UNIVERSITY OF JOHANNESBURG

PROGRAM	: NATIONAL DIPLOMA ENGINEERING: MECHANICAL
SUBJECT	: HYDRAULIC MACHINES III
CODE	: MHM 301
DATE	: MAIN EXAMINATION 21 NOVEMBER 2019
DURATION	: 12:30 – 15:30
WEIGHT	: 60% OF SEMESTER MARK
TOTAL MARKS	: 100 MARKS

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Moderator : MR S. SIMELANE

INSTRUCTIONS:

1. PLEASE ANSWER ALL QUESTIONS NEATLY
2. SHOW ALL CALCULATIONS
3. ANSWERS WITHOUT UNITS WILL BE PENALIZED
4. NUMBER YOUR ANSWERS STRICTLY ACCORDING TO THE QUESTION

NUMBER OF PAGES : 10 (Including cover page and 6 pages of Annexures)

QUESTION 1

A local ventilation system (hood and exhaust duct) is used to remove air and contaminants produced by a dry-cleaning operation (Fig 1). The duct is round and is constructed of galvanized steel with longitudinal seams and with joints every 0.76 m. The inner diameter (ID) of the duct is D = 0.230 m, and its total length is L = 13.4 m. There are five CD3-9 elbows along the duct. The equivalent roughness height of this duct is 0.15 mm, and each elbow has a minor (local) loss coefficient of $K_L = C_0 = 0.21$. Note the notation C_0 for minor loss coefficient, commonly used in the ventilation industry (ASHRAE, 2001). To ensure adequate ventilation, the minimum required volume flow rate through the duct is
Q = 600 cfm (cubic feet per minute), or 0.283 m^3/s at 25°C. Literature from the hood manufacturer lists the hood entry loss coefficient as 1.3 based on duct velocity. When the damper is fully open, its loss coefficient is 1.8. A centrifugal fan with 9.0-in inlet and outlet diameters is available. Its performance data are shown in Table 1, as listed by the manufacturer.
Predict the operating point of this local ventilation system, and draw a plot of required and available fan pressure rise as functions of volume flow rate. Is the chosen fan adequate?

Table 1

Q, m^3/s	$H_{available}$, m
0	19.27
0.118	20.34
0.236	19.27
0.354	16.06
0.47	8.56
0.57	0

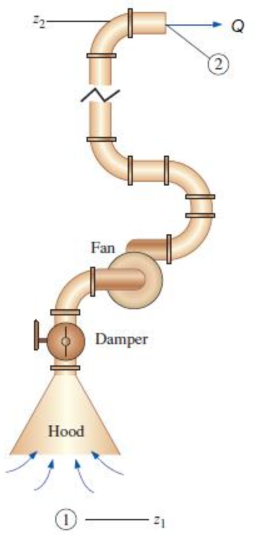


Figure 1

[30]

QUESTION 2

The 12.75 impeller option of the Taco Model 4013 FI Series centrifugal pump of Fig.2 is used to pump water at 25°C from a reservoir whose surface is 15 m above the centreline of the pump inlet. The piping system from the reservoir to the pump consists of 3.2 m of cast iron pipe with an ID of 101.6 mm and an average inner roughness height of 0.508 mm. There are several minor losses: a sharp-edged inlet (K_L = 0.5), three flanged smooth 90° regular elbows (K_L = 0.3 each), and a fully open flanged globe valve (K_L = 6.0). Estimate the net positive suction head ($NPSH_{required}$),

[15]

QUESTION 3

A centrifugal blower rotates at 1750 rpm (183.3 rad/s). Air enters the impeller normal to the blades and exits at an angle of 40° from radial. The inlet radius is 4 cm, and the inlet blade width is 5.2 cm. The outlet radius is 8 cm, and the outlet blade width is 2.3 cm. The volume flow rate is 0.13 m3/s. For the idealized case, i.e., 100 percent efficiency, calculate the net head produced by this blower in equivalent millimetres of water column height. Also calculate the required brake horsepower in watts.

