FDE 205 FLUID MECHANICS

Pressure Drop and Friction Loss in Pipes

- The pressure drop in Laminar flow in a pipe can be calculated by Hagen-Poiseuille equation.

$$\Delta P = \frac{8\mu L Q}{\pi R^4}$$

$$\Delta P = \frac{32\mu L < v >}{D^2}$$

- The pressure drop in a pipe is caused by frictional losses in the pipe.
- The mechanical energy loss due to friction:

$$F_f = \frac{\Delta P}{\rho}(J/kg)$$

- Friction losses can also be determined by using friction factor(f).

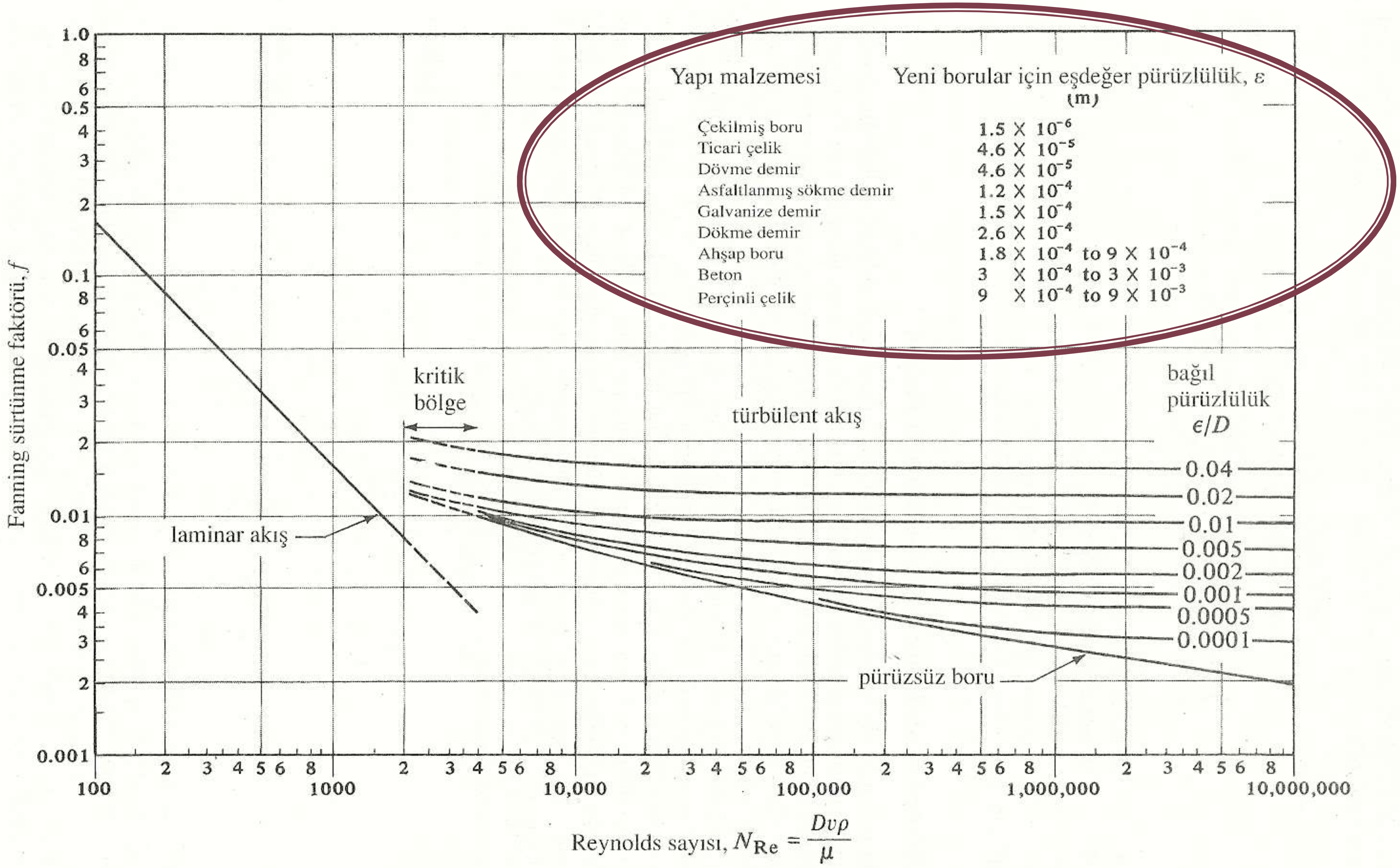
$$F_f = \frac{\Delta P}{\rho} = \frac{4 f \Delta L v^2}{2D}$$

