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Methods of Analytical Pressure Drop Calculation

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Abstract

This paper shows the fundamentals of fluid mechanics necessary to understand and determine pressure losses in the system. For illustration this paper used U-type evacuated tube solar collector model with 52 Collectors units. Pressure drop calculation is done inside U pipe evacuated tube solar collector,in collector bending, in fluid Entranceand fluid Existing,due to Inclination from horizontal surface, in the manifold,due to length from storage tank to collector arrays and in tube bending.

Introduction

Pumpis the heart of a hydraulic system, converts mechanical energy into hydraulic energy,this paper shows the fundamentals of fluid mechanics necessary to understand and determine pressure losses in the system. There are two types of friction losses in pipes: main and minor losses. The first type deals with the resistance to flow offered by straight pipe section while the second one refers to bends, fittings, and other elements present in the pipe system.For illustration this paper used U-type evacuated tube solar collector model figure 1) (with52 Collectors units (figure 2).

Non-positive displacement pump used generally for low pressure and high-volume flow application. Manly used for transporting fluids from one location to another. Knowing the pressure losses in a piping system and the pumping power required allows for sizing considerations of pumps. A quantity of interest in the analysis of pipe flow is the pressure drop since it is directly related to the power Requirements of the pump to maintain flow.

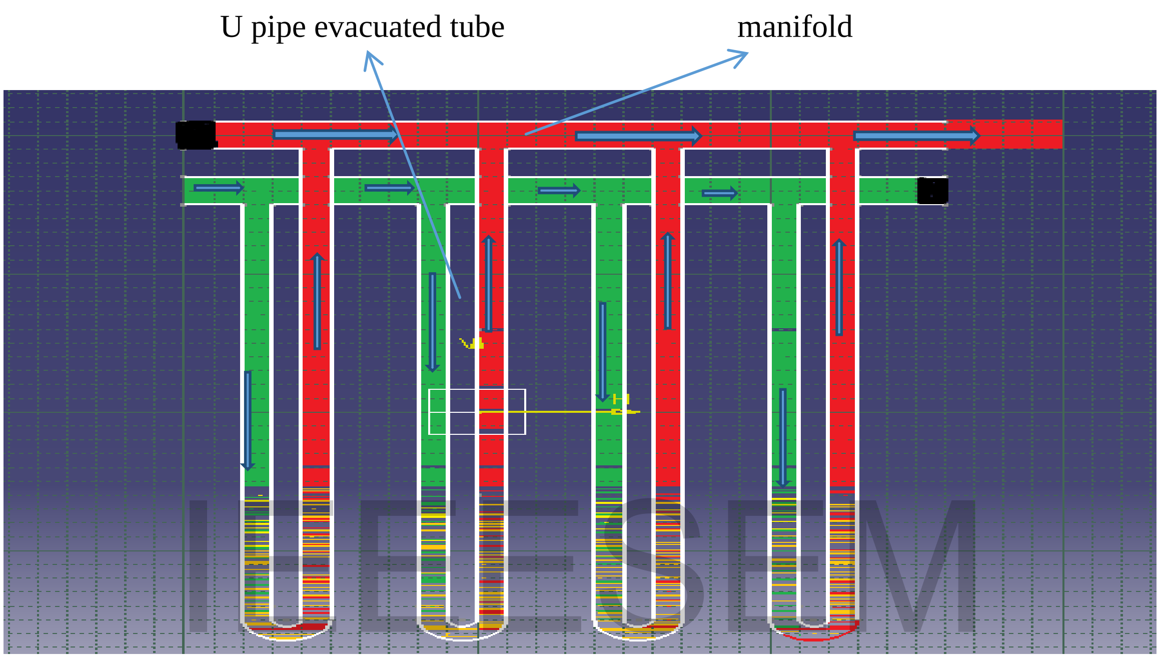

Figure 1: U-type evacuated tube solar collector

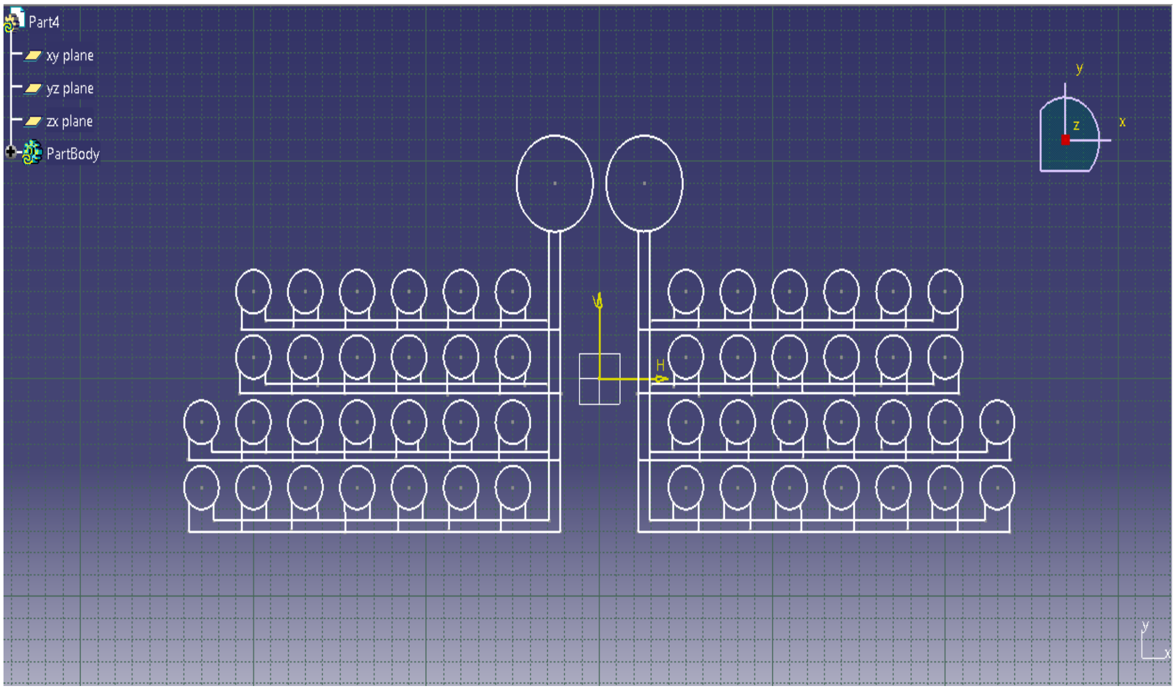

Figure 2: Collector modules in the arrays connected in parallel and detail layout

In practice, it is found convenient to express the pressure loss for all types of fully development internal flows, Engineering design handbook [1973].

$$\Delta \boldsymbol{P} = f\left(\frac{\boldsymbol{L}}{\boldsymbol{d}}\right)\left(\frac{\boldsymbol{\rho} * \boldsymbol{V_{av}}^2}{\mathbf{2}}\right)$$

1.1 Pressure drop inside U pipe evacuated tube solar collector

P = 101325 pa

$$\rho = 985.65 \frac{Kg}{m^3}$$

$\mu = 0.000504 \dfrac{kg}{m.s}$

$\dot{m}$= 0.0227 $\frac{Kg}{s}$

$\dot{Q} = \frac{\dot{m}}{\rho} = \frac{0.0227}{985.65} = 0.0000230304875 \frac{m^3}{sec}$

Volume flow rate in single tube (Q)

$$Q = \frac{0.0000230304875 \ \frac{m^3}{sec}}{15} = 1.54 * 10^{-6} \frac{m^3}{sec}$$

Velocity of fluid in side U-pipe in tubes (V_{av})

$$V_{av} = \frac{\dot{Q}}{A_{cu}} = 0.01956 \ \frac{m}{sec}$$

Reynolds number (R_e)

$$R_e = \frac{\rho * V_{av} * d}{\mu} = \frac{985.65 \frac{Kg}{m^3} * 0.01956 \ \frac{m}{sec} * 0.01 \ m}{0.000504 \frac{Kg}{m.s}} = 383$$

Since $383 < 2300$ the flow is under laminar and the pressure drop for Circular cross section tubes are calculated as

$$\Delta P = f\left(\frac{L}{d}\right)\left(\frac{\rho * {V_{av}}^2}{2}\right)$$

$$f = \frac{64}{R_e} = 0.167101827$$

$$\Delta P1 = f\left(\frac{L}{d}\right)\left(\frac{\rho * {V_{av}}^2}{2}\right) = 0.167101827 * \left(\frac{3.5}{0.01}\right) * \left(\frac{985.65 * (0.01956)^2}{2}\right) = 10.0276 \text{ Pa}$$

