Open channel flow

Definition:

It is the flow of a liquid in a conduit with the free surface (the surface is exposed to the atmosphere) , the conduit can have any cross-section shape, but the fluid must be a liquid to provide the free surface. Fig.1 shows open channel flow that can be produced in two ways, the channel that is open to the atmosphere over its entire length to produce a free surface. The conduit can also be closed along its length but open to the atmosphere at both ends and not running.

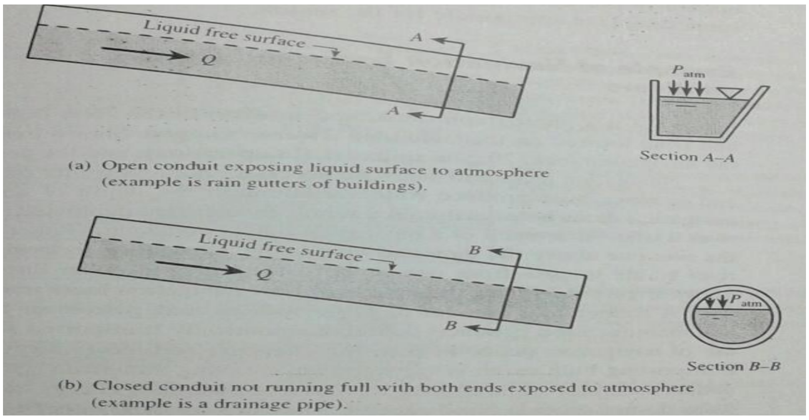


Fig.1

Real world examples of open flow systems abound including those found in nature as well as those made artificially. Systems found in nature include rivers, creeks, and small streams. Examples of artificially made systems are canals, dam spillways, irrigation ditches, storm sewers, and rain gutters for buildings and roadsides. Factory applications include open channel used to carry cooling heating cleaning and mixing liquids for a variety of manufacturing and chemical processes.

Fig.2 (Manmade channel)

Table 1 .Differences between flow in open and closed conduit:

aspects	Open channel	pipe
Cause of flow	Gravity force (by bed slope)	The pipe must run full and the flow in general take place @ the expense of hydraulic pressure
Geometry (cross sec.)	May have any cross sec.shape: 	Pipes generally round in cross sec.
Surface roughness	Varies between wide limits (it varies with depth of flow)	Roughness coefficient varies from a low value to a very high
Piezometric head	(z+y),y is the depth of flow,H.G.L coincide with the water surface.	$Z+p/\gamma$.p is the pressure in the pipe ,H.G.L does not coincide with the water surface.
velocity	The max. velocity occurs @ a little distance below the water surface.	The velocity distribution is symmetrical about the pipe axis. Max. velocity occurring @ the pipe center and the velocity @ the pipe wall reducing to zero.

Types of channels:

1-Natural channels: rivers, streams.

2-Artificial channels: rectangular, trapezoidal.

3-Open channels (without cover): irrigation canals, rivers.

4-Coverd channels: partially filled conduits.

5-Prismatic channels: constant bed slope, same cross-section.

Fig.3 Closed conduits

Types of flow:

1-Steady & unsteady flow:

When the depth, velocity and flow rate do not change with time the flow is steady, otherwise it is unsteady.

2-Uniform & non uniform:

If depth, slope, cross section and velocity areconstant over a given length of thechannel the flow is uniform, if not the flow is non-uniform.

3-Laminer & turbulent flow:

It depends on Reynolds no. ملاحظة: رقم رينولدز هنا يختلف عن الجريان في الانابيب

Re < 500 Laminar

Re > 2000 Turbulent

500 < Re <2000 Transitional

4-Subcritical, critical, supercritical:

It depends on Froude no.:

Froude no.=$\frac{V}{\sqrt{2gD}}$ V: velocity, D: hydraulic depth.

