- Thepressurewhichismeasuredbytakingtheatmosphericpressure as datum is called gauge pressure.
- This is the pressure which is measured by a pressure measuring instrument.
- Theatmosphericpressureistakenaszero.

VacuumPressure(P_{vac})

- The pressure which is below the atmospheric pressure is called vacuum pressure.
- Itisalsocalledsuctionpressureornegativegaugepressure.

Absolutepressure=AtmosphericPressure+GaugePressure P_{abs} = P_{atm}+ P_{gauge}

P_{abs}=P_{atm}-P_{vacuum}

Problem-1

The reading of a barometer is found to be 760 mm of Hg. What should be the atmospheric pressure in N/M^2 and in terms of water if sp. Gravity of Hg is 13.6?

Datagiven

h_1=760mmofHg s_1

= 13.6

weknowdensity(ρ_1)=13600kg/m^3 we

know atmospheric pressure

$P_{atm}=\rho_1 g h_1=13600\times9.81\times0.760=101435.4 N/m^2$

Let$h_2$betheatmosphericpressurein termsofheadofwater We

know the relationship $s_1h_1=s_2h_2$

$13.6 \times 760 = 1\times h_2$

h_2=10.34 mofwater

PROBLEM-02

Ahydraulicpresshasaramof30cmdiameterandaplungerof 4.5 cm diameter. Find the weight lifted by the hydraulic presswhen the force applied at the plunger is 500N.

Solution

Dia. of ram D= 30 cm= 0.3m

Dia.ofplungerd=4.5cm=0.045m

Force on plunger, F=500N

Areaofram(A)=$\pi/4D^2=\pi/4\times0.3^2=0.07068m^2$

Areaofplunger(a)=$\pi/4d^2=\pi/4\times0.045^2=0.00159m^2$

Pressureintensityduetoplunger=forceontheplunger/areaof Plunger= F/a = 500/0.00159 = 314465.4 N/m^2

Duetopascal'slawtheintensityofpressurewillbeequally transmitted in all direction.

Hencethepressureintensity attheram=314465.4N/m^2 But pressure intensity at ram = weight/area of ram

=W/A=W/0.07068N/m^2

Weight=314465.4×0.07068=22222N=22.222KN.ans

PRESSUREMEASURINGINSTRUMENT:

Thepressureoffluidismeasuredbythefollowingdevices-

(1) Manometer

(2) Mechanicalgauge

(1) MANOMETER

Manometers are defined as the devices used for measuring the pressure in a fluid by balancing the column of fluid by the same or another column of the fluid. They are classified as:-

(a) Simplemanometer
(b) Differentialmanometer

(2) Mechanicalgauge

Mechanical gauge are defined as the devices as the devices used for measuring the pressure by balancing the fluid column by the spring weight or dead weight. The most commonly used mechanical gauges are-

(1) Diaphragmpressuregauge
(2) Bourdontubepressuregauge
(3) Deadweightpressuregauge
(4) Bellowspressuregauge

SIMPLE MANOMETER

- Asimplemanometerconsistsofaglasstubehavingoneend is connected to the pointwhere pressure is to be measured and other end is opened to the atmosphere.
- Commontypeofsimplemanometersare
  - (1) Piezometer
  - (2) U-tubemanometer
  - (3) Singlecolumnmanometer

PIEZOMETER

Itisthesimplestformofmanometerusedformeasuringgauge pressure. one end of this manometer is connected where pressure is tobemeasuredandotherendisopenedtotheatmosphere.

PressureatA(P_{A})=ρghN/m^2

U-TUBEMANOMETER

- It consists of a glass tube bent in U-shape, one end of which is connected to a point at where pressure is to be measured and other end remains opens to the atmosphere.
- The tube generally contains mercury or any other liquid whose specific gravity is greater than the specific gravity of the liquid whose pressure is to be measured.

Forgaugepressure

Let B is the point at which pressure is to be measured, whosevalue is P. the datum line is A-A

Leth_1=heightoftheliquid abovedatumline

h_2=heightoftheheavyliquidabovedatumline S_1 = sp. gr. Of light liquid

S_2=sp.gr.Ofheavyliquid

ρ_1 = density of light liquid = $S_1 \times 1000$

ρ_1= densityofheavyliquid= $S_2 \times 1000$

Pressure above datum in left limb

$=P+\rho_1 g h_1$ Pr

essure above datum in right limb $= \rho_2 g h_2$

Equatingthetwopressures, $P+\rho_1 g h_1=\rho_2 g h_2$

$P=\rho_2 g h_2 - \rho_1 g h_1$

Pressure above datum in left limb $=P+\rho_1 g h_1+\rho_2 g h_2$

Pressure above datum in right limb = 0

Equatingthetwopressures, $P+\rho_1 g h_1+\rho_2 g h_2=0$

$P = -(\rho_1 g h_1 + \rho_2 g h_2)$

DIFFERENTIALMANOMETER

- Differential manometers are defined as the devices used for measuringthedifferenceofpressurebetweentwopointsina pipe or in two different pipes.
- A differential manometer consists of a u-tube, containing a heavy liquid, whose two ends are connected to the points, whose pressure is to be measured.
- Mostcommonlytypesofdifferentialmanometersare-
  (1) U-tubeDifferentialmanometer
  (2) InvertedDifferentialmanometer

U-TUBEDIFFERENTIALMANOMETER

(a) Let the two points A and B are at different level and also contains liquids of different sp.gr.these two points are connectedtothedifferentialmanometer.Letthepressureat A and B are P_A and P_B.

$P_A – P_B = h \times g(\rho_g - \rho_1) + \rho_2 gy - \rho_1 gx$

(b) LetthetwopointsAandBareatsamelevelandalsocontains differentialmanometer.LetthepressureatAandBare$P_A$and P_B.

$P_A – P_B = h \times g(\rho_g - \rho_1)$

PROBLEM

The right limb of a simple u-tube manometer containing mercury is open to the atmosphere while the left limb is connected to a pipe in which a fluid of sp. gr. 0.9 is flowing. The centre of the pipe is 12 cm below the mercury in the right limb. Find the pressure of fluid in the pipe if the difference of mercury level in the two limbs is 20cm.

Solution

Sp.gr.offluid,S_1=0.9

Densityoffluid(ρ_1)=900kg/m^3 Sp.gr.

of mercury, S_2= 13.6

Density of mercury(ρ_2) = 13600kg/m^3

Differenceofmercurylevelh_2=20cm=0.2m

Heightoffluid fromA-A,h_1=20-12=8cm=0.08m

Weknowthatpressure offluidinpipe$P=\rho_2 g\ h_2 - \rho_1 g\ h_1$ P=

$13600 \times 9.81 \times 0.2 – 1000 \times 9.81 \times 0.08$

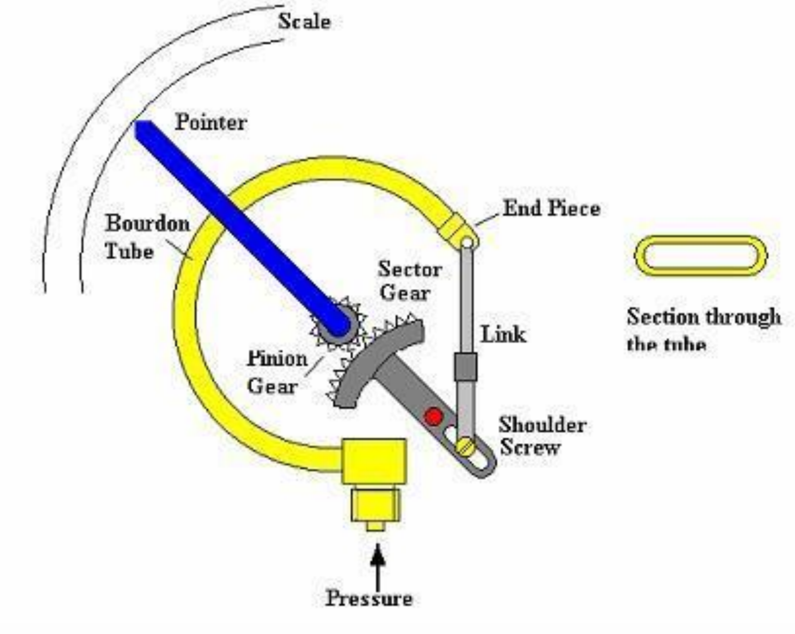
=26683 –706 =25977N/m^2=2.5977 N/cm^2(ans)

2.4.1BOURDONTUBEPRESSUREGAUGE

Themostcommontypeofpressuregaugeisabourdon’stube pressure gauge. It is the simple in construction and is generally used for measuring high pressure.

A bourdon gauge uses a coiled tube, which as it expands due topressureincreasecausesarotationofanarmconnectedto the tube.

It consists of a hollow coiled metallic tube usually made of bronzeornickelasshowninfig.one endofthetubeissealed and other end is connected to the pipe whose pressure is to be measured. When the pressure in the hollow tube increases,thetubewilltend touncoil andwhenthepressure decreases it will tend to coil more tightly. This movement is transferred through a rack and pinion arrangement connected to a pointer over a calibrated dial, directly giving thepressureoffluid.Thisgaugeiscapableofmeasuringboth positive and negative gauge pressure.


Scale
Pointer
Bourdon
Tube
End Piece
Sector
Gear
Link
Pinion
Gear
Shoulder
Screw
Pressure
Section through
the tube

SHORTQUESTIONS

1. Definemanometer?

Manometers are defined as the devices used for measuring the pressure in a fluid by balancing the column of fluid by the same or another column of the fluid. They are classified as:-

(c) Simplemanometer
(d) Differentialmanometer

2. Definepiezometer?

Ans-Itisthesimplestformofmanometerusedformeasuringgauge pressure.oneendofthismanometer isconnected wherepressure is to be measured and other end is opened to the atmosphere.

3. Whatistheuseofdifferentialmanometer?

Ans-differentialmonometerareusedwheredifferenceofpressure is to be measured.

LONGQUESTIONS

Explaintheworkingofbourdontubepressuregauge.(2018- S)
Explain absolute pressure, gauge pressure, vacuum pressure and their relationship through a plot. (2019-S)
calculatethepressureduetoacolumnof0.5mof

(i) water

(ii) oilofspecificgravityof0.82

(iii) mercury.

Assumethedensityofwater=1000kg/m^3(2019-S)

a simple U-tube manometer containing mercury, the left limb is connected to a pipe in which a fluid of sp. gravity 0.8 is flowing.Thecentreofthepipeis6cmbelowthelevelofmercury in right limb. Find the pressure of fluid in pipe of difference of mercury level in two limbs is 18cm. (2019-S)

CHAPTER-

03HYDROSTATICS

HYDROSTATIC PRESSURE

- Hydrostatics isthebranchoffluidmechanicswhichdealswiththe study of fluid at rest.
- Thismeansthattherewillbenorelativemotionbetween the adjacent or neighbouring fluid layers.
- Thereisnoshearstressactingonthe fluid.
- Thentheforcesactingonthefluidparticlewillbe–
    1. Duetopressureoffluidnormaltothesurface
    2. Duetogravity.

