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# ANALYSIS OF UNIFORM PRESSURE DISTRIBUTED DIVIDING FLOW MANIFOLD

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Manifolds are used for distributing and collecting fluids-gases and liquids. In the dividing flow manifold, the fluid approaches the branch point from the upstream side. Some fluid is lost through the lateral and the remainder of the flow proceeds downstream at a decreasing flow rate. This results in increase in pressure towards the downstream side. Frictional effects, however, do cause a decrease of pressure in the flow direction. Therefore, the possibility exists for obtaining a uniform pressure distributed dividing flow manifold by suitable adjustments of flow parameters so that pressure rise due to deceleration is balanced by pressure loss due to friction.

## INTRODUCTION

A manifold is defined as a channel where the fluid enters leaves through passages, in the side walls due to action of a differential pressure (2). Manifolds commonly used in the flow distribution systems can be classified into four categorical types, namely dividing flow, combining flow, parallel flow and reverse flow (2, 8).

The uniform distribution of pressure in a dividing flow manifold is required for even distribution of fluid. There are only two important factors which determine the distribution of flow from the dividing flow manifold; these are inertia and friction (6). Inertia corresponds to the change in velocity head. In a dividing flow manifold, the main fluid stream is decelerated due to the loss of fluid through the laterals. Therefore, the pressure will rise in the direction of flow if the effects of friction are small. Frictional effects, however, do cause a decrease of pressure in the flow

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direction. Therefore, the possibility exists for obtaining a uniform pressure along the dividing flow manifold by suitable adjustments of the flow parameters so that the pressure rise due to flow branching balances the pressure losses due to friction.

## REVIEW OF LITERATURE

In his discussion of manifold flow, Keller defined the following two dimensionless ratios (6).

$$\frac{L}{D} \text{ ratio} = \frac{\text{active length of manifold}}{\text{diameter of manifold}}$$

$$\text{area ratio } (\theta) = \frac{\text{sum of areas of all branch openings}}{\text{cross-sectional areas of manifold}}$$

From his experiments, Keller concluded that an area ratio of less than or equal to 1 and L/D ratio of 70 is required for the dividing flow manifold in order that frictional losses practically cancel the pressure increase due to deceleration (6). He further stated that for an area ratio of 2 or greater, uniformity of pressure distribution along the dividing flow manifold cannot be obtained regardless of the L/D ratio. Dow (3), commenting on Keller's analysis, pointed out that Keller failed to recognise the variation of the Reynolds number and the corresponding variation of the friction factor with distance along the manifold length. Dow maintained that the variations of the pressure is not a unique function of the L/D and area ratios but also depends on the rate of total flow. Dow also stated that the pressure lose due to friction is related to the surface area of the pipe, while the pressure rise due to deceleration is related to the cross-sectional area of the pipe. He proposed that pressure can be controlled by adjusting the ratio of these two areas. Dow reported a classical case of a manifold serving as an infinite reservoir. He said that if the pressure changes accompanying the flow of the fluid through the manifold due to frictional losses and inertia are negligible in comparison to the pressure drop across the discharge ports, then the pressure will be distributed uniformly. Kimber and Hollingsworth (7) reported that at low values of area ratios, the dividing flow manifold displayed a small longitudinal pressure gradient. And at high values of area ratios, the frictional effects in the dividing flow manifold created a complex pressure distribution in which the pressure fell over the initial ports of the dividing flow manifold and rose foldly towards the closed end. Bajura and

Jones (2) reported that the dividing flow manifold porosity and lateral flow resistance are the variables which most significantly affect the pressure distribution in a manifold system. They defined the dividing flow manifold porosity as the ratio of the open area of the pipe to the total area on the pipe surface. Bajura and Jones mentioned that a common design rule-of-thumb is to limit the porosity of the dividing flow manifold to less than 1. They also observed that a large lateral resistance is desirable for good pressure distribution, but large lateral resistance also results in a high total pressure loss for the manifold which can be unacceptable if pumping costs are an important design consideration. Bajura and Jones indicated that the friction factor can be calculated under the assumption that the branch points do not affect the friction pressure loss characteristics of dividing flow manifold (2). They further observed that this conclusion is highly dependent on the spacing between laterals. They recommended that for design purposes the friction factor can be evaluated based on the ordinary pipe friction calculations for the case of widely spaced branch points and should be increased as the branch points become closely spaced. According to Bajura and Jones (2), a branch spacing of 6.8 lateral diameter can be taken as case representative of widely spaced laterals.