Fr < 1 subcritical

Fr =1 critical

Fr >1 supercritical

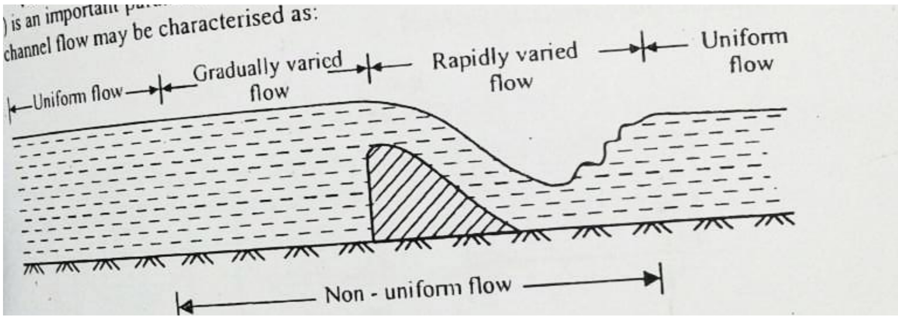


Fig. 4 Uniform and non-uniform flow

Definitions:

1-Depth of flow (y): It is the vertical distance of the lowest point of the channel section from the free surface.

2-Depth of section : It is the depth of flow normal to the bed of the channel.

Where ϴ = the angle of slope

D= y cos ϴ

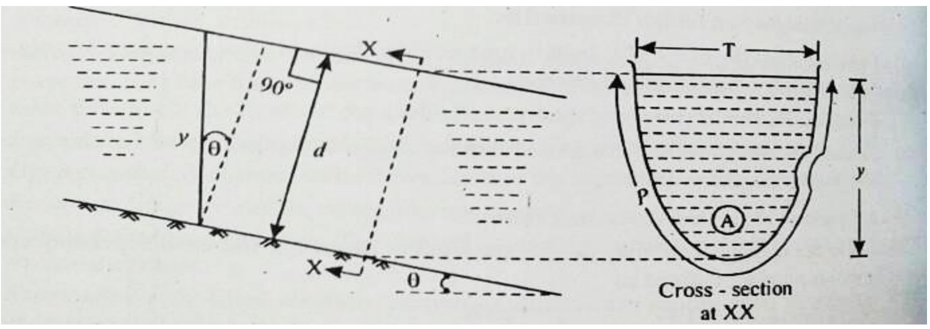


Fig. 5 Terms related to flow in open channel

3- Top width (T):It is the width of the channel section at the free surface.

4-Wetted area (A): The cross-section area of theflow section of the channel.

5-Wetted perimeter P :The length of the channel boundary in contact with water.

6-Hydraulis radius R: The ratio of the cross-section area to the wetted perimeter (R=A/P).

For rectangular section:

$R = \frac{A}{P} = \frac{b*y}{b+2y}$

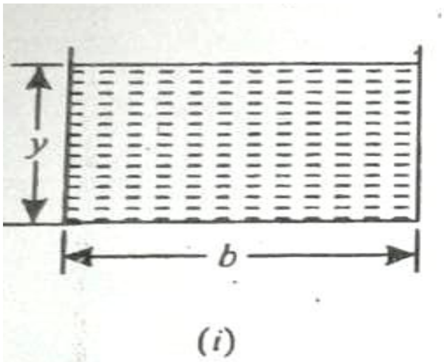
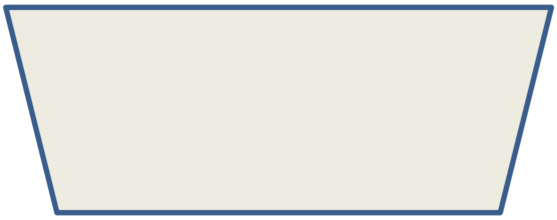


Fig.6

For trapezoidal section:



Area= Y(B+ZY)

P= B+ 2 Y $\sqrt{Z^2 + 1}$

Open channel formula for uniform flow:

1- Chezy's formula (Antoine Chezy 1775):

$Q = A\,C\sqrt{R\,S}$

Q : rate of flow

A: cross section area

C: Chezys constant

R: Hydraulic radius

S: slope of channel bed.

$C = \frac{157.6}{181\frac{k}{\sqrt{R}}}$

Table.2

Surface kind	K
Smooth cement	0.11
brick, concrete, wood	0.21
Earth channels in very good condition	1.54
Earth channel in rough condition	3.17

2- Manning's formula (Rober Manning 1889):

$Q = \frac{1}{n} R^{2/3} A \sqrt{S}$

From which: n constant of Manning's formula

		rectangular	trapezoidal
Mannings: $Q = \frac{1}{n} R^{2/3} A \sqrt{S}$	Area (A)	$b * y$	Y(zy+b)
Chezys: $Q = A\,C\sqrt{R\,S}$	Wetted perimeter (P)	$b + 2y$	$2y\sqrt{z^2+1} + b$

Examples:

Ex. 1

Find the flow for a rectangular channel, 7.5m wide for uniform at a depth of 2.25 m. The channel have a bed slope of 1 in 1000? (c=55).