[10]

QUESTION 4

Water flows in a channel whose bottom slope is 0.002 and whose cross section is as shown in Fig. 4. The dimensions and the Manning coefficients for the surfaces of different subsections are also given on the figure. Calculate the flow rate through the channel when the flow depth is 3.5 m, as well as the effective Manning coefficient for the channel.

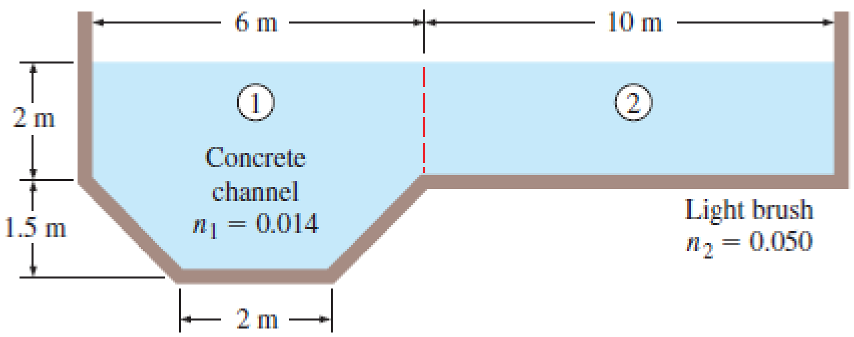


Figure 4.

[25]

QUESTION 5

After graduation, you work for a pump manufacturing company. One of your company's best-selling products is a water pump, which we shall call pump A. Its impeller diameter is D_A = 6 cm, and its performance data when operating at n_A = 1725 rpm (ω_A = 180.6 rad/s) are shown in Table 5. The marketing research department is recommending that the company design a new product, namely, a larger pump (which we shall call pump B) that will be used to pump liquid refrigerant R-134a at room temperature. The pump is to be designed such that its best efficiency point occurs as close as possible to a volume flow rate of V_B = 2400 cm^3/s and at a net head of H_B = 450 cm (of R-134a). The chief engineer (your boss) tells you to perform some preliminary analyses using pump scaling laws to determine if a geometrically scaled-up pump could be designed and built to meet the given requirements.

a) Plot the performance curves of pump A in dimensional form
b) Calculate the required pump diameter D_B and rotational speed *n*

Table 5

$\dot{V}$, cm^3/s	H, cm	η_{pump}, %
100	180	32
200	185	54
300	175	70
400	170	79
500	150	81
600	95	66
700	54	38

[20]

End

$$\mathrm{Re} = \frac{\rho V_{\text{avg}} D}{\mu}$$

$$\dot{V} = V_{\text{avg}} A_c = \frac{\Delta P \pi D^4}{128 \mu L}$$

$$\Delta P_L = f \frac{L}{D} \frac{\rho V^2}{2} \quad \text{and} \quad h_L = \frac{\Delta P_L}{\rho g} = f \frac{L}{D} \frac{V^2}{2g}$$

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

$$\frac{1}{\sqrt{f}} = -2.0 \log\left(\frac{\varepsilon/D}{3.7} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right)$$

$$D_h = \frac{4A_c}{p}$$

Available NPSH: $$\mathrm{NPSH} = \frac{P_{\text{atm}} - P_v}{\rho g} + (z_1 - z_2) - h_{L,\text{total}} - \frac{(\alpha_2 - 1)V_2^2}{2g}$$

