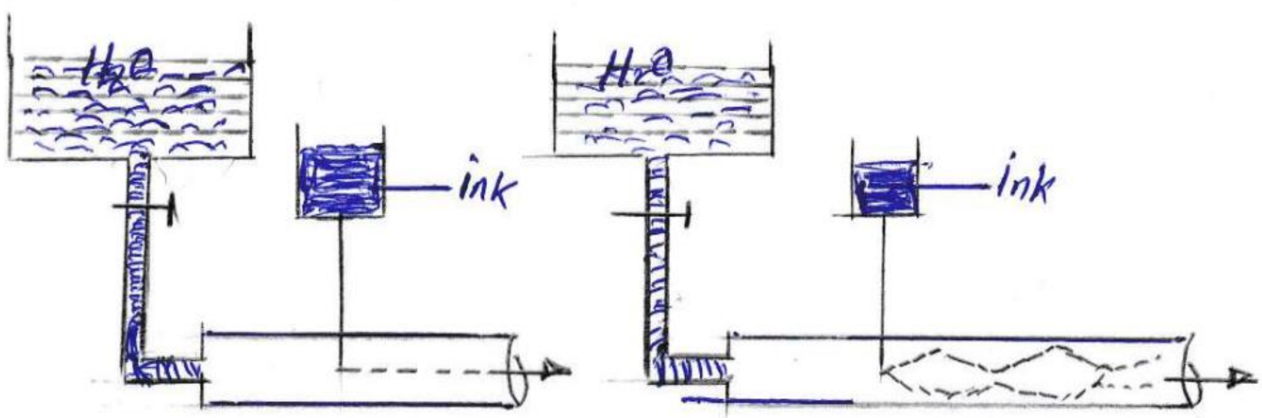
Flow In Real Fluid

4.1 The laminar and Turbulent Flow:

The nature of the fluid flow in pipes depends on the fluid velocity, its physical properties and pipe diameter. So with small velocity we get a very smooth flow, i.e the fluid moves softly layer by layer with interface between them, this called (laminar flow) or (streamline flow). But if the velocity increases eddies will form in the flowing fluid which leads to formation of turbulent stat, this called (Turbulent Flow).

These two types of flow can be seen from Reynolds Number experiment as in the figure below:-



Ink filament remain at the exis of the tube including that the flow is streamline

With increasing the flow a condition was reached at which the filament was broken in to addies causing dispersion across the tube section. This called Turbulent flow.

* The transition velocity between these two types of flow called transition or critical velocity.

It became clear from the experiment that the change in the flow pattern depends on dimensionless group called Reynolds Number (Re):-

$$Re = \rho du/\mu$$

Where ρ = fluid density kg/m^3 dimension is $M L^{-3}$

d = pipe diameter m dimension is L

u = fluid velocity m/s dimension $L T^{-1}$

μ = fluid viscosity kg/m.s dimension $ML^{-1}T^{-1}$ or poise (g/cm.s)

so if the value of (Re) less than (2100) the flow is Laminar, and if the value of (Re) more than (4000) the flow is Turbulent. And the region in between is transition state between Laminar and Turbulent' The Turbulent flow is the most important in petroleum industries.

4.2 Physical Bases of Reynolds Number

If amount of water flowing in a pipe with velocity (u), under two types of forces, first is to keep it continuing flowing which called (inertia forces) which measured on baser of change of inertia and it is directly proportional to (pu^2). And the second force is the shear stress force which increase with increasing velocity as:-

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

Also called viscous forces which directly proportional with (μu/d). It clear that the ratio of intra forces to viscous forces gives Reynold's number as :-

$$\rho u^2/(\mu u/d) = \rho du/\mu = Re.$$

So if the value of inertia forces increases with respect to viscous force, the flow will be close to turbulent state and vice versa.

4.3 Flow In Pipes

اثناء حركة المائع الحقيقي خلال الانابيب سوف يفقد جزء من طاقته بسبب الاحتكاك بين المائع وجدار الانبوب على طول الانبوب وتسمى h_f وكذلك يفقد جزء اخر من طاقته في مناطق معينه اعتمادا على تغير

شكل مقطع الانبوب وتسمى h_L هذه الخسائر تجمع وتضاف في نهاية معادلة برنولي للاخذ بنظر الاعتبار كل الخسائر الناتجه على طول الانبوب

4.3.1 Types of losses :- losses are appeared along the cross section of flow because of the friction between the fluid and the wall of pipe or because of the shape of pipe. there are two types of losses along flow through pipes:-

1- Friction Losses h_f (Major Losses)

In a real pipe line there are energy losses due to friction- these must be taken into account as they can be very significant. The effect of the friction shows itself as a pressure (or head) loss.

Pressure Drop And Friction Factor of Newtonian Fluids:

The fluid moves in any pipe due to pressure, and if we measure the pressure along the pipe, we will find a decreasing in fluid pressure along the pipe as we go far from the pressure source, this because of fluid. If we assume the pipe length is (L) and the fluid entered with pressure (P1) and leave with (P2) so the decreasing in pressure equal the difference between P1 and P2. i.e

$$-\Delta P = P_1 - P_2 \ldots\ldots\ldots\ldots 1$$

Where $-\Delta P$ = pressure drop due to friction. And the -ve sign indicate that the pressure decreases in the direction of the flow.