TOTALPRESSUREANDCENTREOFPRESURE

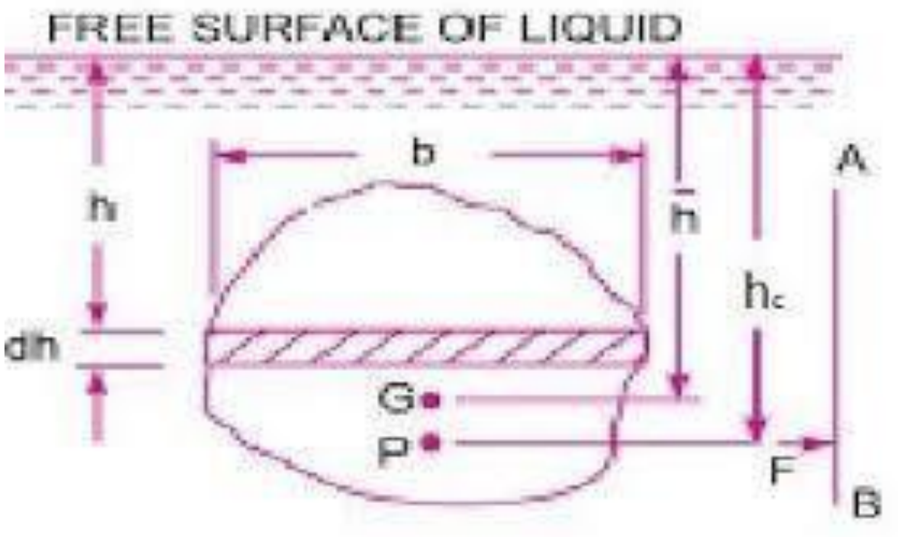
Total pressure is defined as the force exerted by a static fluid on a surface either plane or curved when the fluid comes in contact with the surfaces. This force always acts normal to the surface.

- **Centre of pressure** is defined as the point of application of total pressure on the surface.
- There are four cases of submerged surface on which the total pressure force and centre of pressure is to be determined. The submerged surfaces may be:

  (1) Vertical plane surface
  (2) Horizontalplanesurface
  (3) Inclined plane surface
  (4) Curvedplanesurface

VERTICALPLANESURFACESUBMERGEDINLIQUID

Consideraplaneverticalsurfaceofarbitraryshapeimmersed in a liquid as shown in fig.



LetA=total areaofthe surface

h^{-}=distanceofC.Gofthe areafromthefreesurfaceofliquid G = centre of gravity of plane surface

P =centreofpressure

h^{x}=distanceofcentreofthepressurefromthefreesurface of liquid.

totalpressure(F)= ρgAh^{-}

centreofpressure,$h^{x}=(I_G/Ah^{-})+h^{-}$

PROBLEM

A rectangular plane surface is 2 m wide and 3 m deep. It lies in verticalplanein water.Determinethetotalpressureandpositionof centre of pressure on the plane surface when its upper edge is horizonal and (a) coincides with water surface (b) 2.5 m below the free surface.

Solution

Widthofplanesurface,b=2m Depth of plane surface, d= 3m

(a) Upperedgecoincideswithwatersurface

Total pressure force (F) = $\rho g A \bar{h}$

$=1000\times9.81\times(3\times2)\times(3/2)$

$=88290$ N(ans)

Centreofpressure

$I_G=bd^3/12=2\times3^3/12=4.5m^4$

$h^x=(I_G/A\bar{h})+\bar{h}$

$=4.5/(6\times1.5)+1.5=2.0m$(ans)

(b) Upperedgeis2.5mbelowwatersurface

Total pressure force (F) = $\rho g A \bar{h}$

$=1000\times9.81\times(3\times2)\times(4.0)$

$=235440$ N(ans)

Centreofpressure

$I_G=4.5, A=6, \bar{h}=4.0$

$h^x=(I_G/A\bar{h})+\bar{h}$

$=4.5/(4.5\times6.0)+4.0=4.1875m$(ans)

3.4 BUOYANCY:

Whenabodyisimmersedinaliquid,anupwardforceisexerted bythefluidonthebody. Thisupward force isequaltotheweightof the fluid displaced by the body and is called force of buoyancy or simply buoyancy.

CENTREOFBUOYANCY

- Itisdefinedasthepointthroughwhichforceofbuoyancyis supposed to act.
- As the force of buoyancy is a vertical force and equal to the weightofthefluiddisplacedbythebody,thecentreofbuoyancy will be the centre of gravity of displaced liquid.

3.4ARCHIMEDESPRINCIPLE

It states that "The upward buoyant force that is exerted on a body immersed in a fluid, whether partially or fully submerged, is equal to theweightofthefluidthatthebody displacesandactsintheupward direction at the centre of mass of the displaced fluid".

METACENTRE

- ItIsdefinedasthepointaboutwhicha body startsoscillatingwhen a body is tilted by a small angle.
- Themeta-centremayalsobedefinedasthepointatwhichtheline of action of the force of buoyancy will meet the normal axis of the body when the body is given a small angular displacement.

3.4METACENTRICHEIGHT

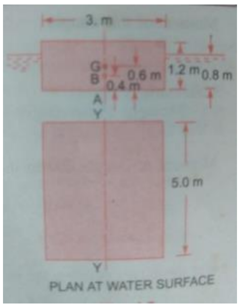
Thedistancebetween thecentreofgravityandthemetacentreofa floatingbody,asofavessel.Thusmetacentricheightis equalto the distance between G and M.

PROBLEM

A rectangular pontoon is 5mlong, 3mwide and 1.20mhigh.The depthofimmersionofthepontoonis0.80minseawater.Ifthecentre of gravityis0.6mabovethe bottomofthepontoon, determine the meta centricheight. The density forsea water = 1025kg/m^3.

Solution

Dimensionofpontoon=5m×3m×1.20m



Depthofimmersion =0.8m

Distance AG=0.6m

Distance AB=1/2×depthofimmersion

=1/2×0.8= 0.4m

Densityofseawater=1025kg/m$_3$

Meta-centreheightGM,givenbyGM=I/V–BG I =

1/12 × 5 × 3^3= 45/4 m^4

V=volumeofthebodysubmergedinwater

=3×0.8×5.0=0.2m

BG=AG-AB=0.6–0.4=0.2m

GM=(45/4)×(1/12.0)–0.2=0.7375m(ans)

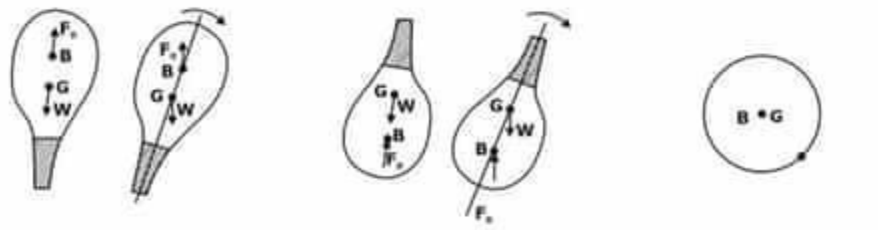
3.5CONCEPTOFFLOATION

- Asubmergedbody Issaidtobestableifitcomesback toits original position after a slight disturbance.
- The relative position of the centre of gravity and centre of buoyancyofthebody determinesthestabilityofasubmerged body.

STABILITYOFAFLOATINGBODY

Thepositionofcentreofgravityandcentreofbuoyancy incaseofa completely submerged body are fixed. Consider a balloon, which is completely submerged in air. Let the lower portion of the balloon contains heavier material, so that itscentre of the gravity is lower than its centre of buoyancy as shown in fig.

Let the weight of the balloon is W. the weight W is acting through G, vertically in the downward direction, while the buoyancy force F_b is actingverticallyup,through B. forequilibrium of theballoon W=F_b,if theballoon isgivenanangulardisplacementinclock wisedirectionas shown in fig.(A),then Wand F_b constitute acoupleactingin theanti-clock wise direction and brings the balloon in original position. Thus the balloon in the position as shown in fig (a) is in stable equilibrium.



(a) STABLE EQUILIBRIUM (b) UNSTABLE EQUILIBRIUM (c) NEUTRAL EQUILIBRIUM

(a) Stableequilibrium:whenW=$F_B$andpointBisaboveG,the body is said to be in stable equilibrium.

(b) Unstableequilibrium:if$W=F_B$,butthecentreofbuoyancy(B)is below the centre of gravity(G) the body is in unstable equilibrium:

(c) Neutral equilibrium: if$W=F_B$,and Band Gareatthesame point, as shown in fig. C the body is said to be neutral equilibrium.

SHORTQUESTIONS

Q-1)StateArchimedesprinciple.(2018-S,2019-S)

It states that "The upward buoyant force that is exerted on a body immersed in a fluid, whether partially or fully submerged, is equal to theweightofthefluidthatthebody displacesandactsintheupward direction at the centre of mass of the displaced fluid".

Q-2)Definebuoyancyandmetacentricheight.(2019-S)

buoyancy-Whenabodyisimmersedinaliquid,anupwardforce is exerted by the fluid on the body. This upward force is equal to the weight of the fluid displaced by the body and is called force of buoyancy or simply buoyancy.

metacentricheight-Thedistancebetweenthecentreofgravityand the metacentre of a floating body, as of a vessel. Thus metacentric height is equal to the distance between G and M.

LONGQUESTIONS

Q-1)Arectangularplanesurfaceis4mwideand6mdeep.Itliesin vertical plane in water. Determine the total pressure and position of centre of pressure on the plane surface when its upper edge is horizontal and-

(i) Coincideswithwatersurface
(ii) 2.5mbelowthewatersurface.(2018-S)

Q-2)explainbrieflyaboutstable,unstableandneutralequilibrium of floating. (2019-S)

Q-3) A Rectangular plate 3m long and 1m wide is immersed verticallyinwaterinsuchawaythatits3msideisparalleltothe water surface and is 1m below it. Calculate (i) total pressure on plate (ii) position of centre of pressure. (2019-S)

Q-4)Ablockofwoodofspecificgravityo.8floatsinwater. Determine the metacentric height of block if its size is 4m×2m×1.6m. (2019-S)

CHAPTER-04

KINEMATICOFFLOW

Introduction

Kinematics of flow is the branch of fluid mechanics which deals with the study of fluid motion without consideration of any forces causing motion is called fluid kinematics.