Net head: $$H = \frac{1}{g}(\omega r_2 V_{2,t} - \omega r_1 V_{1,t})$$

$$\mathrm{bhp} = \omega T_{\text{shaft}} = \rho \omega \dot{V}(r_2 V_{2,t} - r_1 V_{1,t}) = \dot{W}_{\text{water horsepower}} = \rho g \dot{V} H$$

$$H_{\text{water column}} = H \frac{\rho_{\text{air}}}{\rho_{\text{water}}}$$

$$\dot{V} = 2\pi r_1 b_1 V_{1,n} = 2\pi r_2 b_2 V_{2,n}$$

$$V_0 = \frac{a}{n} R_h^{2/3} S_0^{1/2} \quad \text{and} \quad \dot{V} = \frac{a}{n} A_c R_h^{2/3} S_0^{1/2}$$

$$\dot{V}_{\text{rec}} = C_{\text{wd, rec}} \frac{2}{3} b \sqrt{2g} H^{3/2}$$

$$C_{\text{wd, rec}} = 0.598 + 0.0897 \frac{H}{P_w} \quad \text{for} \quad \frac{H}{P_w} \leq 2$$

$$\dot{V} = C_{\text{wd, tri}} \frac{8}{15} \tan\left(\frac{\theta}{2}\right) \sqrt{2g} H^{5/2}$$

V: Volume flow rate	$\frac{\dot{V}_B}{\dot{V}_A} = \left(\frac{\omega_B}{\omega_A}\right)^1 = \left(\frac{\dot{n}_B}{\dot{n}_A}\right)^1$
H: Head	$\frac{H_B}{H_A} = \left(\frac{\omega_B}{\omega_A}\right)^2 = \left(\frac{\dot{n}_B}{\dot{n}_A}\right)^2$
P: Power	$\frac{\mathrm{bhp}_B}{\mathrm{bhp}_A} = \left(\frac{\omega_B}{\omega_A}\right)^3 = \left(\frac{\dot{n}_B}{\dot{n}_A}\right)^3$

Properties of air at 1 atm pressure

Temp. T, °C	Density ρ, kg/m^3	Specific Heat c_p J/kg·K	Thermal Conductivity k, W/m·K	Thermal Diffusivity α, m^2/s	Dynamic Viscosity μ, kg/m·s	Kinematic Viscosity ν, m^2/s	Prandtl Number Pr
−150	2.866	983	0.01171	4.158×10^{-6}	8.636×10^{-6}	3.013×10^{-6}	0.7246
−100	2.038	966	0.01582	8.036×10^{-6}	1.189×10^{-6}	5.837×10^{-6}	0.7263
−50	1.582	999	0.01979	1.252×10^{-5}	1.474×10^{-5}	9.319×10^{-6}	0.7440
−40	1.514	1002	0.02057	1.356×10^{-5}	1.527×10^{-5}	1.008×10^{-5}	0.7436
−30	1.451	1004	0.02134	1.465×10^{-5}	1.579×10^{-5}	1.087×10^{-5}	0.7425
−20	1.394	1005	0.02211	1.578×10^{-5}	1.630×10^{-5}	1.169×10^{-5}	0.7408
−10	1.341	1006	0.02288	1.696×10^{-5}	1.680×10^{-5}	1.252×10^{-5}	0.7387
0	1.292	1006	0.02364	1.818×10^{-5}	1.729×10^{-5}	1.338×10^{-5}	0.7362
5	1.269	1006	0.02401	1.880×10^{-5}	1.754×10^{-5}	1.382×10^{-5}	0.7350
10	1.246	1006	0.02439	1.944×10^{-5}	1.778×10^{-5}	1.426×10^{-5}	0.7336
15	1.225	1007	0.02476	2.009×10^{-5}	1.802×10^{-5}	1.470×10^{-5}	0.7323
20	1.204	1007	0.02514	2.074×10^{-5}	1.825×10^{-5}	1.516×10^{-5}	0.7309
25	1.184	1007	0.02551	2.141×10^{-5}	1.849×10^{-5}	1.562×10^{-5}	0.7296
30	1.164	1007	0.02588	2.208×10^{-5}	1.872×10^{-5}	1.608×10^{-5}	0.7282
35	1.145	1007	0.02625	2.277×10^{-5}	1.895×10^{-5}	1.655×10^{-5}	0.7268
40	1.127	1007	0.02662	2.346×10^{-5}	1.918×10^{-5}	1.702×10^{-5}	0.7255
45	1.109	1007	0.02699	2.416×10^{-5}	1.941×10^{-5}	1.750×10^{-5}	0.7241
50	1.092	1007	0.02735	2.487×10^{-5}	1.963×10^{-5}	1.798×10^{-5}	0.7228
60	1.059	1007	0.02808	2.632×10^{-5}	2.008×10^{-5}	1.896×10^{-5}	0.7202
70	1.028	1007	0.02881	2.780×10^{-5}	2.052×10^{-5}	1.995×10^{-5}	0.7177
80	0.9994	1008	0.02953	2.931×10^{-5}	2.096×10^{-5}	2.097×10^{-5}	0.7154