- f: fanning friction factor
- L: length of pipe (m)
- v: velocity of fluid (m/s)
- D: diameter of pipe (m)

- If the flow is laminar:

$$f = \frac{16}{\mathrm{Re}}$$

- If the flow is turbulent f can be determined from the following figure (Figure 2.10-3)



Şekil 2.10-3. *Borular içinde akış için sürtünme faktörleri. [L. F. Moody, TrCvp. A.S.M.E., 66, 671 (1944): Mech. Eng. 69, 1005 (1947). İzin alınmıştır.]*

- In turbulent flow, fanning friction factor is dependent on material and diameter of the pipe.

- Each material has a specific surface roughness. It is represented by ϵ.

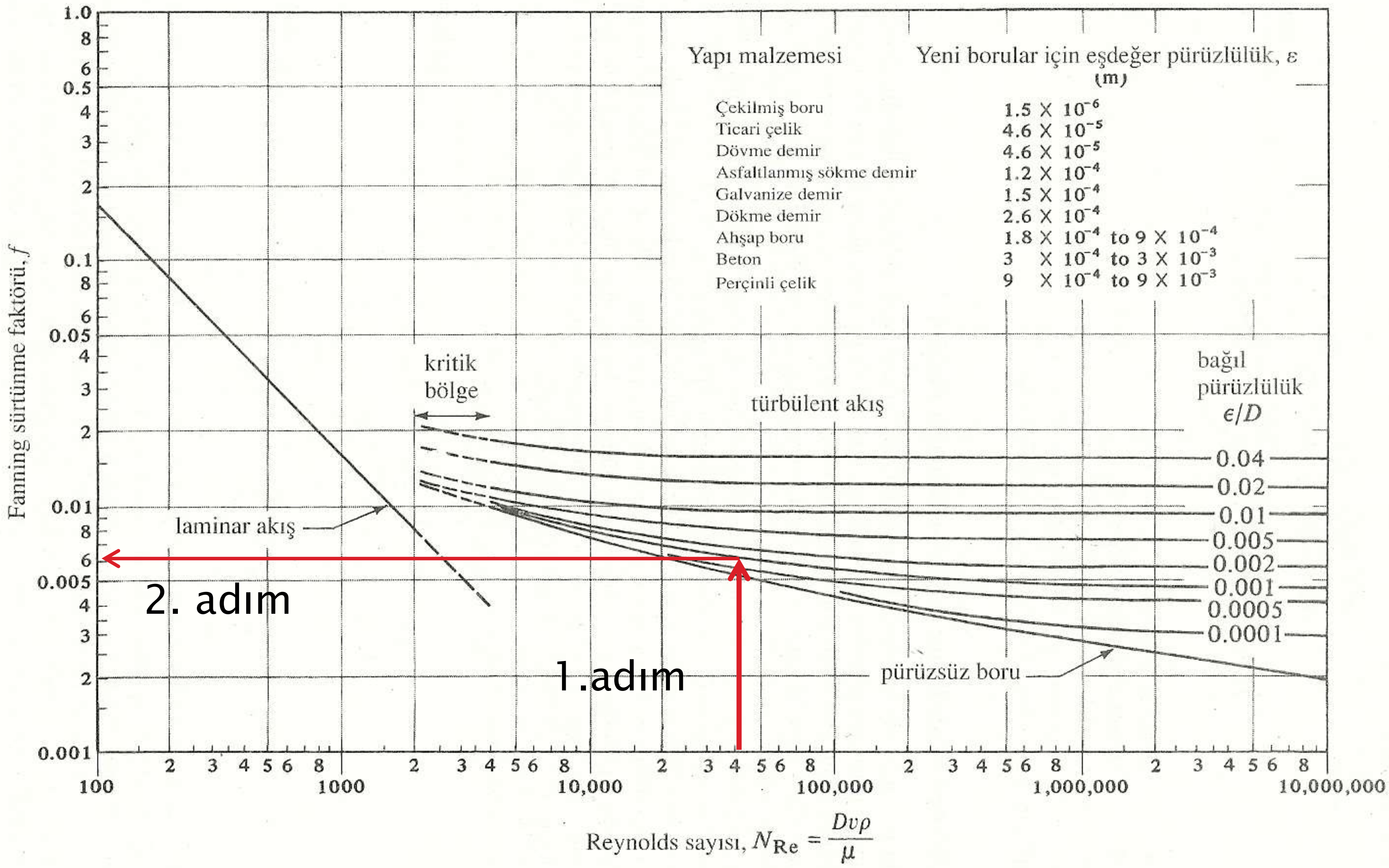
- In order to determine fanning friction factor in turbulent flow from figure:

1. First Re should be calculated.
2. The roughness value should be determined from the table on the figure.
3. ϵ/D (relative roughness) should be calculated .
4. The point where Re and ϵ/D value intersects would give fanning friction factor on y axis.