TYPESOFFLOW

Fluidflowsareclassifiedas:

(1) Steadyandunsteadyflow
(2) Uniformandnon-uniformflow
(3) Laminarandturbulentflow
(4) Compressibleandincompressibleflow
(5) Rotationalandirrotationalflow
(6) Idealandrealflow
(7) One,twoandthreedimensionalflow

STEADYANDUNSTEADYFLOW

- Steady flow is that type of flow in which fluid parameters (velocity, pressure, density, etc.) at any point in fluid flow field do not change with respect to time.
- Mathematically,

$$(\Delta V/\Delta t)_{x,y,z}=(\Delta P/\Delta t)_{x,y,z}=(\Delta \rho/\Delta t)_{x,y,z}=0$$

- Unsteady flow is that type of flow in which fluid parameters (velocity, pressure, density, etc.) at any point in fluid flow field changes with respect to time.
- Mathematically,

$$(\Delta V/\Delta t)_{x,y,zz} \neq 0 (\Delta P/\Delta t)_{x,y,zz} \neq 0 \qquad (\Delta \rho/\Delta t)_{x,y,z} \neq 0$$

UNIFORMANDNON-UNIFORMFLOW

- Uniformflowisthattypeofflowinwhichthevelocityatany given time does not change with respect to space.
- mathematically

$$(\Delta V/\Delta S)_{t=constant}=0$$

- Non-Uniformflowisthattypeofflowinwhichthevelocityatany given time does not change with respect to space.
- mathematically

$$(\Delta V/\Delta S)_{t=constant} \neq 0$$

LAMINARANDTURBULENTFLOW

- laminar flow is defined as that type of flow in which the fluid particles move along well-defined paths or stream line and all the stream lines are straight and parallel.
- Turbulent flow is defined as that type of flow in which the fluid particles moves in a zigzag way
- If the Reynolds number is less than 2000, the flow is called laminarandifthe Reynolds numberismore than 4000 thenthe flowisturbulent,andiftheReynoldsnumberisinbetween2000 to 4000 the flow is either laminar or turbulent.

COMPRESSIBLEANDINCOMPRESSIBLEFLOW

- Compressible flow is that type of flow in which the density of fluidchangesfrompointtopointorinotherwordsdensityisnot constant for the fluid.

- Compressible flow is that type of flow in which the density of fluiddonotchangefrompointtopointorinotherwordsdensity is constant for the fluid.

ROTATIONALANDIRROTATIONALFLOW

- Rotational flow is that types of flow in which the fluid particle while in moving along stream line also rotate about their own axis.
- Irrotational flow is that types of flow in which the fluid particle whileinmovingalongstreamlinedonotrotateabouttheirown axis.

RATEOFFLOWORDISCHARGE(Q)

- It is defined as thequantity of fluid flowing per second through asectionofapipeorachanneliscalledrateofflowordischarge.
- For an incompressible fluid (liquid) the rate of discharge is expressed as the volume of fluid flowing across the section per second.
- Forcompressiblefluid(gas)therateofdischargeisexpressedas the weight of fluid flowing across the section per second. Consider a liquid flowing through a pipe in which

  A=cross-sectionalareaofpipe

  V=averagevelocityoffluidacrossthesectional

  Then discharge $Q = A \times V$

CONTINUITYEQUATION

It states that “the mass of a fluid passing through different cross-section of a pipe, and its flow is same if no fluid is added or removed from the pipe”.

Considertwocrosssectionofapipeasshowninfig.

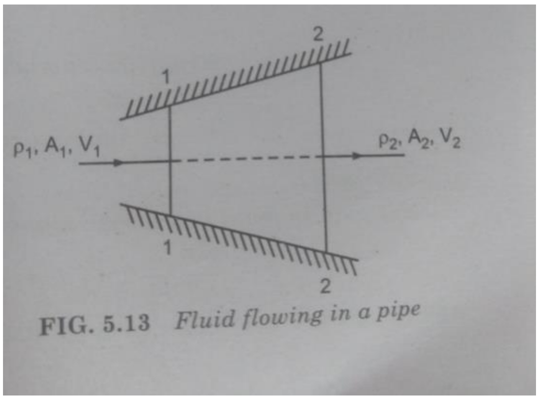


FIG. 5.13 *Fluid flowing in a pipe*

Let,V_1=averagevelocityatcross-section1-1 A_1 = area at section 1-1

ρ_1=densityoffluidatsection1-1

V_2=averagevelocityatcross-section2-2 A_2 = area at section 2-2

ρ_2= density of fluid at section 2-2

thentherateofflowinsection1-1=$\rho_1 A_1 V_1$ rate of flow in section 2-2= $\rho_2 A_2 V_2$

accordingtoconservationofmass

Rateofflowatsection1-1=rateofflowatsection2-2

$\rho_1 A_1 V_1 = \rho_2 A_2 V_2$

ifthefluidisincompressiblethanρ_1=$\rho_1$andcontinuityequation reduces toA_1V_1 =A_2V_2

BERNOULLI’STHEOREM

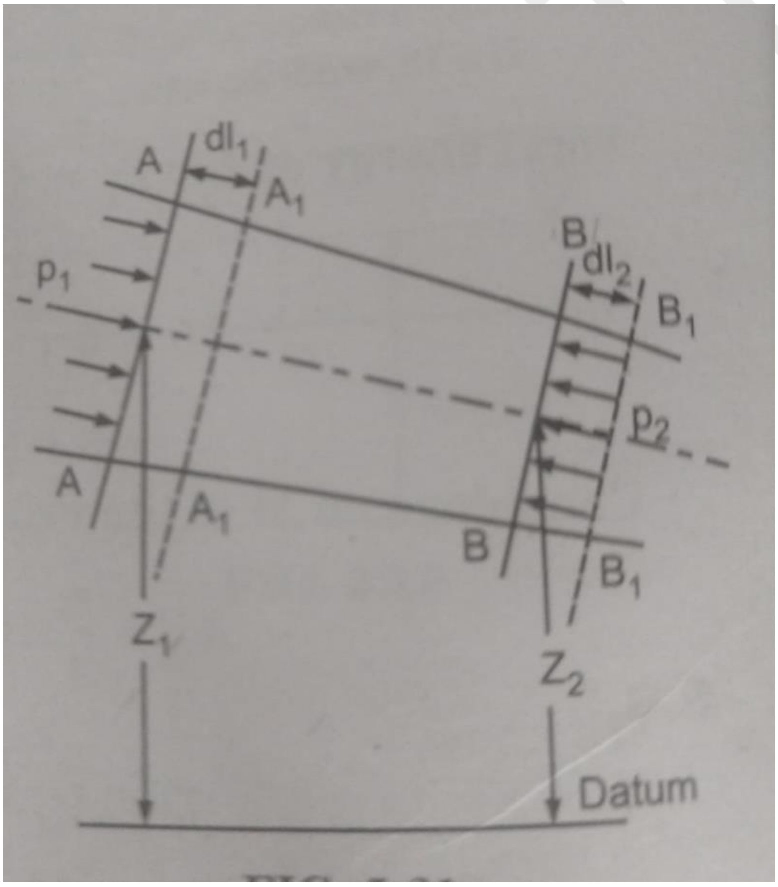
Itstates”inanidealincompressiblefluidwhentheflowissteadyand continuous then the sum of potential energy, kinetic energy and pressure energy is constant along a stream line”.

Mathematically

$$(P/\rho g)+(V^2/2g)+Z=\text{constant}$$

Proof

Consider an incompressible liquid is flowing through a non-uniform pipeasshowninfig.considertwosectionsAAandBBofthepipe.Let the pipe is running full and there is a continuity of flow between the two sections.



Let Z_1, P_1, V_1 and A_1 be the height above datum, pressure intensity, velocity and area of pipe respectively at section A.A.

LetZ,P,VandAbethecorrespondingquantitiesatsectionBB.letthe liquidbetweenthesectionAAandBBmovestopositionA_1A_1andB_1B_1 in an infinitely small interval of time.

LetWbetheweightofliquidbetweenAAandA_1A_1orBBandB_1B_1.

As the flow is continuous

$W=(A_1dl_1)w=(A_2dl_2)w$

Wherew=sp.weightoffluid.

$(A_1dl_1)w=W \quad \therefore (A_1dl_1)=W/w$ .... (1)

$(A_2dl_2)w=W \quad \therefore (A_2dl_2)= W/w$...................... (2)

Fromequation(1)and(2)

Weget$(A_1dl_1)=(A_2dl_2)= W/w$

Work-donebythepressureatAAismovingtheliquidtoA_1A_1

$=force\times distance=(P_1A_1)\times dl_1=P_1A_1dl_1$

Similarly,workdonebythepressureatBBinmovingtheliquidto B_1B_1 =

$- P_2 A_2 dl_2$

(MinussignshowsthatthedirectionofP_2isoppositetoP_1) Total

work done by pressure

$=P_1A_1dl_1 – P_2A_2dl_2$

$=P_1\times(W/w)- \quad P_2\times(W/w)$

$=(W/w)\times(P_1- P_2)$

Lossofpotentialenergy$=WZ_1-WZ_2=W(Z_1-Z_2)$ Gain in kinetic energy = $W/2g(V_2^2-V_1^2)$

Weknowthat,

Lossofpotentialenergy+workdonebypressure=gaininkinetic energy

$W(Z_1-Z_2)+(W/w)\times(P_1-P_2)=W/2g(V_2^2-V_1^2)$

$(Z_1-Z_2) +1/w (P_1-P_2) = 1/2g(V_2^2-V_1^2)$

$Z_1-Z_2+P_1/w-P_2/w=V_2^2/2g-V_1^2/2g$

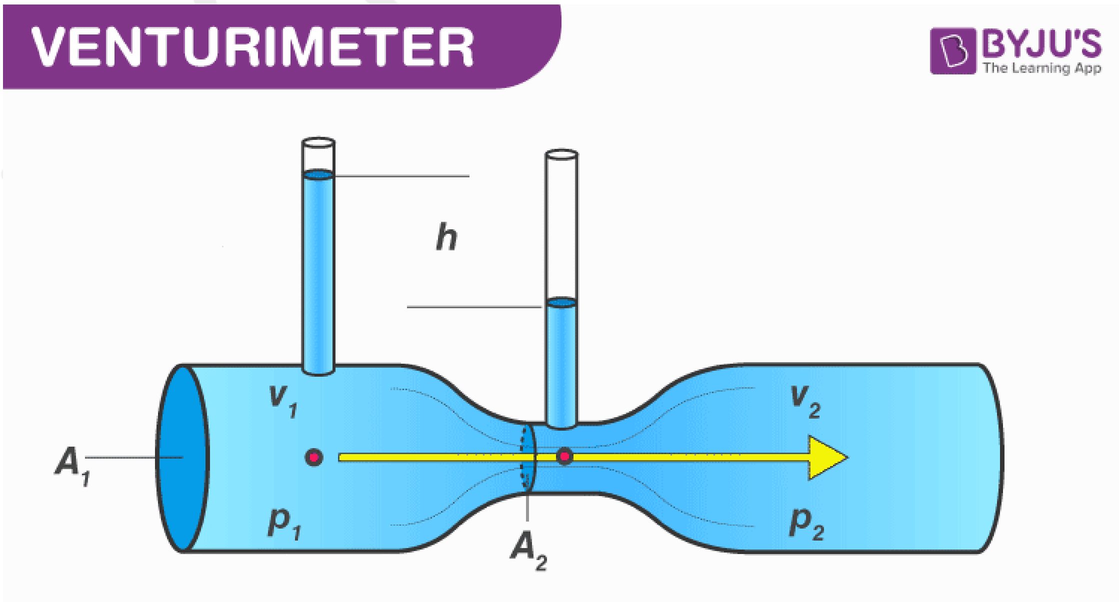
$Z_1+V_1^2/2g+P_1/w=Z_2+V_2^2/2g+P_2/w$

i.e.thesumofpotentialhead,kineticheadandpressureheadisconstant.