And if we take a vert small length of the pipe (dl), diameter (d), so the friction force which equal to shear stress (τ) times the surface area of the pipe ($\pi d\ dl$) cause a reduction in the pressure ($-dP_f$).

Assuming: Friction force = pressure drop

$$\tau\ (\pi d.\ Dl) = -dP_f\ (\pi d^2/4) \ldots\ldots\ldots\ldots 2$$

So,

$$-dP_f = 4\ \tau\ (dl/d) \ldots\ldots\ldots\ldots 3$$

We may introduce (Fanning Friction Factor) on equation (3) which used for Laminar and turbulent flow and defined by:

$$F = \tau/(1/2\rho u^2) \quad \ldots\ldots 4$$

Substitute the value of (τ) in equation (3) get:

$$-\ dP_f = 4f(dl/d)(\rho u^2/2) \quad \ldots\ldots 5$$

The energy lost due to friction is (L_f):

$$L_f = -\Delta P_f/\rho$$

Therefor:

$$L_f = 4\ f\ (l/d)(u^2/2) \quad \ldots\ldots 7$$

Also we can calculate the pressure drop in term of pressure head (h_f), as:

$$h_f = -\Delta P/\rho g = 4\ f\ (l/d)(u^2/2g) \quad \ldots\ldots 8$$

The relation between Reynolds number and friction factor:

Stanton and pannel were measured the pressure drop due to friction at (1919) for a number of fluids flowing in a pipes of different diameter and roughness. They found a relation between friction factor and Reynolds number. They used a new friction factor (ø) different than fanning friction factor.

$$\Phi = \tau / \rho u^2 \quad \ldots\ldots 9$$

From equations (4) and (9) get:

$$f = 2\,\phi \quad \ldots\ldots 10$$

As: f = fanning friction factor.

Φ = friction factor.

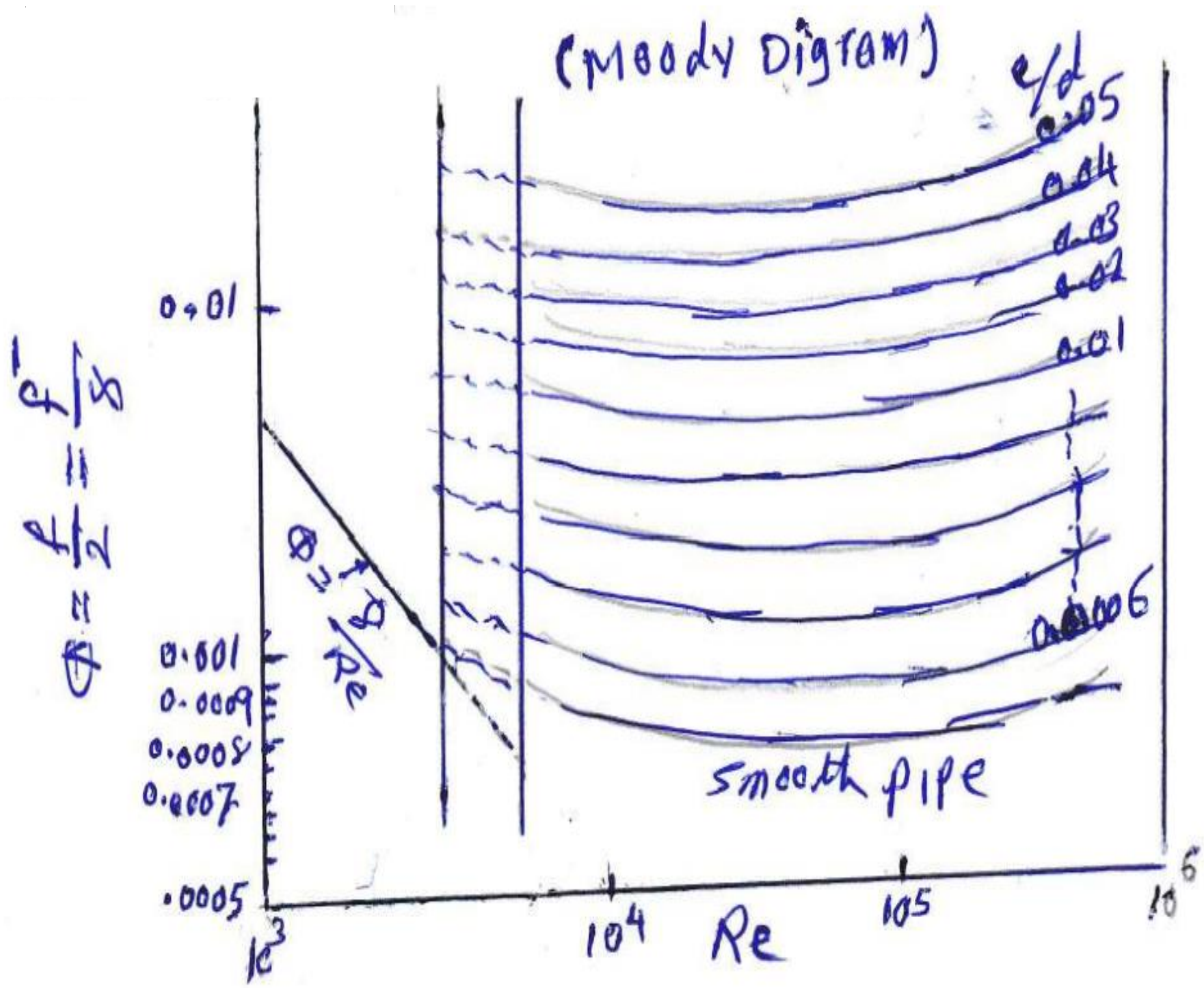
Before that a number of scientists did a number of experiments dealing with the flow of incompressible fluids in a smooth pipe, they got a single curve represent the relation between friction factor and Reynolds number (Re). This curve has three parts:- The first part represent the Laminar flow (Re< 2100). Followed by transition region and then Turbulent flow region (Re> 4000).