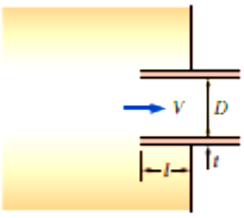
PHYSICAL PROPERTIES OF TAP WATER AT 1 ATMOSPHERE

Temperature T [ºC]	Density ρ [kg.m^{-3}]	Dynamic viscosity μ [kg.m^{-1}s^{-1}]	Surface tension σ [N.m^{-1}]	Vapour pressure head $p/\rho g$ [m]	Bulk modulus of elasticity K [MN.m^{-2}]
0	999.9	1.792 x 10^{-3}	0.0762	0.06	2040
5	1000.0	1.519 x 10^{-3}	0.0754	0.09	2060
10	999.7	1.308 x 10^{-3}	0.0748	0.12	2110
15	999.1	1.14 x 10^{-3}	0.0741	0.17	2140
20	998.2	1.005 x 10^{-3}	0.0736	0.25	2200
25	997.1	0.894 x 10^{-3}	0.0726	0.33	2220
30	995.7	0.801 x 10^{-3}	0.0718	0.44	2230
35	994.1	0.723 x 10^{-3}	0.071	0.58	2240
40	992.2	0.656 x10^{-3}	0.0701	0.76	2270
45	990.2	0.599 x 10^{-3}	0.0692	0.98	2290
50	988.1	0.549 x 10^{-3}	0.0682	1.26	2300
60	983.2	0.469 x 10^{-3}	0.0668	2.03	2280
70	977.8	0.406 x 10^{-3}	0.065	3.2	2250
80	971.8	0.357 x 10^{-3}	0.063	4.86	2210
90	965.3	0.317 x 10^{-3}	0.0612	7.18	2160
100	958.4	0.284 x 10^{-3}	0.0594	10.33	2070

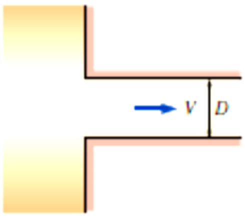
Loss coefficients K_L of various pipe components for turbulent flow (for use in the relation $h_L = K_L V^2/(2g)$, where V is the average velocity in the pipe that contains the component)*

Pipe Inlet

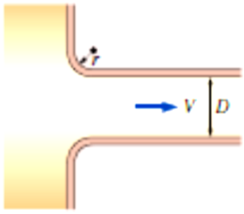
Reentrant: $K_L = 0.80$ ($t \ll D$ and $l \approx 0.1D$)



Sharp-edged: $K_L = 0.50$

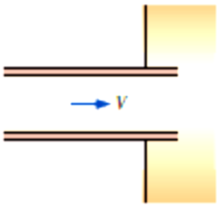


Well-rounded ($r/D > 0.2$): $K_L = 0.03$
Slightly rounded ($r/D = 0.1$): $K_L = 0.12$
(see Fig. 8–39)