4.3VENTURIMETER

Aventurimeterisadeviceusedformeasuringtherateofaflowafluid flowing through a pipe. It consists of three parts:

(1) Ashortconvergingpart(2)Throat
(3)Divergingpart



A venturimeter is a device used for measuring the rate of flow of a fluid flowing through a pipe

Dischargethroughventuri-meter

$$Q_{act} = C_d \frac{a_1 a_2}{\sqrt{a_1^2 - a_2^2}} \sqrt{2gh}$$

Where,C_d=coefficientofdischarge A_1

= area at inlet

A_1=areaai throat

h=differenceinliquidlevel

4.3PITOT TUBE

Itisadeviceusedformeasuringthevelocityofflowatanypoint in a pipe or a channel.

Velocityofflow(V)=$\sqrt{(2g(H-h))}$

Problem

A pipe of diameter 400mm carries water at a velocity of 25m/s.thepressureatthepointsAandBaregivenas 29.43N/cm^2 and 22.563 N/cm^2 respectively while the datum headatAandBare28mand30m.findthelossofheadbetween A and B.

Solution

Diaofpipe,D=400mm=0.4m

Velocity, V = 25 m/s

P_A=28m

V_A=v=25m/s

TotalenergyatA,$E_A=Z_A+V_A^2/2g+P_A/w$

$=28+(25^2/2\times9.81)+29.43\times10^4/(1000\times9.81)$

=89.85m

AtpointB,$P_B=22.563N/cm^2=22.563\times10^4N/cm^2$ Z_B = 30m

$V_B=V=V_A$=25m/s

TotalenergyatB,

$E_B=(P_B/\rho g)+(V_B^2/2g)+Z_B$

$=22.563\times10^4/(1000\times9.81)+25^2/(2\times9.81)+30$

=84.85m

Lossofenergy =E_A–E_B=89.85-84.85=5.0m(ans) Problem

A horizontal venturi meter with inlet and outlet diameters 30cm and 15 cm respectively is used to measure the flow of water. The reading of differential manometer connected to the inlet and the throatis20cmof mercury.Determinetherate offlow.TakeC_d=0.98.

Solution

Diaatinletd_1=30cm

Areaatinlet$a_1=\pi/4d_1^2=706.85cm^2$ Dia

at throat d_2= 15 cm

Areaatthroat$a_2=\pi/4d_2^2=176.7cm^2$

C_d=0.98

Reading of differential manometer = x= 20 cm of mercury

Differenceofpressurehead,h=x(S_h/S_o-1)=252cmofwater

=125.756lit/s

SHORTQUESTIONS

Defineuniformandlaminarflow.2018-S

Ans-Uniformflowisthattypeofflowinwhichthevelocityatany given time does not change with respect to space.

mathematically

$$(\Delta V/\Delta S)_{t=constant}=0$$

laminarflowisdefinedasthattypeofflowinwhichthefluidparticles move along well-definedpaths or streamlineand all thestreamlines are straight and parallel.

Defineaboutnonuniformflowandturbulentflow.2019-S

Non-Uniform flow isthattype of flowinwhich the velocityat any given time does not change with respect to space.

mathematically

$$(\Delta V/\Delta S)_{t=constant} \neq 0$$

Turbulent flow is defined as that type of flow in which the fluid particles moves in a zigzag way

whatisthedifferencebetweenlaminarflowandturbulentflow. 2019-S

laminarflowisdefinedasthattypeofflowinwhichthefluidparticles move alongwell-definedpathsor streamlineand allthestreamlines are straight and parallel.

Turbulent flow is defined as that type of flow in which the fluid particles moves in a zigzag way

IftheReynoldsnumberislessthan2000,theflowiscalledlaminarand if the Reynolds number is more than 4000 then the flow is turbulent, and if the Reynolds number is in between 2000 to 4000 the flow is either laminar or turbulent.

whatisthefunctionofventurimeter.2019-S

Venturi meter Is a device used to measure the rate of flow or discharge in a pipe.

LONGQUESTION

Statecontinuityequationandproveitforonedimensionalflow. (2018-S)

water is flowing through a pipe having diameter 300mm and 200mm at bottom and upper end respectively. The intensity of pressure at bottom end is 24.525 N/cm^2 and the pressure at the upper end is 9.81 N/cm^2, determine the difference in datum head if the rate of flow through the pipe is 40lit/sec. (2018-S)

Water flows through a 300mm x 150mm horizontal venturi meter at the rate of 0.04 m^3/sec. A differential manometer with gauge liquid of specific gravity of 1.25 indicates a deflection of 1.05m. calculate the coefficient of discharge for the venturi meter. (2019-S)

What Is pitot tube. Why it is used. Derive an expression for velocity of liquid flow at any point in a pipe by using pitot tube. (2019-S)

CHAPTER-05

ORIFICES,NOTCHES&WEIRS

5.1-ORIFICE

- Orificeisasmallopeningofanycross-section(suchascircular, triangular, rectangular etc.) on the side or at the bottom of a tank, through which a fluid is flowing.
- Itisusedformeasuringtherateofflowordischarge.

Classificationoforifices

Theorificesareclassifiedonthebasispf theirsize,shape,nature of discharge and shape of the upstream edge. The following are the important classifications-

(1) The orifices are classified as small orifice or large orifice depending upon the size of the orifice and head of liquid from the centre of the orifice. If the head of liquid from the centre oforificeis morethan fivetimesthedepth oforifice, the orifice is called small orifice. And if the head of the liquidsislessthanfivetimesthedepthoforifice,itisknown as large orifice

(2) Theorificesareclassifiedas(i)circularorifices,(ii)triangular orifices, (iii) rectangular orifices (iv) square orifices depending upon their cross-sectional areas.

(3) Theorificesareclassifiedas(i)sharp edgedorifice,(ii)bell-mouthedorificedependingupontheupstreamedgeofthe orifices.

(4) Theorificesareclassifiedas(i)freedischargingorificesand (ii)drownedorsubmergedorificesdependinguponthe nature of discharge.

Thesub-mergedorificesarefurtherclassifiedas(a)fullysub-merged orifices and (b) partially sub- merged orifices.

FLOWTHROUGHAN ORIFICE

Consider a tank fitted with a circular orifice in one of its sides as shown in fig. let H be the head of liquid above the centre of the orifice. The liquid flowing through the orifice forms a jet of liquid whose area of cross-section is less than thatoforifice.Theareaofjetoffluidgoesondecreasingand at a section CC, the area is minimum. This section is called vena-contracta. Beyond this section the jet diverges and is attracted to the downward direction by the gravity.

Considertwopoints1and2asshownin figure.Point1is inside the tank and point 2 is vena-contracta.

LettheflowissteadyandataconstantheadH.by applying Bernoulli's equation at point 1 and 2.

$$Z_1+V_1^2/2g+P_1/w=Z_2+V_2^2/2g+P_2/w$$

But, $Z_1=Z_2$

$$V_1^2/2g+P_1/w=V_2^2/2g+P_2/w$$ Now,

$P_1/w = H$

$P_2/w=0$(atmospheric)

V_1isverysmallincomparisontoV_2astheareaofthetankis very large as compared to the area of the jet of the liquid.

$$H+0=0+V_2^2/2g \quad V_2 =$$

$$\sqrt{(2gH)}$$

Thisisthetheoreticalvelocity.Actualvelocitywillbelessthanthis value.

ORIFICECO-EFFICIENTS

Thehydrauliccoefficient'sare-

(1) co-efficientofvelocity,C_v
(2) co-efficientofcontraction,C_c
(3) co-

efficientofdischarge,C_dCO-

EFFICIENT OF VELOCITY, C_V

- Itisdefinedastheratiobetweenactualvelocityofajetof liquid at vena-contracta to the theoretical velocity of jet.
- ItisdenotedbyC_V.M athematically

  C_V=actualvelocityofjetatvena-contracta/theoretical velocity

  $=V/\sqrt{(2gH)}$

  Where,V=actualvelocity

  $\sqrt{(2gH)}$=theoreticalvelocity

  Thevalueof$C_v$variesfrom0.95to0.99.

CO-EFFICIENTOFCONTRACTION,C_C

- Itisdefinedastheratiooftheareaofthejetatvena-contracta to the area of orifice.
- ItisdenotedbyC_C.
- Leta=areaof orifice

  a_c=areaof jetat vena-contarcta

  then,C_C=areaofjetatvena-contarcta/areaof orifice

  $= a_c/a$

  Thevalueof$C_C$variesfrom0.61to0.69dependingupon the shape and size of orifice.

CO-EFFICIENT OF DISCHARGE, C_d

- It is defined as the ratio between the actual discharge from an orifice to the theoretical discharge from an orifice.
- It is denoted by C_d.
- Mathematically, $C_d = Q/Q_{th}$

  C_d = actual area × actual velocity/(theoretical area × theoretical velocity)

  = (actual area/theoretical velocity) × (actual velocity × theoretical velocity)

$$C_d = C_v \times C_c$$

The value of C_d varies from 0.61 to 0.65.

NOTCHES AND WEIRS

- **A notch** is a device used for measuring the rate of flow of a liquid through a small channel or a tank.
- It may be defined as an opening in the side of a tank or a small channel in such a way that the liquid surface in the tank or channel is below the top edge of the opening.
- **A weir** is a concrete or masonary structure, placed in an open channel over which the flow occurs. It is generally in the form of vertical wall, with a sharp edge at the top, running all the way across the open channel.
- The notch is of small size while weir is a bigger size. Notch generally made of metallic plate while the weir is made of concrete or masonary structure.

5.4 CLASSIFICATION OF NOTCHES AND WEIRS

The notches are classified as:

(1) According to the shape of the opening:

a. Rectangular notch
b. Triangular notch
c. Trapezoidal notch
d. Stepped notch

(2) According to the effect of the sides of the nappe:

a. Notch with end concentration.
b. Notch without end concentration.