While Stanton and pannel results showed only one line for laminar flow for any pipe. This will tell us that friction factor (ø) does not effected by the roughness of the pipe surface when the flow is Laminar. But with Turbulent flow there is one line for each roughness.

In (1944) the scientist (Moody) developed a friction factor (f') equal to:

$$f' = 8\tau / \rho u^2 \quad \ldots\ldots 11$$

As a function of both (Re) and dimensionless group (e/d) which called relative roughness, as (e) represent the surface roughness in unit of length. See the figure:

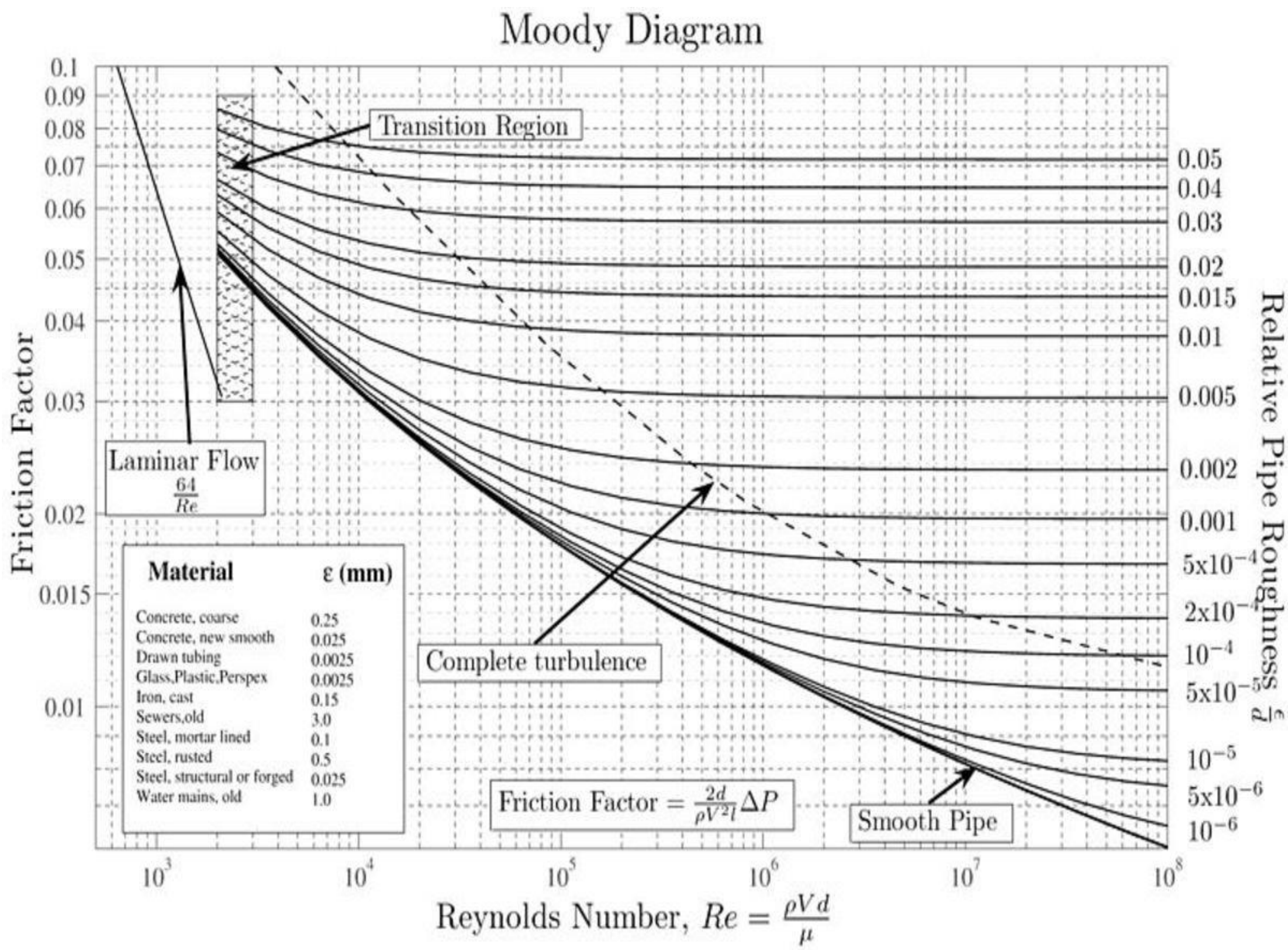


From the above figure we can see the region of Laminar flow represented by a straight line and equation:

$$\Phi = 8/Re \qquad \text{.......12}$$

OR: $$f = 16/Re \qquad \text{.......13}$$

Also we find in Turbulent region that the friction factor is a function of (Re) and relative roughness (e/d), but when (Re) exceed (10^5) the friction factor will be function of (e/d) only.



NOTE:

1- $f = 2\tau/\rho u^2$ and $\phi = \tau/\rho u^2$ and $f^{-} = 8\tau/\rho u^2$

Therefor: $f = 2\phi$ and $f^{-} = 8\phi$ and $f = f^{-}/4 = 8\phi/4 = 2\phi$

2- In case of Laminar flow (Re<2000) :

$\Phi = 8/Re$ and $f = 16/Re$

And in case of Turbulent flow (Re >4000)

$\Phi = 0.0396/Re^{0.25}$ OR

The following table shows the values of roughness (e) for pipes of different made:

Type of pipe metal	e (mm) roughness
Drawn tubing	o.oo15
Steel pipe	0.000046
Calvinized iron	0.152
Cast iron	0.260
Wood	0.18 – 0.91
Concrete	0.3 – 3.0

There are a number of correlations used to calculate (ϕ) as a function of (Re) such as:

a- If the pipe is smooth and (Re) between 2.5×10^3 and 10^5, the correlation is:

$$\Phi = 0.0369\, Re^{-0.25} \quad \text{..............................}14$$

b- If the pipe smooth and Re between 2.5×10^3 and 10^7:

$\Phi^{-0.5} = 2.5 \text{ Ln } (Re\ \phi^{0.5}) + 0.3$ 15

OR $1/\sqrt{\phi} = 2.5 \text{ Ln } (Re\ \phi^{0.5}) + 0.3$ 16

$\Phi^{-0.5} = -2.5 \text{ Ln}(0.27\ (e/d) + 0.885\ Re^{-1}\ \phi^{-0.5}$ 17

Example 1

Fluid flowing in steel pipe with velocity (4.57 m/s), if the inside pipe diameter is (51.5 mm) and viscosity (4.46×10^{-3} N.s/m^2) and density (801 kg/m^3. Calculate the friction lost (or may call it the lost in energy or pressure due to friction) in a part of the pipe length (35.6m).

Solution:

From equation (7) :

$$L_f = 4 f (L/d) (u^2/2)$$

الأفتراضات: المائع غير انضغاطي, نيوتوني, الأنبوب خشن لأنه لم يذكر عكس ذلك, خسائر الأحتكاك في مدخل ومخرج الأنبوب تهمل.

اذن أولا يجب حساب رقم رينولد لتحديد نوع الجريان:

$$Re = (\rho d u)/\mu$$

$$= [(801)(0.052)(4.57)]/4.46\times10^{-3} = 43100$$

So the flow is Turbulent. Now we need (e/d) the relative roughness, to find the value of friction factor (f). So from the table get the value of (e) roughness of steel pipe = 4.6×10^{-5}

Therefor: $e/d = 4.6\times10^{-5}/0.0525 = 8.8\times10^{-4}$

And from ((MOOdy Chart)) get $\phi = 0.003$

So: $f = 2\phi = 0.006$

Therefor: $L_f = 4 f (L/d)(u^2/2)$

$= 4 \times 0.006 \times (36.6/0.0525) \times (4.57^2/2)$

$= 174.7$ J/kg

Note: This example may be solved by using equation (16) directly without using (Moody Chart). By trial and error.

Example 2

If the difference between the liquid levels in two tanks (2.4 m) and pipe of (0.075m) diameter and (15 m) long used between them. What will be the volumetric flow rate of the fluid in the pipe. If fanning friction factor is (0.008) and liquid density = 700 kg/m^3 and dynamic viscosity 2.2x10^{-2}kg/m.s and the flow was laminar.

Solution:

From $\phi = 8/Re$ **(For Laminar flow)**

So: $Re = 8/0.004 = 2000$

So: $2000 = [(700)(0.075)(u)]/2.2\times10^{-2}$

$U = 0.839$ m/s

And $Q = u \times A$ **and** $A = \pi/4\, d^2 = 0.0044 m^2$

$Q = 0.0037\ m^3/s$

Also mass flow rate $G = Q \times \rho$ kg/s

Example 3

A horizontal pipe transfer acetic acid, diameter =75 mm, L =70 m. If the friction loss (L_f = 107.896 J/kg). calculate the type of flow and flow rate.
p = 1060 kg/m^3, μ =25 mNs/m^2 and f = 20x10^{-3}.