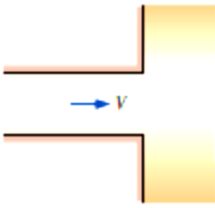


Pipe Exit

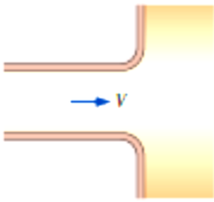
Reentrant: $K_L = \alpha$



Sharp-edged: $K_L = \alpha$



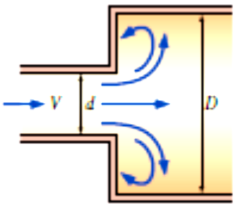
Rounded: $K_L = \alpha$



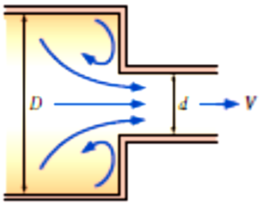
Note: The kinetic energy correction factor is $\alpha = 2$ for fully developed laminar flow, and $\alpha \approx 1.05$ for fully developed turbulent flow.

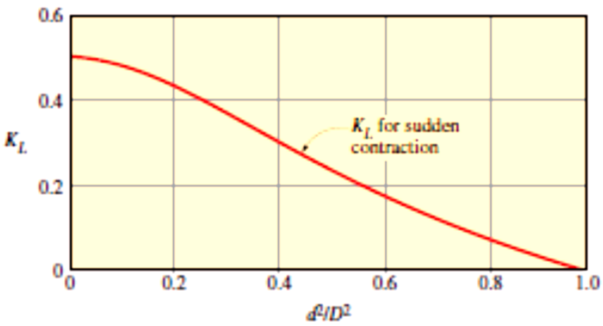
Sudden Expansion and Contraction (based on the velocity in the smaller-diameter pipe)

Sudden expansion: $K_L = \alpha\left(1 - \frac{d^2}{D^2}\right)^2$



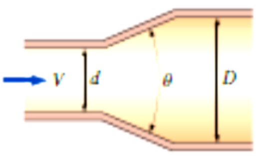
Sudden contraction: See chart.