## ANALYSIS

There are two important factors which determine the distribution of flow from the dividing flow manifold. These are inertia and friction. The inertia corresponds to the change in velocity head (6). Figure 2 depicts the flow through dividing flow manifold and the dimensional measurements.

For dividing flow manifold due to escape of fluid through the side ports, fluid in the manifold decelerates and as a result pressure rises in the flow direction. The pressure rise in the flow direction is given by Equation 1 (6).

$$\frac{d(P)}{w} = -\frac{d(V^2)}{2g} - f\frac{d(X)}{D_m}\frac{V^2}{2g} \qquad (1)$$

In equation 1, the first term is deceleration and the second is friction. The deceleration term is negative because an increase of pressure corresponds to a decrease in velocity in the direction of flow. The friction term always causes a decrease in pressure in the direction of flow. It is negative since x is being measured from the inlet end. The integration of equation 1 gives the pressure at any distance x from the inlet end, as represented by equation 2.

$$P_x = P_i + [(\frac{V_i^2 - V_x^2}{2g}) w - \int_0^x f \frac{w}{D_m} \frac{V^2}{2g} d(x)] \quad (2)$$

Minimizing pressure variation

Let $\frac{fL}{3D_m} = K$

and $\bar{P} = \frac{1}{L} \int_0^L Px\, dx$, where $\bar{P}$ is the average manifold pressure.

The requirement of uniform discharge at all the uniformly spaced and equal discharge areas means that the velocity in the manifold decreases linearly. For the closed end design, the velocity in the manifold near the closed end is zero. Therefore,

$$V_x = (\frac{L - x}{L}) V_i \quad (3)$$

Substituting equation 3 into equation 2 and carrying the integration results in equation 4.

$$P_x = P_i + \{w \frac{V_i^2}{2g} [1 - (1 - \frac{x}{L})^2] - f \frac{wL}{3D_m} \frac{V_i^2}{2g} [1 - (1 - \frac{x}{L})^3]\} \quad (4)$$

Using equation 4, and choosing a value of $K$ such that

$$\int_0^L (P_x - \bar{P})^2 dx$$ is minimized.

Rewriting equation 4, substituting $\lambda$ for $fL/3D_m$, and simplifying

$$P_x = P_t + \frac{w\,V_t^2}{2g}\left[\left(2\frac{x}{L} - \frac{x^2}{L^2}\right) - \lambda\left(3\frac{x}{L} - 3\frac{x^2}{L^2} + \frac{x^3}{L^3}\right)\right]$$

$$P_x = P_t \mp \frac{w\,V_t^2}{2g}\left[\left(\frac{x}{L}\right)(2 - 3\lambda) \mp \left(\frac{x^2}{L^2}\right)(3\lambda - 1) - \lambda\left(\frac{x^3}{L^3}\right)\right]$$

Evaluating $\bar{P}$,

$$\bar{P} = \frac{1}{L}\int_0^L P_x\,dx = \frac{1}{L}\left\{P_t L + \frac{w\,V_t^2}{2g}\left[\frac{L}{2}(2-3\lambda) + \frac{L}{3}(3\lambda - 1) - \lambda\left(\frac{L}{4}\right)\right]\right\}$$

$$\bar{P} = P_t + \frac{w\,V_t^2}{2g}\left[1 - \frac{3}{2}\lambda + \lambda - \frac{1}{3} - \frac{1}{4}\lambda\right]$$

$$\bar{P} = P_t + \frac{w\,V_t^2}{2g}\left(\frac{2}{3} - \frac{3}{4}\lambda\right)$$