Solution:

From $L_f = 4 f(L/d)(u^2/2)$

$$107.896 = (4)(0.002)(70/0.075)(u^2/2)$$

$$U = 5.37 \text{ m/s}$$

$$Re = \rho du/\mu = [(1060)(0.075)(5.37)]/0.025 = 17076.6$$

Therefor the flow is Turbulent.

$Q = A \times U$ and $A = \pi/4\, d^2 = 0.0044 \text{ m}^2$

$$= (5.37)(0.0044) = 0.0236 \text{ m}^3/\text{s}$$

2- Local losses h_L (Minor Losses)

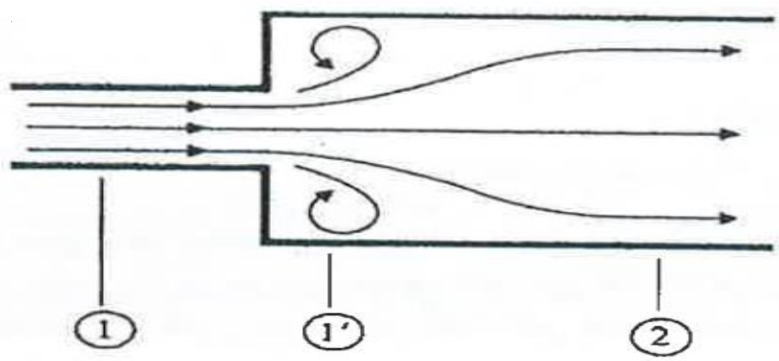
In practice pipes have fittings such as bends, junctions, valves etc. such features cause additional losses, termed local losses. Once again the approach to these losses is empirical, and it is found that the following is reasonably accurate:-

$$h_L = K_L \frac{v^2}{2g}$$

In which h_L is the local head loss and **K** is a constant for a particular fitting.

- **Sudden Enlargement**

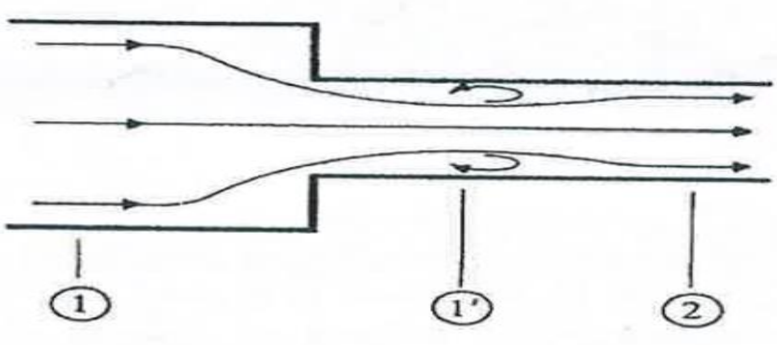
Sudden enlargements (such as a pipe existing to a tank) can be looked at theoretically:-



$$h_L = K_L \frac{(v_1^2 - v_2^2)}{2g}$$

- **Sudden Contraction**

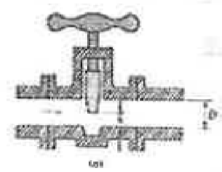
  We use the same approach as for sudden enlargement but need to incorporate the experimental information that the area of flow at point 1 is roughly 60% of that at point 2



$$h_L = K_L \frac{(v_2^2 - v_1^2)}{2g}$$

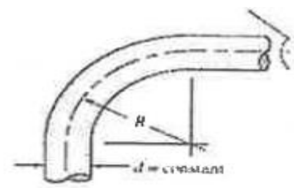
- **Valves**

$$h_L = K_V \frac{v^2}{2g}$$



- **Elbows (bend conduit)**

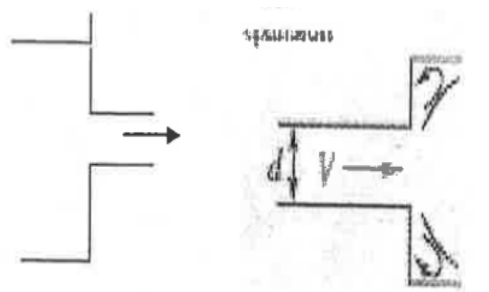
$$h_L = K_e \frac{v^2}{2g}$$



Entrance and Exist of Pipe

$$h_L = K \frac{v^2}{2g}$$

K = 0.5 entrance of pipe
K = 1.0 exit of pipe



الخسائر الموضعية تحدث في مواقع معينة حسب مقطع الجريان مثل وجود انحناء او صمام او مدخل انبوب او مخرجه او تقلص او تمدد في مقطع الجريان بوجود واحد او اكثر من هذه الانواع تحدث خسائر موقعيه تضاف الى الخسائر بسبب الاحتكاك التي تكون موجودة دائما على طول مقطع الجريان.