Example 2.10-3

- A liquid is flowing through a horizontal straight pipe at 4.57 m/s. The pipe used is commercial steel, schedule 40, 2-in. Nominal diameter. The viscosity of the liquid is 4.46 cp and the density 801kg/m^3 . Calculate the mechanical-energy friction loss F_f in J/kg for a 36.6-m section of pipe.

$$F_f = \frac{4 f \Delta L v^2}{2D}$$



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- If diameter (D), velocity (v) and length of pipe (ΔL)is known, then a direct solution is possible using the following equation.

$$F_f = \frac{4 f \Delta L v^2}{2D}$$

- However in some cases, the friction loss is given and volumetric flow rate and pipe length are also set , the unkown to be calculated is the diameter.

- In another case, with friction loss again being already set, the diameter and pipe lenght are specified. The velocity of the fluid can be asked to be calculated.

- These kinds of problems can be solved by trial and error method.

Example

- Water at 4.4 °C is to flow through a horizontal commercial steel pipe having a length of 305m at the rate of $9.46X10^{-3}$ m^3/s. If the friction loss of the system is 59.82 J/kg, calculate the diameter of the pipe?

Trial and error method:

1. First a diameter (D) is assumed.
2. Re is calculated and type of flow is determined (laminar or turbulent)
3. Fanning friction factor is calculated.
4. D is calculated from friction equation.
5. If the assumed D value and calculated D value are different, the same steps should be repeated by using calculated D value until the solution agrees closely with the assumed value.

Friction losses in Expansion, Contraction, and Pipe Fittings

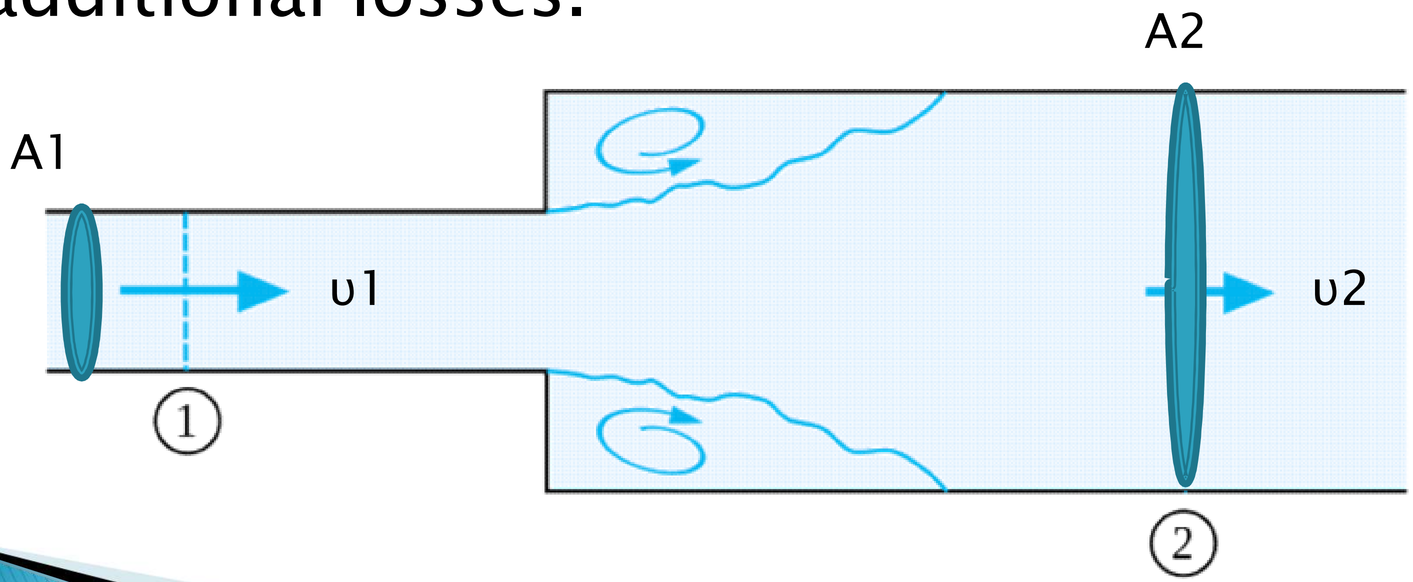
- The friction loss in straight pipe:

$$F_f = \frac{4f\Delta L v^2}{2D}$$

- This formula is valid only for straight pipe. However, if the velocity of the fluid is changed in direction or magnitude, additional frictional losses occur.