Total pressure drops 4300.75 Pa

1.2 Pressure drop in collector bending (180°)

For bending it is defined a total loss coefficient (K) and the value K depends on length and diameter of pipe,Sadik and Hongtan [2002].

$$\Delta p2 = k * \frac{\rho * {v_{av}}^2}{2} = 7.9 * \left(\frac{985.65 * (0.01956)^2}{2}\right) = 1.49 \text{ Pa}$$

Total pressure drops because of180°bend = 581 Pa

1.3 Pressure drop in fluid Entrance

$$\Delta p3 = k * \frac{\rho * {v_{av}}^2}{2} = 7.6 * \left(\frac{985.65 * (0.01956)^2}{2}\right) = 1.433 \text{ Pa}$$

Total pressure drops also happen when fluid inter into collector (smaller diameter) than intake manifold and equals to 558.8 Pa

1.4 Pressure drop in fluid Existing

$\Delta p4 = k * \frac{\rho * {v_{av}}^2}{2} = 7.583 * \left(\frac{985.65 * (0.01956)^2}{2}\right)$ = 1.43 Pa

Pressure drop also happen when fluid flows from collector to manifold and equals to =557 Pa.

1.5 Due to Inclination from horizontal pressure drop

$\Delta p5 = \rho g h = 985.65 * 9.81 * 0.7 = 6768.46\ Pa$

1.6 pressure drop in the manifold

1.6.1 Length of intake manifold

Seen from Figure 2

0ne collector widths = 1.178 m

There are 12 collectors in 2 arrays and the total length = 14.136 m

And there are also 14 collectors in 2 arrays and the total length = 16.492 m

1.6.2 Length of return manifold

Same as intake manifold

1.6.3 Lengthfrom Storage tank to Collector arrays

Total length =4*1.8 m + 4*0.2 m +2m = 10 m

Intake manifold pressure drop

For diameter of 22 mm manifold tube the pressure drops for intake manifold calculated

$$\Delta P = f\left(\frac{L}{d}\right)\left(\frac{\rho * {V_{av}}^2}{2}\right)$$

Area of intake manifold $A_{im} = \pi * r^2 = 0.00037994\ m^2$

The total Volume flow rate rates,$\dot{Q} = 26 * 0.0000230304875 \frac{m^3}{sec}$

Velocity inside intake manifold

$V_{im} = \frac{\dot{Q}}{A_{im}} = 1.576 \frac{m}{sec}$

Reynolds number

$R_e = \frac{\rho * V_{im} * d}{\mu} = \frac{985.65 \frac{Kg}{m^3} * 1.576 \frac{m}{sec} * 0.022\, m}{0.000504 \frac{Kg}{m.s}} = 67{,}807.3$

Since 2300 $<$ 67,807.3 the flow is under turbulent and the pressure drop for Circular cross section tubes are calculated as

$$\Delta P = f\left(\frac{L}{d}\right)\left(\frac{\rho * V_{av}{}^2}{2}\right)$$

For the material of galvanized iron cast, equivalent roughness(ε) 0.15 mm with pipe diameter of 0.022 mm

$\frac{\varepsilon}{d} = 0.00682$

Therefore, from the moody chart with corresponding Reynolds number $f = 0.032$

$f, friction\ factor$

$\Delta P6 = f\left(\frac{L}{d}\right)\left(\frac{\rho * V_{av}{}^2}{2}\right) = 0.032 * \left(\frac{7.1}{0.022}\right) * \left(\frac{985.65 * (1.576)^2}{2}\right) = 12{,}641.4$ Pa

There are 2 arrays and the total pressure drop equals to 25,282.76 Pa

$\Delta P7 = f\left(\frac{L}{d}\right)\left(\frac{\rho * V_{av}{}^2}{2}\right) = 0.032 * \left(\frac{8.246}{0.022}\right) * \left(\frac{985.65 * (1.576)^2}{2}\right) = 14{,}681.75$ Pa