$$h_L = \sum K_L \frac{v^2}{2g}$$

Total losses = Friction loss + Local loss

$$H = h_f + h_L$$

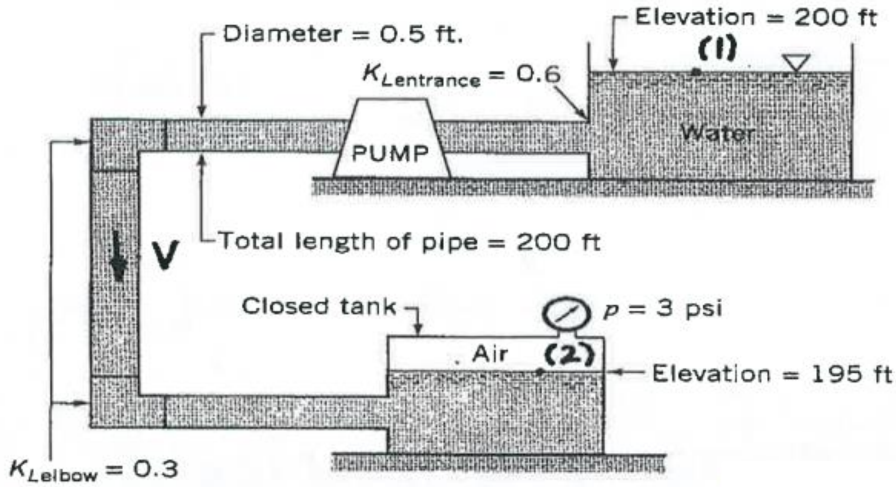
Then the new form of Bernoulli's equation result:-

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + Z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + Z_2 + h_f + h_L$$

هذه الخسائر سوف تضاف الى الطرف الثاني من معادلة برنولي لتحسب على طول مقطع الجريان بين اي نقطتين من الجريان خلال المقطع.

Example 4

The pump shown in fig below add a 15 ft head to water being pumped when the flow rate is 1.5 ft^3/s. determine the friction factor for the pipe.



For flow from the upper tank to the lower tank:

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1+h_p=\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+\left(f\frac{\ell}{D}+\Sigma K_L\right)\frac{V^2}{2g} \qquad (1)$$

where $p_1=0$, $V_1=0$, $z_1=200\text{ ft}$, $h_p=15\text{ ft}$, $z_2=195\text{ ft}$, $V_2=0\frac{ft}{s}$, and

$\Sigma K_L = K_{L_{ent}} + 2K_{L_{elbow}} + K_{L_{exit}} = 0.6+2(0.3)+1=2.2$ (see Fig. 8.25)

Thus, Eq. (1) becomes

$$200\text{ ft}+15\text{ ft}=\frac{(3\frac{lb}{in.^2})(144\frac{in.^2}{ft^2})}{62.4\frac{lb}{ft^3}}+195\text{ ft}+\left(f\frac{(200\text{ft})}{(0.5\text{ft})}+2.2\right)\frac{V^2}{2(32.2\frac{ft}{s^2})} \qquad (2)$$

but with

$$V=\frac{Q}{A}=\frac{1.5\frac{ft^3}{s}}{\frac{\pi}{4}(0.5\text{ft})^2}=7.64\frac{ft}{s}$$, Eq. (2) gives $f=\underline{\underline{0.0306}}$

Example 5

Water flows from the nozzle attached to the tank shown in fig. determine the flow rate if the loss coefficient for the nozzle is 0.75 and friction factor is 0.11.

$$\frac{p_1}{\gamma}+\frac{V_1^2}{2g}+z_1=\frac{p_2}{\gamma}+\frac{V_2^2}{2g}+z_2+\left(f\frac{\ell}{D}+K_L\right)\frac{V^2}{2g}, \text{ where } p_1=150\,kPa,\ p_2=0, \quad (1)$$

$z_1=0.8\,m$, $z_2=\ell\sin 40^\circ=(1.9\,m)\sin 40^\circ=1.22\,m$, $V_1=0$,

$V=\frac{Q}{A}$, and $V_2=\frac{Q}{A_2}=\left(\frac{A}{A_2}\right)V=\left(\frac{D}{D_2}\right)^2 V=\left(\frac{15\,mm}{7.5\,mm}\right)^2 V=4V$