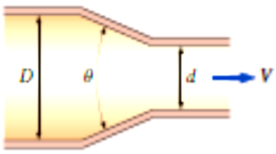


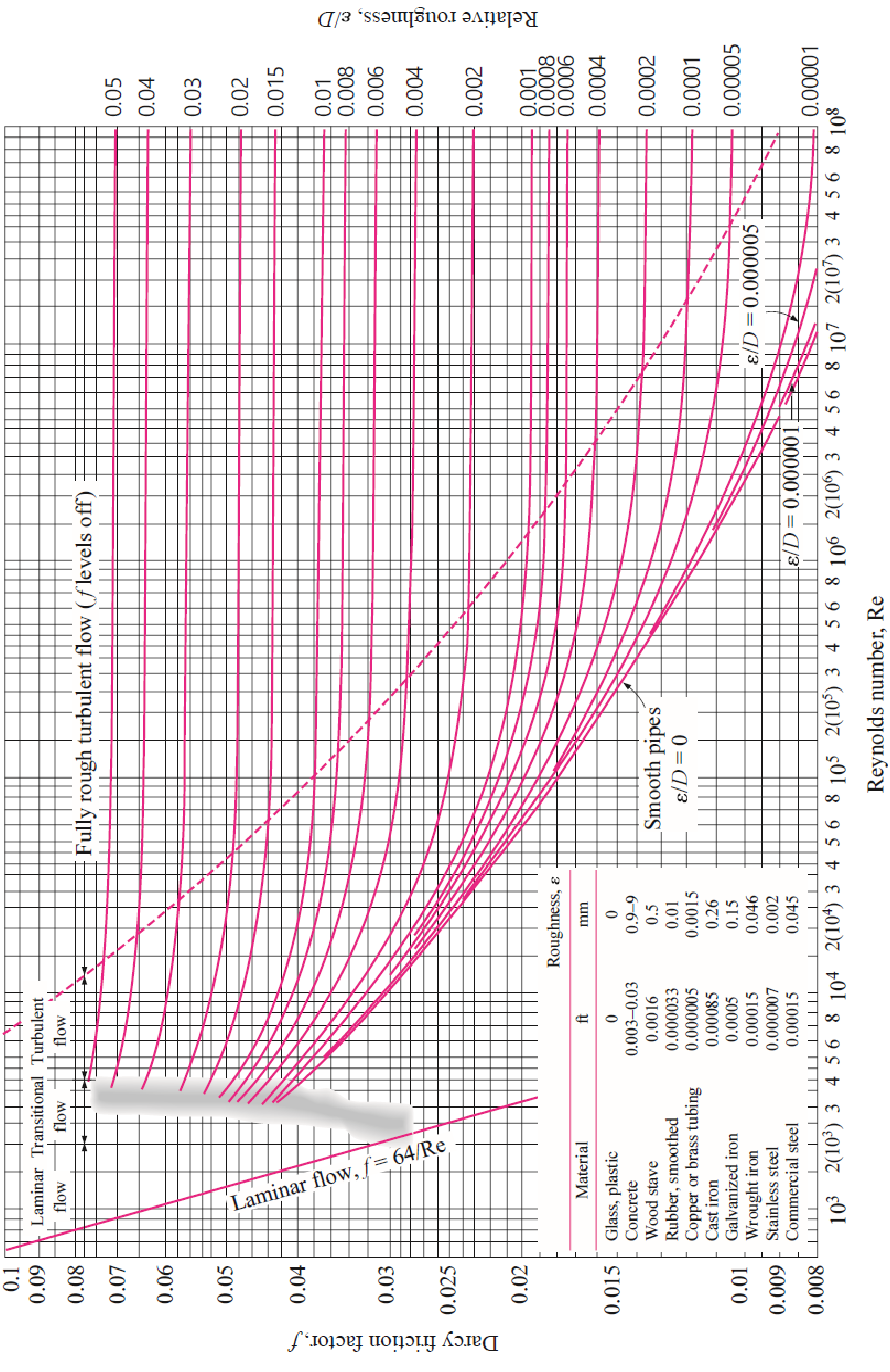
Gradual Expansion and Contraction (based on the velocity in the smaller-diameter pipe)

Expansion (for $\theta = 20°$):
$K_L = 0.30$ for $d/D = 0.2$
$K_L = 0.25$ for $d/D = 0.4$
$K_L = 0.15$ for $d/D = 0.6$
$K_L = 0.10$ for $d/D = 0.8$