1) Sudden Enlargement Losses

- If the cross section of a pipe enlarges very gradually, very little or no extra losses are incurred.
- If the change is sudden, it results in additional losses.



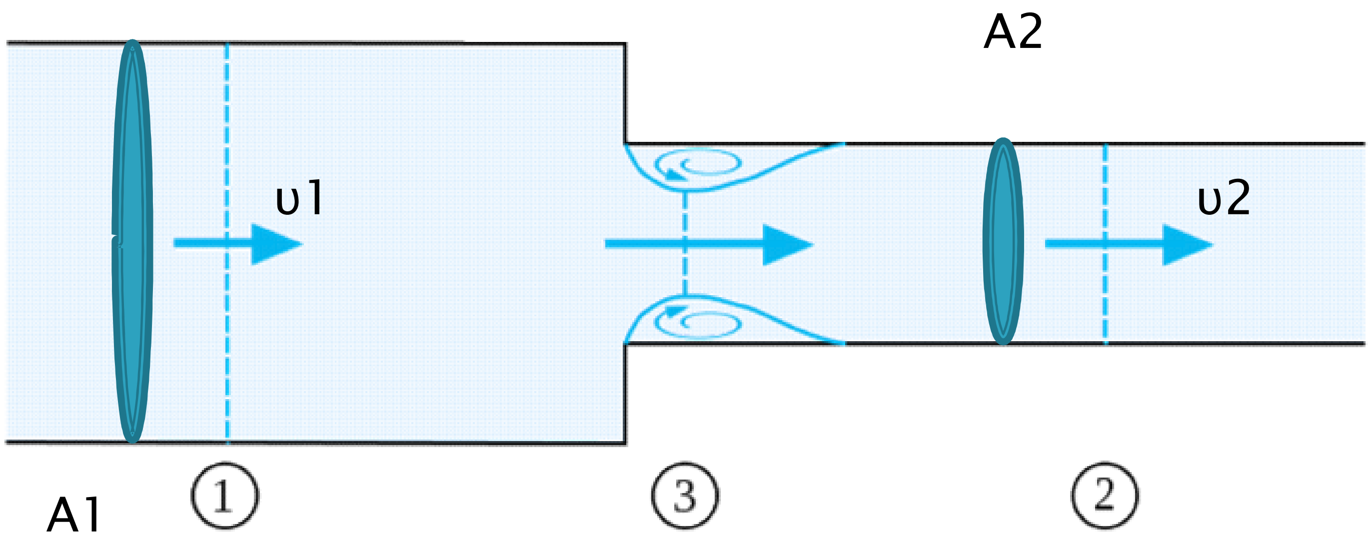
$$h_{ex} = K_{ex} \frac{\upsilon_1^2}{2\alpha}$$

$$K_{ex} = \left(1 - \frac{A_1}{A_2}\right)^2$$

- h_{ex} : friction loss in sudden enlargement (J/kg)
- K_{ex} : expansion loss coefficient
- υ_1 : velocity in the smaller area(m/s)
- α = ½ laminar
- α = 1 turbulent

2) Sudden Contraction Losses

- When the cross section of the pipe is suddenly reduced, the stream can not follow around the sharp corner, and additional frictional losses due to eddies occur.



$$h_c = K_c \frac{\upsilon_2^2}{2\alpha}$$

$$K_c = 0.55\left(1 - \frac{A_2}{A_1}\right)$$

- h_c : friction loss in sudden contraction (J/kg)
- K_c : contraction loss coefficient
- υ_2 : the velocity in the smaller section(m/s)
- α = ½ laminar
- α = 1 turbulent

3) Losses in fittings and valves

- A fitting is used in pipe and plumbing systems to connect straight pipe or tubing sections, to adapt to different sizes or shapes, and for other purposes, such as regulating or measuring fluid flow.
- Pipe fittings and valves also disturb the normal flow lines in a pipe and cause additional friction losses.