There are 2 arrays and the total pressure drop equals to 29,363.51 Pa

Return manifold pressure drop

Same as intake manifold pressure drop

1.7 Pressure drop from storage tank to collector arrays

Take volume flow rates, $\dot{Q} = 4 * \dot{Q} = 0.0023952 \frac{m^3}{sec}$

For diameter of 37 mm tube the pressure drops calculated

Area of intake manifold $A_{im} = \pi * r^2 = 0.001074665\, m^2$

Velocity inside tube

$V_{im} = \frac{\dot{Q}}{A_{im}} = 2.228 \frac{m}{sec}$

Reynolds number

$R_e = \frac{\rho * V_{im} * d}{\mu} = \frac{985.65 \frac{Kg}{m^3} * 2.228 \frac{m}{sec} * 0.037 m}{0.000504 \frac{Kg}{m.s}} = 161{,}271.37$

Since $2300 < 161{,}271.37$the flow is under turbulent and the pressure drop for Circular cross section tubes are calculated as

$$\Delta P = f\left(\frac{L}{d}\right)\left(\frac{\rho * {V_{av}}^2}{2}\right)$$

For the material of galvanized iron cast the equivalent roughness(ε) is 0.15 mm with the pipe diameter 37 mm

$\frac{\varepsilon}{d} = 0.004054054$

Therefore, from the moody chart with corresponding Reynolds number $f = 0.026$

$\Delta P8 = f\left(\frac{L}{d}\right)\left(\frac{\rho * {V_{av}}^2}{2}\right) = 0.026 * \left(\frac{10}{0.037}\right) * \left(\frac{985.65 * (2.228)^2}{2}\right) = 17{,}190.74$ Pa

Total pressure dropsfrom storage tank to collector arrays = 34,381.5 Pa

1.8 Pressure drop in bending

Seen from Figure 2, there are 8 bends

Pressure drop in fluid entrance, one 90° bends and three tee bends

For three tee bends

$\Delta p9 = 3 * k * \frac{\rho * {v_{av}}^2}{2} = 3 * 0.45 * \left(\frac{985.65 * (1.576)^2}{2}\right)$= 1652.5 Pa

For one 90° bends

$\Delta p10 = k * \frac{\rho * {v_{av}}^2}{2} = 0.85 * \left(\frac{985.65 * (1.576)^2}{2}\right)$=1040.46 Pa

Pressure drop in fluid existing

Pressure drop in fluid existence, one 90° bends and three tee bends

For three tee bends

$\Delta p11 = k * \frac{\rho * {v_{av}}^2}{2} = 3 * 0.45 * \left(\frac{985.65 * (2.228)^2}{2}\right)$= 3302.61 Pa

For one 90° bends

$\Delta p12 = k * \frac{\rho * {v_{av}}^2}{2} = 0.85 * \left(\frac{985.65 * (2.228)^2}{2}\right)$= 2079.42 pa

1.9Total specific work (Y)

Once the pressure loss is known, the required pumping power to overcome the pressure loss is determined from

Specific work =$\frac{\text{Total pressure drop}}{density}$ =164.51 $\frac{m^2}{s^2}$

Head loss (H) = $\frac{\text{Specific work}}{\boldsymbol{g}}$ ≅17 m

Total volume flow rate for the pump equals to 0.0023952 $\frac{m^3}{sec}$

Table 1: Pump performance specification, Electrical pump catalogues (NOCCHI)

CODE	**MODEL**	**NORMAL POWER (kW)**	**VOLTAGE (V)**	**AMP 3×400 V**	**Motor type**	**Frequ ency**	**Weight (KG)**

PA021010	NRB2 32×120 B	1.1 kW	230/400	4.7/2.7	80 B2	50 Hz	63

Summary

Total pumping pressure needed for design is the sum of all the above pressure drops$\Delta p = 164{,}510$ Pa. The proper centrifugal electric drive pump satisfying the requirement of head = 17 m and flow rate = 8.623 $\frac{m^3}{h}$.

Reference

- Engineering design handbook, [1973] (laminar or turbulent flow, circular or noncircular pipes, smooth or rough surfaces horizontal or inclined pipes.
- Electrical pumps catalogue, NOCCHI Pentair water.
- Sadik kakac and hongtan liu, "heat exchanger selection, rating and thermal design, second edition," university of Miami in 2002.