Energy & Work Conservation Study Aid

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The Future is Out There. Go FORTH……

OBJECTIVE

- ***To show an ability*** to execute process for applying conservation of Energy/Work equation for viscous pipe and component flow.
- ***To show an ability*** to derive non-linear friction characteristic equation involving friction factor and volume flow rate, or diameter.
- ***To show an ability*** to solve non-linear friction characteristic equation through an ***iterative trial-n-error process via EXCEL or MATLAB***.

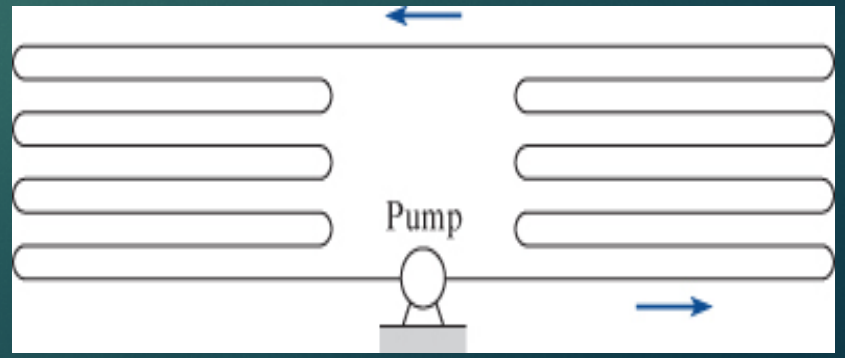
On the human excursion to Mars, as thermal systems engineer for base camp Excalibur 1, you are required to determine both the OG1 Mineral Oil (**https://www.multitherm.com/pdf/OG_1.PDF**) heat exchanger tube diameter "D" (DRAWN TUBING) and volume flow rate (Q) below assuming a maximum pressure drop of **5 psig** at **160C**. The total tube length is "**L=40m**" with return **flanged bends** as shown.

The pump head is defined as $\dot{W}_{p_{actual}}[Watts] = 100 - 3500Q^2, where\ Q\ is\ m^3/sec.$

Let D be 2cm, 4cm, and 10cm and for each diameter plot:

- X:AXIS: Pump Efficiency(70-90%), Left YAXIS: Volume Flow Rate, Right YAXIS: Pump Work
- Evaluate effect of temperature variation from 110C to 170C in steps of 5C due to variations in the solar dust storms;

Plot Pump Efficiency (X axis) vs mass flow rate (Y axis)
Verify Units on friction characteristic parametric equation.



Convert Pump Power from WATTS to "head" in "m"

$$\dot{W}_{p_{actual}}[Watts] = 100 - 3500Q^2, \text{where } Q \text{ is } m^3/sec$$

$$h_{pump_{IDEAL}}(Q,T,\eta_{pump}) = \frac{\dot{W}_{p_{actual}}}{\dot{m}g}\eta_{pump} = \frac{\dot{W}_{p_{actual}}}{\rho(T)Qg}\eta_{pump} = \frac{100 - 3500Q^2}{\rho(T)Qg}\eta_{pump}$$

Major and Minor Losses

Constant Diameter Series Piping

$$h_L = \frac{fL}{D}\frac{V^2}{2g} + \sum_L K_L \frac{V_L^2}{2g}$$

$$L = 40m, \quad K_{bend} = 0.3, \quad 14 \text{ Bends}$$

$$h_L = \frac{V^2}{2g}\left(\frac{fL}{D} + 14 \bullet 0.3\right)$$

$$= \frac{Q^2/A^2}{2g}\left(\frac{fL}{D} + 14 \bullet 0.3\right)$$

CONSERVATION ENERGY/WORK

$$\gamma = \rho(T) \bullet g$$

$$\Delta P = P_2 - P_1 = 5\,psig \bullet \frac{144\,ft^2}{in^2} = 720\,PSF = 3,435\,PA$$

$$\frac{P_1}{\gamma} - \frac{P_2}{\gamma} + h_p = \cancel{\frac{V_2^2}{2g}} - \cancel{\frac{V_1^2}{2g}} + h_L$$

$$\frac{P_1}{\gamma} - \frac{P_2}{\gamma} + \frac{100 - 3500Q^2}{\rho(T)Qg}\eta_{pump} = \frac{Q^2/A^2}{2g}\left(\frac{fL}{D} + 14 \bullet 0.3\right)$$

$$Q^3\left[\frac{1}{A^2 2g}\left(\frac{fL}{D} + 14 \bullet 0.3\right)\right] + Q^2\left[\frac{3500}{\rho g}\eta_{pump}\right] - Q\left[\frac{P_1}{\gamma} - \frac{P_2}{\gamma}\right] - \frac{100}{\rho g}\eta_{pump} = 0$$

$$aQ^3 + bQ^2 + cQ = d$$

Friction Characteristic Equation

ITERATIVE SOLUTION

Must guess "f", solve for "Q": Assume Turbulent

$$Q^3\left[\frac{1}{A^2 2g}\left(\frac{fL}{D}+14\bullet 0.3\right)\right]+Q^2\left[\frac{3500}{\rho g}\eta_{pump}\right]-Q\left[\frac{P_1}{\gamma}-\frac{P_2}{\gamma}\right]-\frac{100}{\rho g}\eta_{pump}=0$$

Check Validity of "f" with Halland Equation

$$\frac{1}{\sqrt{f}}=-1.8\log_{10}\left(\left(\frac{\varepsilon/D}{3.7}\right)^{1.11}+\frac{6.9}{\mathrm{Re}}\right)$$

Re-Guess and Repeat Until Convergence

$$\dot{W}_{p_{actual}}[Watts]=100-3500Q^2, where\ Q\ is\ m^3/sec$$

f guess	VEL	Red	fhalland	Q
0.03	26.73805	236,139	0.015579	0.00840
0.015579	36.28736	320,475	0.01486	0.01140
0.01486	39.47046	348,586	0.014678	0.01240
f guess	**VEL**	**Red**	**fhalland**	**Q**
0.01	44.56342	393,565	0.014428	0.01400
0.014428	39.47046	348,586	0.014678	0.01240
0.014678	39.47046	348,586	0.014678	0.01240
f guess	**VEL**	**Red**	**fhalland**	**Q**
0.1	19.00948	167,884	0.016497	0.00597
0.016497	38.10809	336,555	0.014753	0.01197
0.014753	38.10809	336,555	0.014753	0.01197
0.014753	39.8588	352,016	0.014657	0.01252
0.014657	39.95429	352,859	0.014652	0.01255

m/s2	kg/m3	N/m3	PA	m	m2	m		Pa-s		
g	density	Gamma	P2-P1	DIA	AREA	L	EFF	VISC	e	e/d
9.81	839	8230.59	-34354	0.02	0.000314	40	0.8	1.90E-03	1.50E-06	7.50E-05