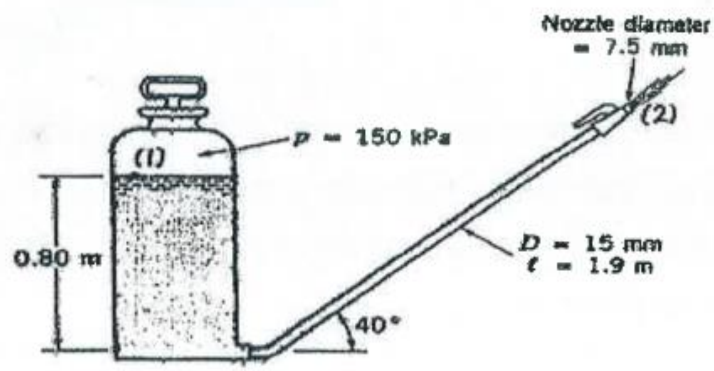
Thus, with $f=0.11$ and $K_L=0.75$ Eq.(1) gives

$$\frac{150\times10^3\frac{N}{m^2}}{9.80\times10^3\frac{N}{m^3}}+0.8\,m=1.22\,m+\left(4^2+0.11\left(\frac{1.9\,m}{0.015\,m}\right)+0.75\right)\frac{V^2}{2(9.81\frac{m}{s^2})}$$

or

$V=3.09\frac{m}{s}$

Thus, $Q=AV=\frac{\pi}{4}(0.015\,m)^2(3.09\frac{m}{s})=5.46\times10^{-4}\frac{m^3}{s}$



Example 6

When water flows from the tank shown in figure, determine the water velocity if the water depth in tank h=1.5 ft. the total length of 0.6 in diameter pipe is 20 ft, and the friction factor is 0.03. the loss coefficients are: 0.5 for entrance, 1.5 for each elbow and 10 for valve.

$$\frac{p_1}{\gamma} + z_1 + \frac{V_1^2}{2g} - h_L = \frac{p_2}{\gamma} + z_2 + \frac{V_2^2}{2g}$$

where

$p_1 = p_2 = 0$, $z_2 = 0$, $z_1 = 3\,ft + h$, $V_1 = 0$, $V_2 = V$ and

$h_L = \left(f\frac{l}{D} + \sum_i K_{L_i}\right)\frac{V^2}{2g}$ with $\sum_i K_{L_i} = 0.5 + 5(1.5) + 10 = 18$

Thus,

$$z_1 = h_L + \frac{V_2^2}{2g} = \left(f\frac{l}{D} + \sum K_{L_i} + 1\right)\frac{V^2}{2g}$$

Consider the flow when $h = 1.5\,ft$ so that $z_1 = 4.5\,ft$

Hence,

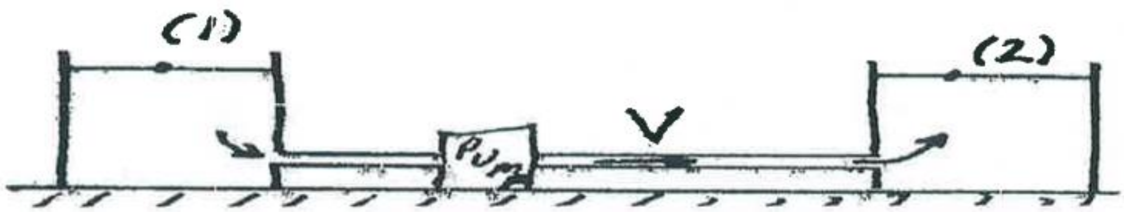
$$4.5\,ft = \left(0.03\,\frac{20\,ft}{\left(\frac{0.6}{12}ft\right)} + 18 + 1\right)\frac{V^2}{2\left(32.2\,\frac{ft}{s^2}\right)}$$

$V = 3.06\,\frac{ft}{s}$ so that $Q = AV = \frac{\pi}{4}\left(\frac{0.6}{12}ft\right)^2\left(3.06\,\frac{ft}{s}\right) = 0.00601\,\frac{ft^3}{s}$

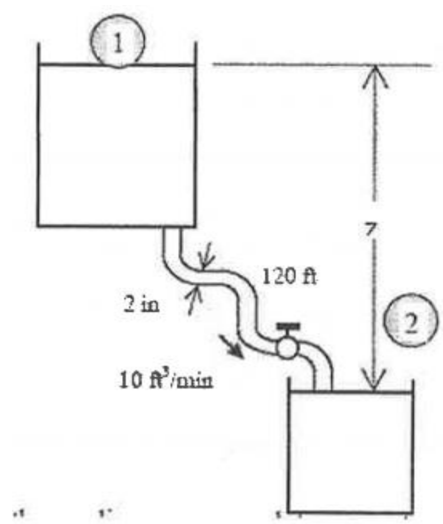
4.4 Problems

1- 2.27 m^3/h water at 320 K is pumped in a 40 mm internal diameter pipe through a length of 150 m in a horizontal direction and up through a vertical height of 10 m. in the pipe there is control valve which may be taken as equivalent to 200 pipe diameter. And also other pipe fittings equivalent to 50 pipe diameter. Also in the line a heat exchanger across which there is a loss in head of 1.5 m of water and 900 elbow. If the main pipe has a roughness of 0.2 mm what power must be supplied to the pump. If it is 60% efficient.