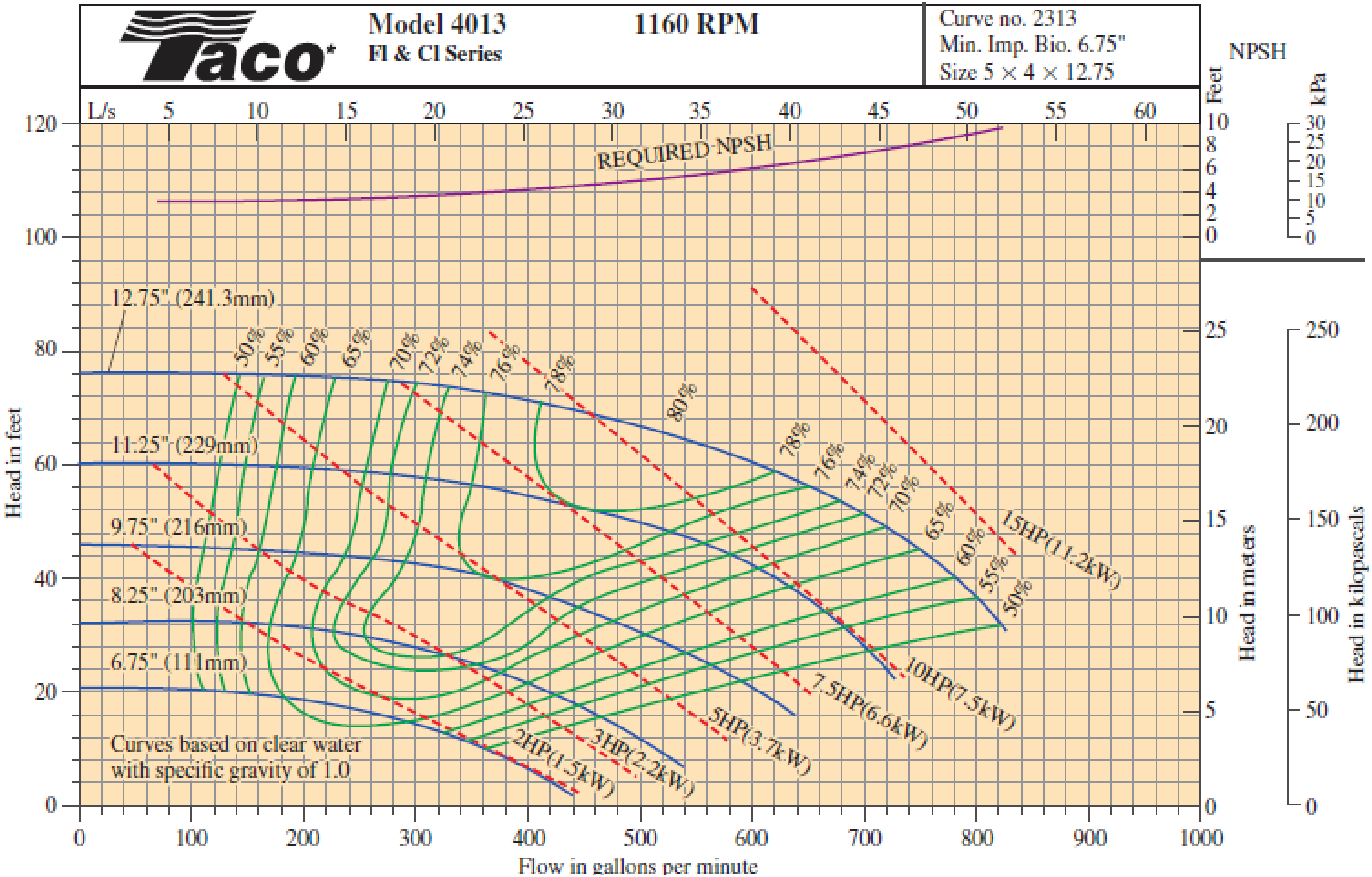


Contraction:
$K_L = 0.02$ for $\theta = 30°$
$K_L = 0.04$ for $\theta = 45°$
$K_L = 0.07$ for $\theta = 60°$





Material	ft	mm
Glass, plastic	0	0
Concrete	0.003–0.03	0.9–9
Wood stave	0.0016	0.5
Rubber, smoothed	0.000033	0.01
Copper or brass tubing	0.000005	0.0015
Cast iron	0.00085	0.26
Galvanized iron	0.0005	0.15
Wrought iron	0.00015	0.046
Stainless steel	0.000007	0.002
Commercial steel	0.00015	0.045



Taco
Model 4013
Fl & Cl Series
1160 RPM
Curve no. 2313
Min. Imp. Bio. 6.75"
Size 5 × 4 × 12.75
NPSH
Feet
kPa
L/s
REQUIRED NPSH
12.75" (241.3mm)
11.25" (229mm)
9.75" (216mm)
8.25" (203mm)
6.75" (111mm)
50%
55%
60%
65%
70%
72%
74%
76%
78%
80%
15HP(11.2kW)
10HP(7.5kW)
7.5HP(6.6kW)
5HP(3.7kW)
3HP(2.2kW)
2HP(1.5kW)
Curves based on clear water
with specific gravity of 1.0
Head in feet
Head in meters
Head in kilopascals
Flow in gallons per minute