Weirs are classified as follows:

(1) According to the shape of the opening

a. Rectangular weir
b. Triangular weir
c. Trapezoidal weir

(2) According to the shape of the crest:

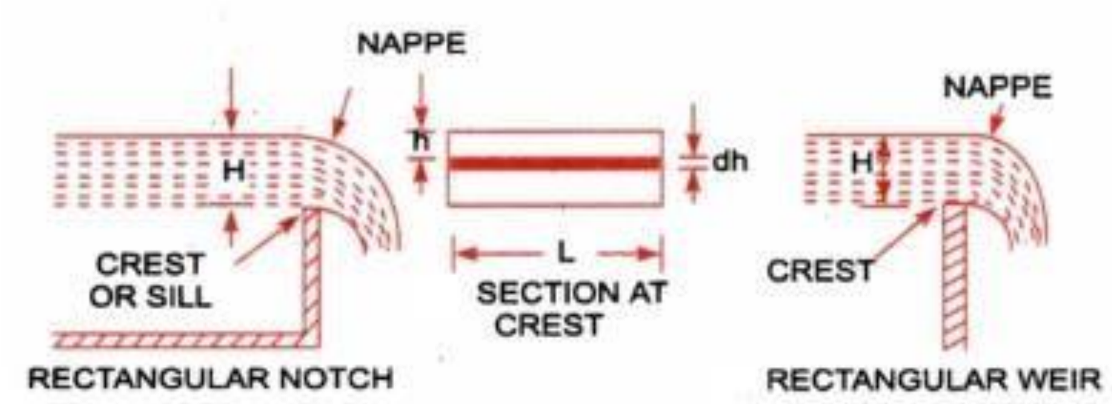
a. Sharp crested weir
b. Broad crested weir
c. Narrow crested weir
d. Ogee shaped weir

(3) According to the effect of sides on the emerging nappe.

a. Weir with end contraction
b. Weir without end concentration

DISCHARGEOVERRECTANGULARNOTCHORWEIR

Thedischargeoverrectangularnotchandweiristhesame.



Now, let us consider that we have channel carrying water and let us thinkarectangularnotchorweirwiththischannelas displayedhere in above figure.

Wehavefollowingdatafromabovefigureandthesedataareas mentioned here.
H=Headofwaterovverthecrest
L=Lengthoftherectangularnotchorweir
Letusconsideroneelementaryhorizontalstripofwaterof thickness dh and length L as displayed in above figure.
dh=Thicknessofelementaryhorizontalstripofwaterflowingover the rectangular notch or weir
h=Depthofelementaryhorizontalstripofwaterflowingoverthe rectangular notch or weir
C_d=Co-efficientofdischarge

Areaofelementaryhorizontalstripofwater=Lxdh

WewilldeterminethevalueofdischargedQthroughtheelementary horizontalstripof water. Aftersecuringtheexpressionfordischarge through the elementary horizontal strip, we will integrate the expression between the limit 0 to H and we will have the expression for the discharge over a rectangular notch or weir.

$$dQ = C_d \times \text{Area of strip} \times \text{Theoretical velocity}$$
$$= C_d \times L \times dh \times \sqrt{2gh}$$

Total discharge i.e. Q over a rectangular notch or weir

$$Q = \int_0^H C_d \, . \, L \, . \, \sqrt{2gh} \; . \, dh = C_d \times L \times \sqrt{2g} \int_0^H h^{1/2} \, dh$$

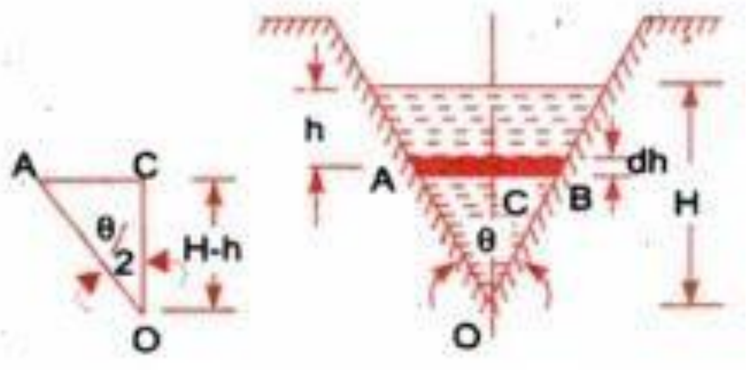
$$= C_d \times L \times \sqrt{2g} \left[\frac{h^{1/2+1}}{\frac{1}{2}+1} \right]_0^H = C_d \times L \times \sqrt{2g} \left[\frac{h^{3/2}}{3/2} \right]_0^H$$

$$= \frac{2}{3} C_d \times L \times \sqrt{2g} \; [H]^{3/2}$$

DISCHARGEOVERTRINGULARNOTCHORWEIR

Theexpressionofthedischargeoveratriangularnotchor overaweir will be same.

Now, let us consider that we have channel carrying water and let us thinkatriangularnotchorweirwiththischannelasdisplayedherein following figure.



Wehavefollowingdatafromabovefigureandthesedataareas mentioned here
H=HeadofwaterabovetheV-notch θ =
Angle of notch

Letusconsideroneelementaryhorizontalstripof waterof thickness dhandatadepthofhfromfreesurfaceofwaterasdisplayedherein above figure.

dh=Thicknessofelementaryhorizontalstripofwaterflowingover the triangular notch or weir
h=Depthofelementaryhorizontalstripofwaterfromfreesurfaceof water
C_d=Co-efficientofdischarge

WewilldeterminethevalueofdischargedQthroughtheelementary horizontalstripof water. Aftersecuringtheexpressionfordischarge through the elementary horizontal strip, we will integrate the expression between the limit 0 to H and we will have the expression for the discharge over entire triangular notch or weir.

dQ=C_dxAreaofstripxTheoreticalvelocity

Areaofstrip
Firstwewillsecurethevalueofareaofhorizontalelementarystrip

$$\tan\frac{\theta}{2} = \frac{AC}{OC} = \frac{AC}{(H-h)}$$

$$AC = (H-h)\tan\frac{\theta}{2}$$

$$\text{Width of strip } = AB = 2AC = 2\,(H-h)\tan\frac{\theta}{2}$$

$$\text{Area of strip } = 2\,(H-h)\tan\frac{\theta}{2} \times dh$$

Nowwewillsecureheretheexpressionfor

$$= 2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g}\left[\frac{2}{3} H.H^{3/2} - \frac{2}{5} H^{5/2}\right]$$

$$= 2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g}\left[\frac{2}{3} H^{5/2} - \frac{2}{5} H^{5/2}\right]$$

$$= 2 \times C_d \times \tan\frac{\theta}{2} \times \sqrt{2g}\left[\frac{4}{15} H^{5/2}\right]$$

$$= \frac{8}{15} C_d \times \tan\frac{\theta}{2} \times \sqrt{2g} \times H^{5/2}$$

For a right-angled *V*-notch, if $C_d = 0.6$

$$\theta = 90°, \quad \therefore \quad \tan\frac{\theta}{2} = 1$$

Discharge $$Q = \frac{8}{15} \times 0.6 \times 1 \times \sqrt{2 \times 9.81} \times H^{5/2}$$

$$= 1.417\ H^{5/2}$$

PROBLEM

The head of water over an orifice of diameter 100mm is 10m. the water is coming out from the orifice is collectedinacirculartankofdiameter1.5m.theriseof water level in this tank is 1.0m in 25 seconds. Also the co-ordinates of a point on the jet, measured from vena-contractaare4.3mhorizontaland0.5mvertical. Find the coefficients, C_d, C_v, C_c.

SolutionDat

agiven

Head,H= 10m

Diaoforifice,d=100mm=0.1m Area

of orifice, a = 0.007853 m^2

Diaofmeasuring tank,D=1.5m

Area of the tank, A = 1.767 m^2

Rise of water level, h = 1m

Intime= 25sec

Horizontaldistance,x=4.3m Vertical

distance, y = 0.5 m

Nowtheoretical velocity, $V_{th}= \sqrt{(2gH)} = \sqrt{(2 \times 9.81 \times 10)} = 14$m/s Theoretical

discharge, $Q_{th}= V_{th} \times$ area of orifice

$= 14 \times 0.007854 = 0.1099 m^3/s$

Actual discharge, $Q_{act}= A \times h / t = 1.767 \times 1.0 / 25 = 0.07068$

$C_d= Q_{act} / Q_{th} = 0.07068 / 0.1099 = 0.643$ (ans)

Co-efficientofvelocity,$C_v=x/\sqrt{(4yH)}=4.3 /(4 \times 0.5 \times 10)$

=0.96ans

Co-efficientcontraction$C_c=C_d/C_v=0.643/0.96=0.669$(ans)

IMPORTANTQUESTIONS

1.Defineorificeandnotch.

- **Ans-Anotch**isadeviceusedformeasuringtherateofflowofa liquid through a small channel or a tank.
- **Anotch**isadeviceusedformeasuringtherateofflowofaliquid through a small channel or a tank.

Longquestions

1. Defineorificecoefficientsandestablishtherelationbetween them.
2. Deriveanexpressionfordischargeoverrectangularorifice.
3. Deriveanexpressionfordischargeovertriangularorifice.

CHAPTER-06FLOWTHROUGHPIPE

DEFINITIONOF PIPE

Pipeisaclosedconduitwhichisusedtoconveyliquidsandgases.

LOSSOFENERGYINPIPES

Whenafluidis flowingthroughapipe,thefluidexperiencessome resistance due to which some of the energy of fluid is lost. This loss of energy is classified as:

Major energy losses: The viscosity causes loss of energy in the flows, which isknown asfrictionallossormajorenergylossanditis calculated by the following formula;

(a)Darcy-weisbachformula

(b) Chezy'sformula

Minor energylosses: Thelossofenergyduetochangeofvelocityof the flowing fluid in magnitude or direction is called minor loss of energy**.** The minor loss of energy includes the following cases-

a. Suddenexpansionofpipe
b. Suddencontractionofpipe
c. Bendinginpipe
d. Pipefittings

HEADLOSS DUETO FRICTION

(a) Darcy-weisbachformula

Thelossofheadcanbemeasuredbythefollowingequations h_f =4f L V^2 / (2gd)

Wherehf=Lossofhead duetofriction

f =Co-efficientoffrictionwhichisafunctionofReynolds number

f=64/R_e(forRe<2000)(laminarflow)

=0.079/$R_e^{1/4}$forRvaryingfrom4000to10^6(turbulent flow)

L=Lengthofpipe

V=meanvelocityofflow D = Diameter of pipe

(b) chezy’s formula

$$h_f = \frac{f'}{\rho g} \times \frac{P}{A} \times L \times V^2$$

Where,
hf =loss of headduetofriction P = perimeter of pipe
A =areaofcrosssectionofpipe L = length of pipe
V=meanvelocityof flow

NowtheratioofA/p =(areaofflow/wetted perimeter) iscalled hydraulic mean depth. It is denoted by m.