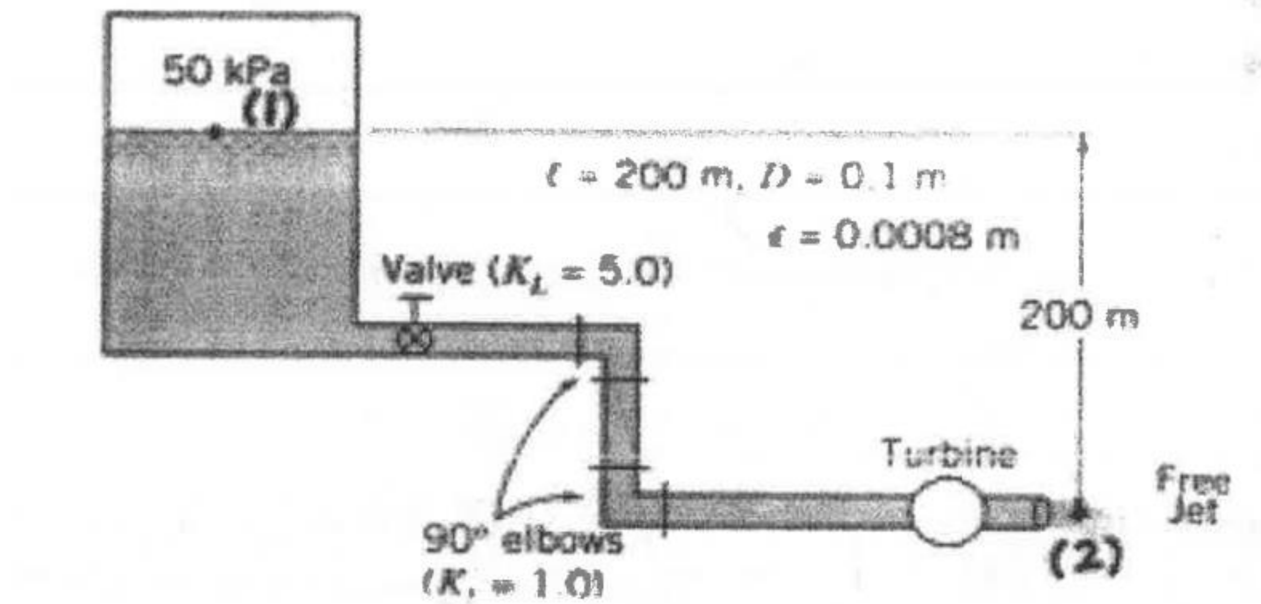
2- Water is pumped between two large open reservoirs through 1.5 km of smooth pipe. the water in two reservoirs are at the same elevation. When the pump add 20 kW to the water the flowrate is 1 m^3/s. if minor losses are negligible, determine the pipe diameter.



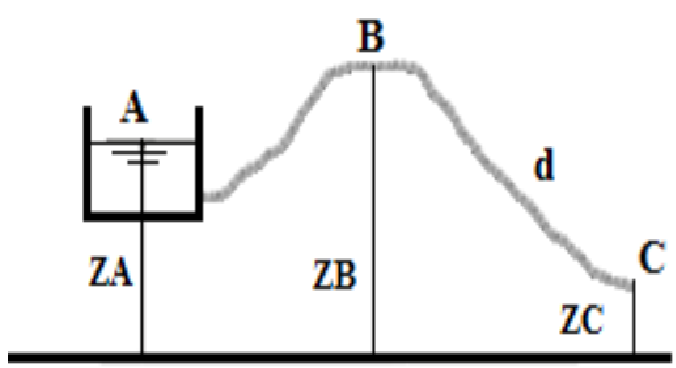
3- The flow rate through a pipe system of 120 ft long and 2 in diameter shown in fig is 10 ft^3/min. Determine the elevation Z if the losses coefficient for entrance is 0.03, elbow is 0.3, gate valve is 0.4 and exist is 1. The roughness of cast iron pipe Ɛ is 0.00085ft, *p*=62.30 lb/ft^3 and μ=1.307x10^{-3} lb/ft.s Ɛ =0.00085 ft.



1- Water drain from a tank through a pipe system as shown in fig. The head of turbine is equal to 116m. Determine the flowrate.



2- A pipe transmits water from a tank A to point C that is lower than water level in the tank by 4 m. The pipe is 100 mm diameter and 15 m long. The highest point on the pipe B is 1.5 m above water level in the tank and 5 m long from the tank. The friction factor (4 f) is 0.08, with sharp inlet and outlet to the pipe. a. Determine the velocity of water leaving the pipe at C? b. Calculate the pressure in the pipe at the point B?



3- Liquid oil relative density = 0.705, μ = 2 $N.s/m^2$, flowing in a pipe diameter (0.15 m) and length (2 km), with volumetric flow rate (0.02 m^3/s). If (e) is 0.0001. Calculate the pressure drop due to friction.

4- Liquid oil flowing in a smooth pipe its diameter is (0. 25 m) with velocity (3 m/s). If kinematic viscosity is ($5.568x10^{-6}$ m^2/s) calculate the friction loss in each kilometer of the pipe. Oil density is 750 kg/m^3.

A smooth pipe length is (50 m) transfer H_2SO_4 with mass flow rate (G =3 kg/s), u = 3.3 m/s. If pressure drop due to friction is782.2 KN/m^2. calculate the pipe diameter. p = 1840 $kg/m^3$and μ = 25 mNs/m^2.