- Elbow (Dirsek): An elbow is a pipe fitting installed between two lengths of pipe or tubing to allow a change of direction, usually a 90° or 45° angle, though 22.5° elbows are also made.

90^o elbow

45^o elbow

- Tee (T- Bağlantısı): A tee is the most common pipe fitting. It is used to either combine or split a fluid flow.

- Return bend (Dönüş): Return bend is used to allow a change of directionby 180° angle

- Coupling (Kaplin–Manşon):
- A coupling connects two pipes to each other.

- Union (Rekor): A union is similar to a coupling, except it is designed to allow quick and convenient disconnection of pipes for maintenance or fixture replacement.

(Küçük çaplı boruların sökülebilir dişli elemanlarıdır. Çoğunlukla tesisat ve basıncın fazla olmadığı yerlerde kullanılır.)

Valves

- A valve is a device that regulates, directs or controls the flow of a fluid by opening, closing, or partially obstructing various passageways. Valves are technically pipe fittings, but are usually discussed as a separate category.
- In an open valve, fluid flows in a direction from higher pressure to lower pressure.
- Some valves are operated either fully open or fully closed.
- Some others can be operated at half open position.
- Different types of valves are present:
  - Sürgülü vanalar (Gate Valve),Glob Vanalar (Globe Valve), Çek Vanaları (Check Valve) vb.
- A proper valve has to be selected depending on the process and the product in food industry.

3) Losses in fittings and valves

$$h_f = K_f \frac{\upsilon_1^2}{2}$$

- h_f : friction loss in fittings and valves (J/kg)
- K_f : the loss factor for fittings or valves
- υ_1 : the average velocity in the pipe leading to the fitting (m/s)

- Experimental values for Kf are given in tables for turbulent and laminar flow.

- Table 2.10-1 : Friction loss for Turbulent flow through valves and fittings
- Table 2.10-2 : Friction loss for Laminar flow through valves and fittings

TABLE 2.10-1. *Friction Loss for Turbulent Flow Through Valves and Fittings*

Type of Fitting or Valve	*Frictional Loss, Number of Velocity Heads, K_f*	*Frictional Loss, Equivalent Length of Straight Pipe in Pipe Diameters, L_e/D*
Elbow, 45°	0.35	17
Elbow, 90°	0.75	35
Tee	1	50
Return bend	1.5	75
Coupling	0.04	2
Union	0.04	2
Gate valve		
Wide open	0.17	9
Half open	4.5	225
Globe valve		
Wide open	6.0	300
Half open	9.5	475
Angle valve, wide open	2.0	100
Check valve		
Ball	70.0	3500
Swing	2.0	100
Water meter, disk	7.0	350

Source: R. H. Perry and C. H. Chilton, *Chemical Engineers' Handbook*, 5th ed. New York: McGraw-Hill Book Company, 1973. With permission.

TABLE 2.10-2. *Friction Loss for Laminar Flow Through Valves and Fittings (K1)*

	Frictional Loss, Number of Velocity Heads, K_f Reynolds Number					
Type of Fitting or Valve	*50*	*100*	*200*	*400*	*1000*	*Turbulent*
Elbow, 90°	17	7	2.5	1.2	0.85	0.75
Tee	9	4.8	3.0	2.0	1.4	1.0
Globe valve	28	22	17	14	10	6.0
Check valve, swing	55	17	9	5.8	3.2	2.0

- All these frictional losses will be used in Mechanical energy Balance.

$$\frac{1}{2\alpha}\Delta v^2 + g\Delta z + \frac{\Delta P}{\rho} + \sum F + Ws = 0$$

$\sum F =$ Friction loss in straight pipe+
friction loss due to sudden enlargement+
friction loss due to sudden contraction+
friction loss due to fittings and valves

$$\sum F = \frac{4 f \Delta L v^2}{2D} + K_{ex} \frac{\upsilon_1^2}{2\alpha} + K_c \frac{\upsilon_2^2}{2\alpha} + K_f \frac{\upsilon_1^2}{2\alpha}$$

Homework: Example 2.10-6

Example 2.10-7

- Water at 20°C is being pumped from a tank to an elevated tank at the rate of $5X10^{-3}$ m^3/s. All of the piping given in the figure below is 4-in. Schedule 40 pipe. The pump has an efficiency of 65%. Calculate the kW power needed for the pump.