Hydraulicmeandepth,m=A/P=d/4

$$V=C\sqrt{(mi)}$$

problem

Find the headlost dueto friction ina pipeof diameter300mm andlength50mthroughwhichwaterisflowing ata velocityof 3m/s using (i) Darcy weisbach (ii) Chezy's Formula (c=60)

(TakeV=0.01stoke(forwater))

Solution:

Given:Diameterofthepipe,d =300mm(divideby'1000'toconvert it from 'mm' to 'm')

Diameterd=0.3m

Length, L= 50m

Velocity, v=3m/s

KinematicViscosity,V=0.01stoke

$V=0.01cm2/s$

$V=0.01\times10^{-4}m^2/s$

ByDarcy's Formula,

$hf=4f\times L\times v^2\times d\times 2g$

weknowco-efficientoffriction

f=0.079Re

$\therefore Re=V\times dv=3.0\times 0.300.01\times10^{-4}$

$Re = 9 \times 10^5$

$\therefore f = 0.079 (9 \times 105) 14$

$f = 2.56 \times 10 - 3$

$or f = 0.00256$

Therefore,Headlost,$hf = 4 \times 0.00256 \times 50 \times 320.3 \times 2.0 \times 9.81$

$hf = 782.87 \times 10 - 3$

$hf = 0.7828m$

NowbyusingChezy'sformula:-

$V = c\sqrt{mi}$

where,$c = 60, m = d4 = 0.304 = 0.075m$

$3 = 60\ \sqrt{0.075}$.................(i)

$i = (360) 2 \times 10.075$..................*(ii)*

Byequating,weget

$i = 0.333$

But,$i = hfL$

$\therefore, 0.333 = hf50$

$\therefore hf = 1.665m$

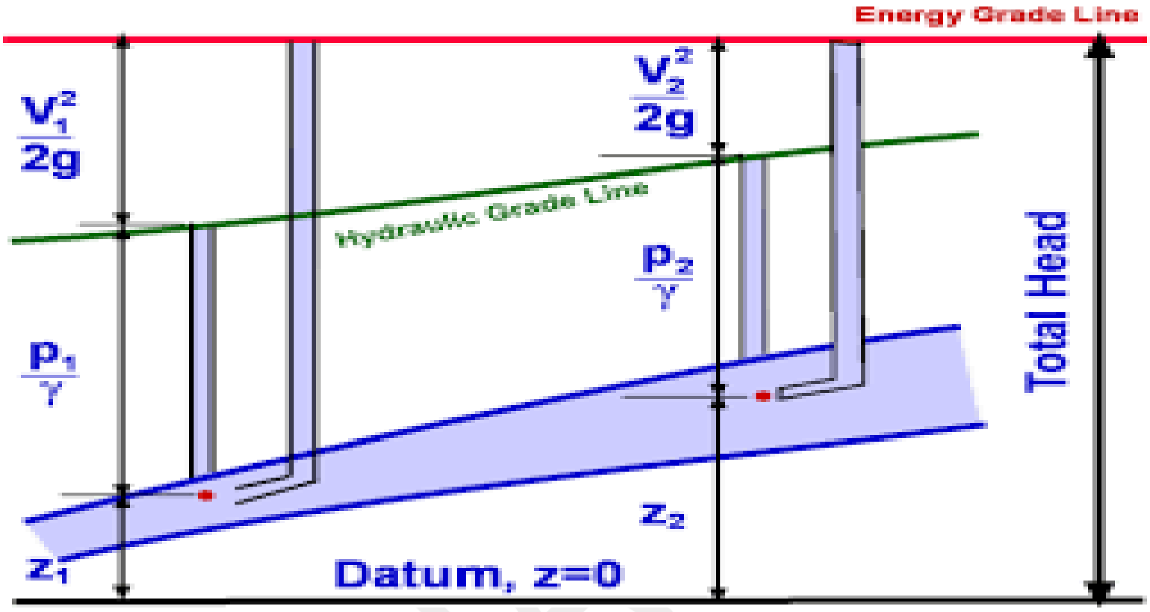
HYDRAULICGRADIENTLINE

Hydraulic gradientlineisbasicallydefinedasthelinewhich willgive the sum of pressure head and datum head or potential head of a fluid flowing through a pipe with respect to some reference line.

Hydraulicgradientline=Pressure head+Potentialhead ordatum head

$$H.G.L= P/\rho g+Z$$

Where,
H.G.L=Hydraulicgradientline $P/\rho g$
= Pressure head
Z=Potentialhead ordatumhead



6.5TOTALENERGYLINE

Totalenergylineisbasicallydefinedasthelinewhichwillgivethe sum of pressure head, potential head and kinetic head of a fluid flowing through a pipe with respect to some reference line.

Totalenergyline=Pressurehead+Potentialhead+Kinetichead

$$H.G.L=P/\rho g+Z+V^2/2g$$

Where,
T.E.L=Totalenergyline
$P/\rho g$ = Pressure head
Z = Potential head or datum head
$V^2/2g$=Kineticheadorvelocityhead

Relationbetweenhydraulicgradientlineandtotalenergyline

$H.G.L = E.G.L - V^2/2g$

IMPORTANTQUESTIONSSH

ORT QUESTIONS

1. **Definehydraulicgradientline.**

   Ans-Hydraulic gradient line is basically defined as the line which will give the sum of pressure head and datum head or potentialheadofafluidflowingthrough apipewith respectto some reference line.

2. **Definepipeandhydraulicmeandepth.**

   Ans-

   Pipe-itisaclosed conduitwhichisusedtocarryfluidunder pressure.

   Hydraulicmeandepth-itisdefinedastheareaofflowsection divided by the top water surface width.

LONGQUESTIONS

1. Writedowntheexpressionoflossofenergyduetofriction accordingtoDarcy'sformulaandChezy'sformulawithproper notation.
2. WriteinbriefaboutFroude'slawoffluidfriction.
3. Find the head lost due to friction in a pipe of diameter 200mm and300mmlengththroughwhichwaterisflowingwithavelocity of 5m/s using-
   i. Darcy'sformula
   ii. Chezy'sformula,takeC=50andf=0.0079

CHAPTER – 07IMPACTOFJET

INTRODUCTION

The liquid comes out in the form of a jet from the outlet of the nozzle fittedinthe outlet ofthepipe through whichthe liquid is flowing under pressure. if some plate, which may be fixed or moving is placed in the path of the jet, a force is exerted by the jet on the plate. This force exerted by the jet on the plate is called impact of jet.

7.1IMPACTOFJETONFIXEDPLATEWHENTHEPLATEIS VERTICAL TO THE JET

Considerajet of watercomingoutofthenozzle,strikes aflat vertical plate as shown in the Figure 1.

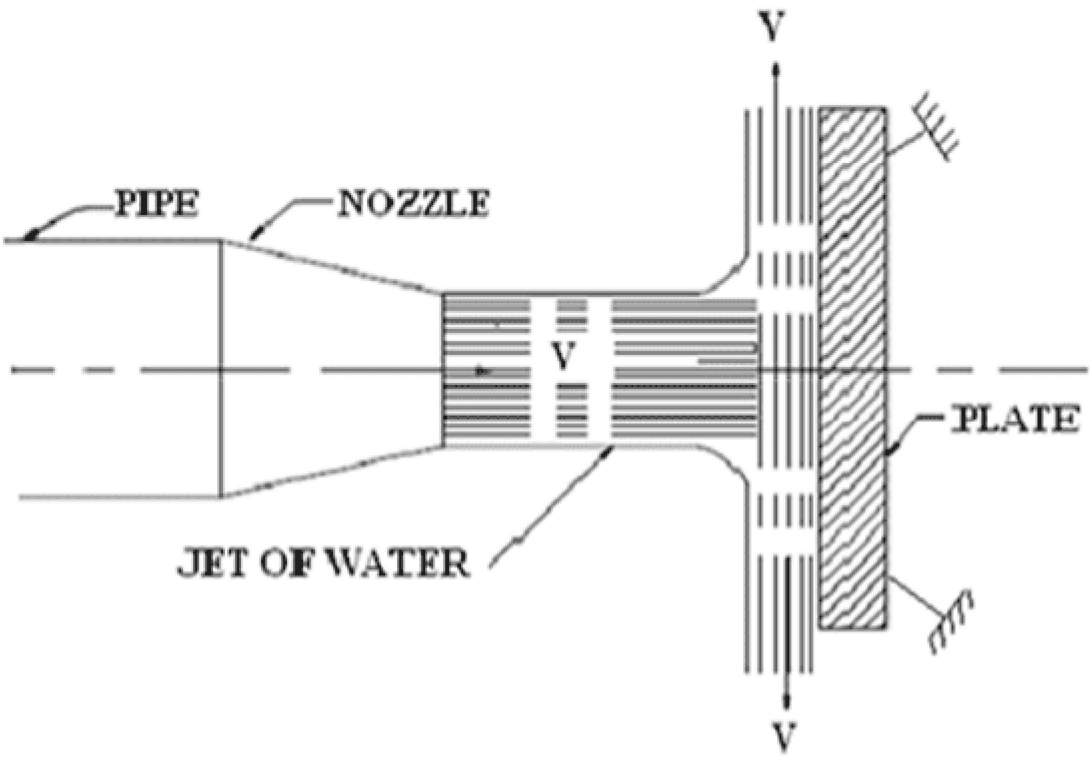


Figure 1

let,
ρ =densityofwater
a=areaof jet=$(\pi/4)d^2$
v=absolutevelocityof jet

Thejetafterstrikingtheplatewillmovealongtheplate. But the plate is right angles to the jet. Hence the jet after strikingwill get deflectedby90Â°.Hencethecomponent ofthe velocity of the jet, inthe direction of thejet, afterstrikingwill be zero.

Theforce exerted by thejeton the platein thedirection of the jet.

=(initialmomentum-finalmomentum)/time

=mass×(initialvelocity-finalvelocity)/time

=mass/time(initialvelocity-finalvelocity)
$=\rho av(v-0)$
$=\rho av^2$

For deriving the above equation, we have taken initial velocity minus final velocity and not final velocity minus initial velocity. If the force exerted on the jet is to be calculated then final minus the initial velocity is taken. But if the force exertedbythe jet onthe plate istocalculated, theninitial velocityminus the final velocity is taken.

7.1IMPACTOFJETONMOVINGPLATEWHENTHEPLATEIS VERTICAL TO THE JET

Consider,**ajetofwaterstrikestheflatmovingplate movingwithauniform**velocityawayfrom thejet.

v=Velocityofjet
u=velocityofflatplate
Relativevelocityofjetw.r.tplate=v-u

Mass ofwaterstriking/secontheplate=ρa(v-u)
Forceexertedby jet onthemovingplateinthedirection of jet
F_x=Massofwaterstriking/secx[Initialvelocity–Final velocity]
=ρa(V-u)[(V-u)-0]

$=\rho a(V-u)^2$
In thiscase, work is donebythejet ontheplateas theplateis moving,
Workdonebythejetontheflatmovingplate

=ForcexDistanceinthedirectionofforce/Time
$=F_x x u=\rho a(V-u)^2 u$

Problem

Wateris flowing through a pipe atthe end of which anozzle is fitted. The diameter of nozzle is 100 mm, and the head of water at the centre nozzle is 100 mm. find the force exerted by the jet of water on a fixed vertical plate. The coefficient if velocity is given as 0.95.

solution

givendata
diameter of nozzle, d =100mm =0.1m
head of water, H = 100m
coefficient of velocity, C_v= 0.95 area of thenozzle , a =0.007854m^2

theoreticalvelocityofjet,
V_{th}= √(2gh) =√(2x9.81 x100)= 44.294m/s
C_v= actual velocity/ theoretical velocity
Actual velocity = C_vx theoretical velocity
=0.95x44.294=42.08m/s
F=ρav²=1000x0.007854x42.08² =13907.2N=13.9KN

7.1FORCEEXERTEDBY AJETON ASTATIONARYINCLINED FLAT PLATE:

Let a jet of water,comingoutfrom the nozzle;strikean inclined flat plate as shown in the figure.2.