A= b * y =7.5*2.25=16.875 m^2

P= b+2y = 7.5 + 2 * 2.25 =12 m

R= A/P= 1.406 m

$V=c\sqrt{R\,S} = 55\sqrt{1.406 * \frac{1}{1000}} = 2.06$ m/s

Q= A V =16.875 * 2.06= 34.76 m^3/s

<u>Non-uniform flow:</u>

1-The change in width, depth and bed slope.

2-An obstruction, constructed across the channel.

Specific energy and specific energy curve:

The total energy per unit weight of liquid is:

Total energy= $Z+Y+\frac{V^2}{2g}$

Z: elevation of the channel

Y: depth of flow.

V: average velocity.

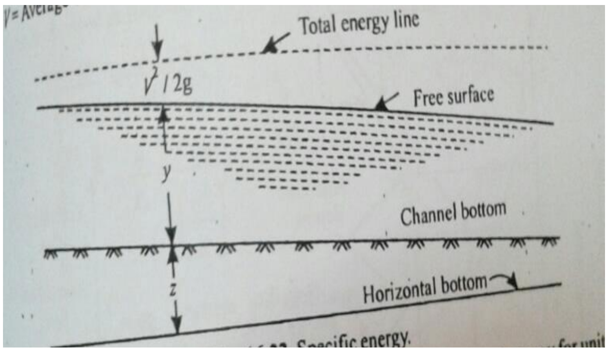


Fig.7

Critical depth:

$Y_c = (\frac{q^2}{g})^{1/3}$

Critical velocity:

$V = \frac{Q}{A} = \frac{Q}{b.d} = \frac{q}{y}$ (b=1 , per unit width)

$V = \sqrt{g\, y_c}$

Minimum specific energy in terms of critical depth:

$E = y_c + \frac{q^2}{2gy_c^{\,2}}$ so $y_c = \frac{2}{3} E_{nim}$

Critical flow:

$Fr = \frac{V_c}{\sqrt{gy_c}} = 1$ (critical flow at Fr= 1)

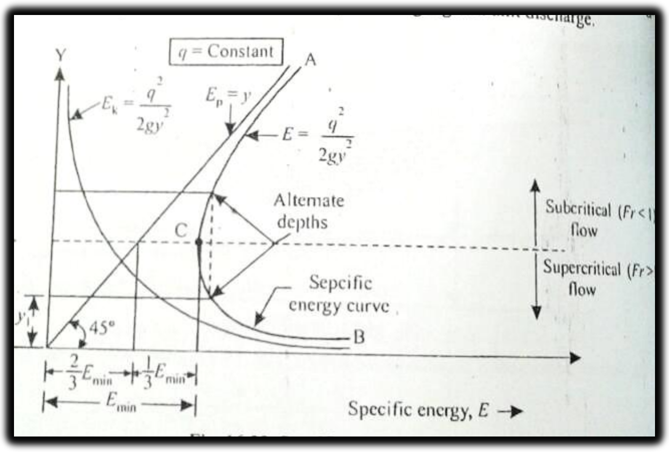


Fig.8 Specific energy curve

Ex.2

A 8 m wide channel conveys 15 m^3/s of water at a depth of 1.2 m. Calculate:

1- Specific energy of the flow.

2- Critical depth, critical velocity, and min. specific energy.

3- Froude number.

Av. Velocity $= \frac{Q}{b\,y} = \frac{15}{8*1.2}$ =1.562 m/s

q= $\frac{Q}{b} = \frac{15}{8}$ =1.875 m^3/s per m

E =y+ $\frac{v^2}{2g}$ = 1.324 m

$Y_c = (\frac{q^2}{g})^{1/3}$ = 0.71 m

$V_c = \sqrt{g\,y_c}$ = 2.64 m/s

$E_{min} = \frac{3}{2} y_c$ =1.065 m

Fr = $\frac{v}{\sqrt{gy}}$ = 0.455 < 1 *subcritical*

Additional example:

A trapezoidal channel lined with concrete, n=0.013, the width=10 m, side slope=1:1, the depth=5m, and channel bed slope = 4 / 1000, find discharge?