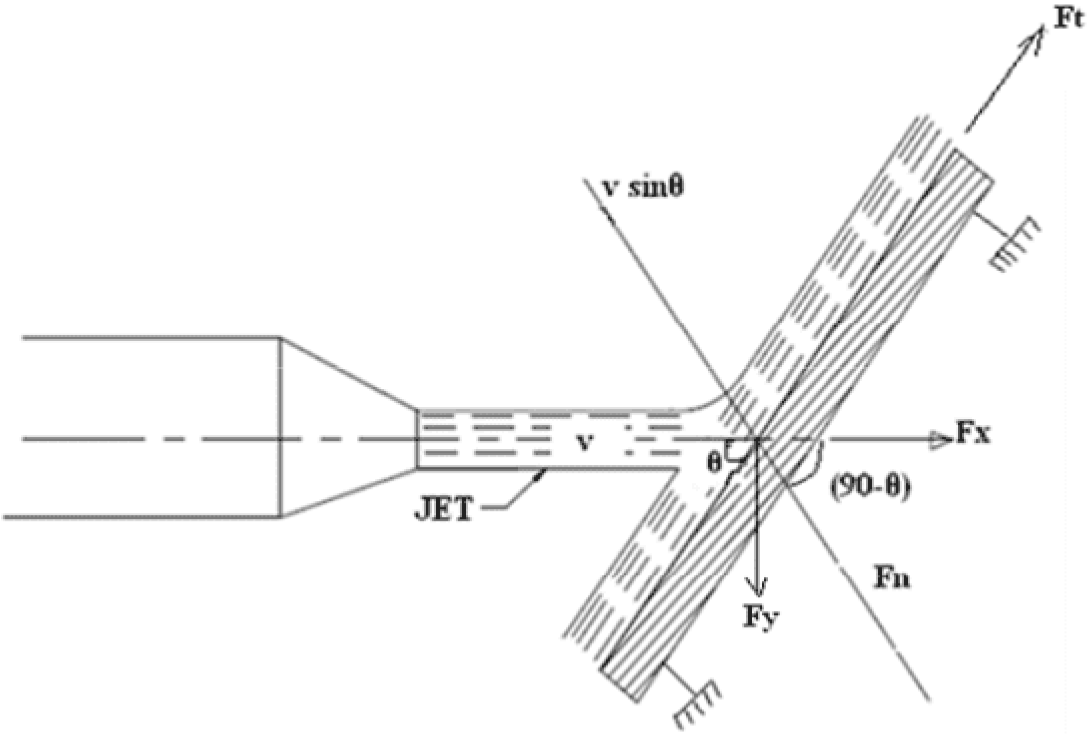


Figure.2.

Let

a=areaof jet=(π/4)d²

v = velocity of thejetinthe direction of X θ
= Angle between the jet and the plate

thenmassofwaterpersecondstrikingtheplate= ρav

If the plate is assumedsmooth and if it is assumedthat there is no loss of energy due to the impact of the jet, then the jet will move over the plate after striking with a velocity equal to initial velocity i.e., with a velocity V.

Let findtheforce exerted by the jet onthe plateIn thedirection normal to the plate. Let this force is represented by F_n

then, F_n= Mass of the jet strikingper secondÃ[initial velocityof the jet before striking in the direction of n - final velocity of the jet after striking in the direction of n

$$F_n=\rho av[v\sin\theta-0]=\rho av^2\sin\theta$$

If the force can be resolved into two components, one in the directionofthe jet andthe other perpendiculartothe direction of the flow. Then we have,

$F_{x=}\rho av^2\sin\theta$

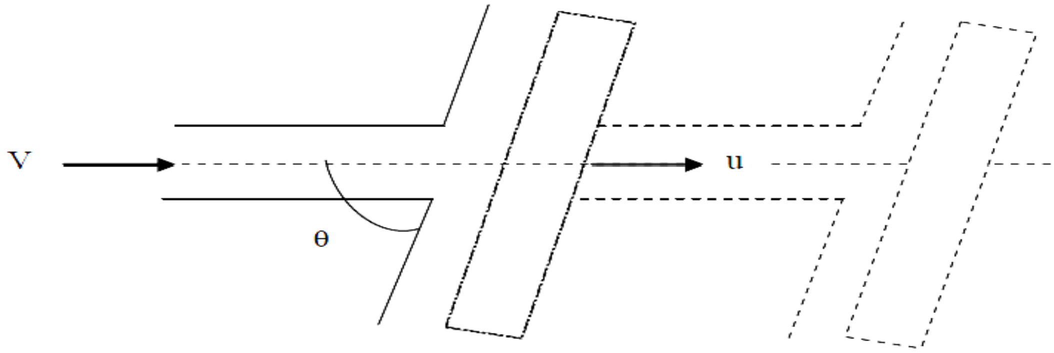
(alongthedirectionoftheflow)and $F_{y=}$

$\rho av^2 \sin\theta \cos\theta$

(perpendiculartoflow)

7.1FORCEEXERTEDBY AJET ON AMOVING INCLINEDFLAT PLATE:

Consider,ajetofwaterstrikestheflatmovingplate movingwithauniform velocityaway fromthe jet.



v=Velocityofjet
u= velocityofflatplate
Relativevelocityofjetw.r.tplate=v-u

If the plate is smooth, it is assumed that the loss of energydue to impact of jet is zero, then the jet of water leaves the inclined plate with a velocity (V –u).

Force exerted by jet onthe inclined plate inthedirection normal to the jet

F_n= Mass of water striking/ sec x[Initial velocity - Final velocity]

$=\rho a(V-u)[(V-u)\sin\theta-0]$

$=\rho a(V-u)^2\sin\theta$

Thisnormalforcecanberesolvedintotwocomponents one in the direction of jet and other perpendicular to the direction of jet

ComponentofFninthedirection ofjet.
$F_x=\rho a(V-u)^2\sin^2\theta$

Component ofFn inthe directionperpendicular to the direction of jet

F_y=ρa(V-u)^{2}sinθcosθ

Workdonebythejet ontheflatmoving plate

=ForcexDistanceinthedirectionofforce/ Time

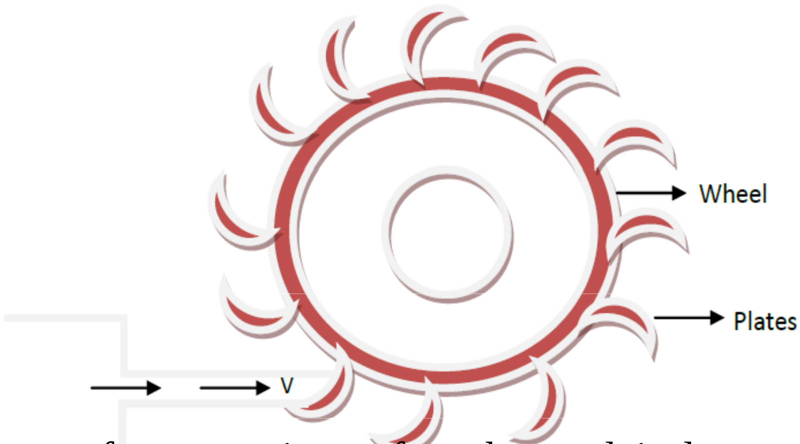
=ρa(V-u)^{2}sin^{2}θxu

7.2FORCEEXERTEDBYTHEJETOFWATERON SERIES OF VANES

Let,

v=Velocityofjet

a=areaofx-sectionofjet. u = velocity of vane



Inthis,massofwatercomingoutfromthenozzleisalways in constantwith plate. When all plates are considered.

Massof water striking/s w.r.t plate=ρav

Jetstrikestheplatewithavelocity=V–u

f

Forceexertedbythe jetontheplateinthedirectionofmotionof plate=Mass/secx(Initialvelocity-Finalvelocity)

Work done bythe jet ontheseries of bladepersecond= force x dist. Per second in the direction of force

$=F_x xu= \rho aV(V-u)xu$

Kineticenergyofjetpersecond=½mV^2

$$= \frac{1}{2} \rho aV x V^2$$

=½ρaV^3Efficiency, $\eta = \frac{Work\ done\ by\ jet/s}{K.E\ by\ jet/s}$

$$= \frac{\rho aV\ (V - u)\ x\ u}{\frac{1}{2}\ (\rho aV)V^2}$$

$$\eta = \frac{2\ u\ (V - u)}{V^2}$$

Conditionformaximum efficiency, $\frac{d\eta}{du} = 0$

$$= \frac{d}{du}\left[\frac{2\ u\ (V - u)}{V^2}\right] = 0$$

$$= \frac{d}{du}\left[\frac{2\ uV\ - 2U^2)}{V^2}\right] = 0$$

$$= \left[\frac{2\ V\ - 4u)}{V^2}\right] = 0$$

$$u = \frac{V}{2}$$

Putthe valuesofu in $\eta = \frac{2u(V-u)}{V^2}$

7.3IMPACTOFJET ONMOVINGCURVEDVANES

Considerajet of waterenteringandleavingamovingcurved vane as shown in fig.4

$$\eta_{max} = \frac{2\frac{V}{2}(V-\frac{V}{2})}{V^2}$$

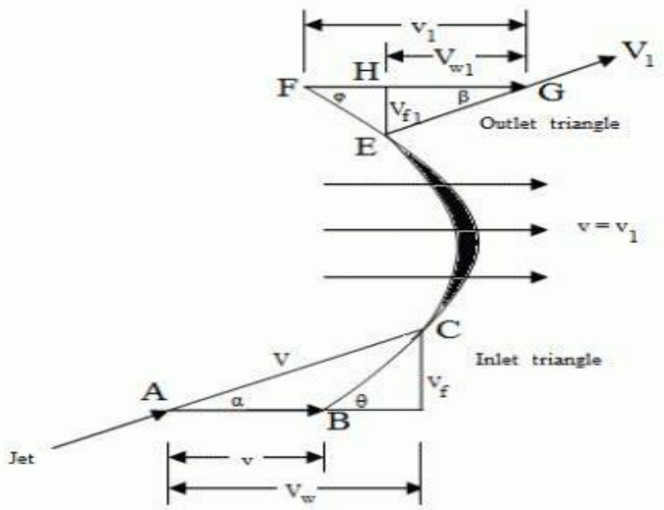


Fig-4 : Jet impinging on a moving curved vane

Let,•V=Velocityofthejet(AC),while entering the vane,

• V_1=Velocityofthejet(EG),whileleavingthe vane,

• U_1,U_2=Velocityofthevane(AB,FG)

• α=Angle withthe direction of motion of thevane, at which the jet enters the vane,

• β =Anglewith thedirection of motion of thevane, at whichthe jet leaves the vane,

• V_r=Relative velocityof the jet and the vane (BC) at entrance (it is the vertical difference between V and U_1)

- V_{r1}= Relative velocity of thejetand the vane (EF) at exit (it is the vertical difference between $V_1$and U_1)
- Ѳ =Angle, which Vrmakes with the direction ofmotion of the vane at inlet (known as vane angle at inlet),
- β =Angle, which V_{r1}makes with the direction of motionof the vane at outlet (known as vane angle at outlet)
- V_w= Horizontal component of V (AD, equal to). It is a component paralleltothe directionof motionof the vane (known as velocity of whirl at inlet),
- V_{w1}= Horizontalcomponent ofV1 (HG, equalto).It isa component parallel to the direction of motion of the vane (known as velocity of whirl at outlet),
- Vf=Verticalcomponent ofV (DC, equalto).Itis acomponent at right angles to the direction of motion of the vane (known as velocity of flow at inlet),
- V_{f1}= Vertical component of V1 (EH, equal to). It is a component at right angles tothe direction of motionof the vane (known as velocity of flow at outlet),
- a = Cross sectional area of the jet. As the jet of water enters and leavesthe vanestangentially,therefore shapeofthe vanes will be such that $V_r$and V_{r1}will be a long with tangents to the vanes at inlet and outlet.

Therelationsbetweentheinlet andoutlettriangles (untiland unless given) are: (i) $V=V_1$, and (ii) $V_r=V_{r1}$ we know that the force of jet, in the direction of motion of the vane,

F_x=massofwater striking persecond xchange in whirl velocity

$=\rho a(V-u)X[(V-u)–(-(V-u)COS\theta)]$

$=\rho a(V-u)x[(V-u)+(V-u)COS\theta)]$

$=\rho a(V-u)^2x[1+COS\theta]$

Workdonebythejetinthedirectionofjet=

=$F_x$xdistancetravelledpersecondinthe direction ofx

=ρa$(V\text{-}u)^2$x[1+COS θ]XU

=ρa$(V\text{-}u)^2$xUX[1+COSθ]

PROBLEM

A jet of water of diameter 7.5 m strikes a curved plate at its centrewith avelocityof20m/s.thecurvedplate ismovingwitha velocity of 8 m/s in the direction of the jet. The jet is deflected throughanangleof165˚.Assumingtheplatesmoothfind:

(1)Forcethroughontheplateinthedirectionofjet,
(2)Powerofthejet,and
(3)Efficiency of the jet

solution

Given data

Diameter of the jet, d = 7.5 cm = 0.075 m

Area, a = $A = \pi r^2$= 0.004417 m^2

Velocity of jet, v = 20 m/s

Velocityof plate,u=8m/s

Angleofdeflectionofthejet,=165˚

Anglemadeby therelative velocity at the outlet of the plate, θ= 15˚

1)Force exerted by the jet onthe plate inthe direction of jet,
F_x= ρ a $(V\text{-}u)^2$ x [1+ COS θ]
=1000x0.004417x$(20\text{-}8)^2$[1+cos15]
=1250.38N(ans)

Workdonebythejetinthedirectionofjet=$F_x$xu

=1250.38x8=10003.38Nm/s

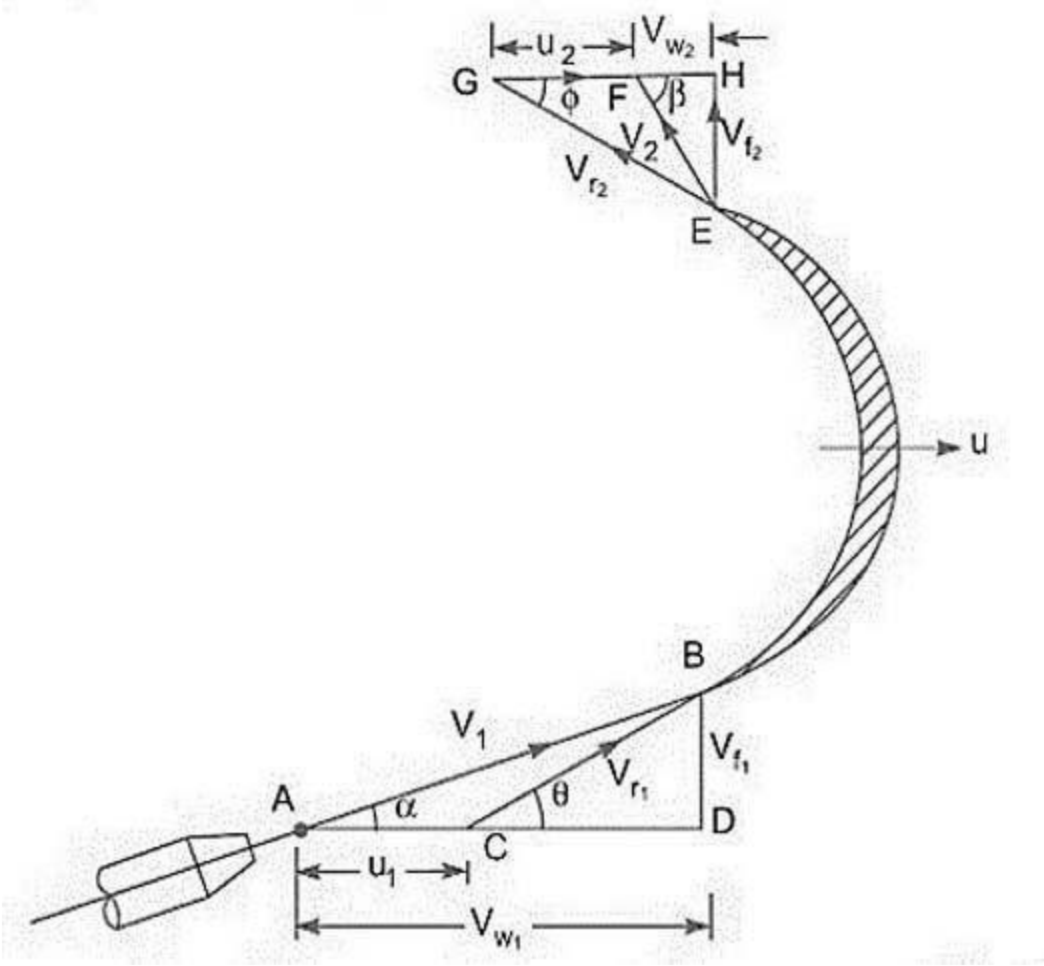
Powerofthejet=10003.38/1000=10kw(ans)

Efficiencyofthejet=output/input

= work done bythejet persecond/kinetic energyofjetper second

=56.4(ans)

Velocitytriangles,workdoneandefficiencyofmovingcurved plate



V1 = Velocity of the jet at inlet

u1=velocityofthevaneatinlet

Vr1=relativevelocityofthejetandplateatinlet α=anglebetweenthedirectionofthejetanddirectionofmotion of the plate (Guide blade angle) ϴ = angle made by the relative velocity with direction of motion at the inlet (Vane angle at inlet) Vw1 = velocityofwhirlatinlet(componentofV1inthedirectionofmotion)

Vf1=velocityofflowatinlet(componentofV1in thedirection perpendicular of motion)

Similarly,V2=Velocityofthejetatoutlet u2 =

velocity of the vane at outlet

Vr2=relativevelocityofthejetandplateatoutlet

β =anglebetweenthedirection ofthejetanddirection ofmotion of theplate (Guidebladeangle)Φ=anglemadebytherelative velocity with direction of motion at the outlet (Vane angle at outlet) Vw2 = velocity of whirl at outlet (component of V2 in the direction of motion)

Vf2=velocityofflowatoutlet(componentofV2in thedirection perpendicular of motion)

InletvelocityTriangle:AC=V1,

AB=u1, BC=Vr1,AD=Vw1, BD=Vf1

Outletvelocitytriangle:GF =V2,EF =u2,EG=Vr2, FH =Vw2, GH = Vf2

Aswaterglidessmoothly,thereforeneglectingfrictionbetweenvane and water Vr1= Vr2 Also tip velocity at inlet and outlet are same.

u1=u2

Forceexertedbythejetin thedirectionofmotion=massofwater strikingpersecX(initialvelocitywith whichjetstrikes thewaterin the dir. Of jet – final velocity in Direction of jet)

$F=\rho a V r_1[(Vw_1-u_1)-(-u_2+Vw_2)]$

$=\rho a V r_1[(Vw_1-u_1+u_2+Vw_2)]$ F

$=\rho a V r_1$ [Vw_1+Vw_2]

Ifβ=90˚,thenVw_2=0………. F=

$\rho a V r_1$ [Vw_2]

Ifβ>90˚thenVw_2=………. F=

$\rho a V r_1$ [Vw_1 -Vw_2]

Ingeneral,

F=ρaVr1[Vw1±Vw2]

WorkDone:Workdonepersecbythejet=ForceXDistanceper sec

W.D.=FX$distancetime$=F=ρaVr1[Vw1±Vw2]Xu

Work Done:

Workdonepersecperunitweightof strikingpersec=ForceX Distance per sec / weight of water stinking per sec

$=1/g[[Vw_1 \pm Vw_2]xu$Nm/N

Efficiency:Itisaratioofworkdonepersecto initialK.E.ofWork done per sec per unit weight of striking per sec of jet

$=\rho a V r_1[Vw_1 \pm Vw_2]X\ u/(1/2\rho a V_1 x V^2)$ $_1$

IMPORTANTQUESTIONS

Shortquestion

1.Whatdoyoumeanbyimpactofjet?

Ans -The liquidcomes out in the form of a jet from the outlet of thenozzle fittedinthe outlet ofthe pipe through whichthe liquid is flowing under pressure. ifsome plate, whichmaybe fixed or moving is placed in the path of the jet, a force is exerted by the jet on the plate. This force exerted by the jet on the plate is called impact of jet.

Longquestions

1. Deriveanexpressionofforce exertedbyajetonstationarycurved plate? 2018(s)

2. A jet of water of diameter 7.5cm strikes a velocity of 20m/s. The curvedplateismovingwithavelocity of8m/sinthedirectionofjet. The jet is deflected through an angle of 165·. Assuming the plate is smooth and find-

(i)forceexertedonplanetinthedirectionofjet.

(ii) powerof jet

(iii) efficiencyofjet2018(s)

3. Water is flowing through a pipe at the end of which a nozzle is fitted. The diameter of nozzle is 120mm and head of water at the centreofnozzleis 90m.findtheforceexertedbythejetofwateron a fixed vertical plate. Take a coefficient of velocity is given as 0.95? 2019(s)