Evaluating pressure variations,

$$P_x - \bar{P} = \frac{w\,V_t^2}{2g}\left[\left(\frac{3}{4}\lambda - \frac{2}{3}\right) + (2-3y)\left(\frac{x}{L}\right) + (3\lambda-1)\left(\frac{x^2}{L^2}\right) - \lambda\left(\frac{x^3}{L^3}\right)\right]$$

$$(P_x - \bar{P})^2 = \frac{w^2\,V_t^4}{4g^2}\left\{\left(\frac{3}{4}\lambda - \frac{2}{3}\right)^2 + 2\left(\frac{3}{4}\lambda - \frac{2}{3}\right)(2-3\lambda)\left(\frac{x}{L}\right)\right.$$

$$+ \left[(2-3\lambda)^2 + 2\left(\frac{3}{4}\lambda - \frac{2}{3}\right)(3\lambda-1)\right]\left(\frac{x^2}{L^2}\right)$$

$$+ 2\left[(2-3\lambda)(3\lambda-1) - \lambda\left(\frac{3}{4}\lambda - \frac{2}{3}\right)\right]\left(\frac{x^3}{L^3}\right)$$

$$+ \left[(3\lambda-1)^2 - 2y(2-3\lambda)\right]\left(\frac{x^3}{L^4}\right)$$

$$- 2y(3\lambda - 1)\left(\frac{x^5}{L_5}\right) + \lambda^2\left(\frac{x^6}{L^6}\right)\}$$

$$I = \int_0^L (\bar{P}_a - P)^2\,dx = \frac{w^2V_i^4L}{4g^2}\{\left(\frac{3}{4}\lambda - \frac{2}{3}\right)^2 + \left(\frac{3}{4}\lambda - \frac{2}{3}\right)(2 - 3\lambda)$$

$$+ \frac{1}{3}[(2-3\lambda)\frac{2}{\quad} - 2\left(\frac{3}{4}\lambda - \frac{2}{3}\right)(3\lambda - 1)]$$

$$+ \frac{1}{3}[(2-3\lambda)(3\lambda - 1) - \lambda\left(\frac{3}{4}\lambda - \frac{2}{3}\right)]$$

$$+ \frac{1}{5}[(3\lambda - 1)^2 - 2\lambda(2 - 3\lambda)] - \frac{1}{3}\lambda(3\lambda - 1) + \frac{\lambda^2}{7}$$

$$\frac{\delta I}{\delta \lambda} = 0 = 2\left(\frac{3}{4}\lambda - \frac{2}{3}\right)\left(\frac{3}{4}\right) + \frac{3}{4}(2 - 3\lambda) - 3\left(\frac{3}{4}\lambda - \frac{2}{3}\right)$$

$$+ \frac{1}{3}[2(2-3\lambda)(-3) + \frac{3}{2}(3\lambda - 1) \mp 6\left(\frac{3}{4}\lambda - \frac{2}{3}\right)]$$

$$+ \frac{1}{2}[-3(3\lambda - 1) + 3(2 - 3\lambda) - \left(\frac{3}{4}\lambda - \frac{2}{3}\right) - \frac{3}{4}\lambda]$$

$$+ \frac{1}{5}[6(3\lambda - 1) - 2(2 - 3\lambda) + 6\lambda] - \frac{1}{3}(3\lambda 1 - \lambda + \frac{2\lambda}{7}$$

$$0 = \frac{9}{8}\lambda - 1 + \frac{3}{2} - \frac{9}{4}\lambda - \frac{9}{4}\lambda \mp 2 - 4 + 6\lambda + \frac{3}{2}\lambda - \frac{1}{2} + \frac{3}{2}\lambda - \frac{4}{3} - \frac{9}{2}\lambda$$

$$\mp \frac{3}{2} + 3 - \frac{9}{2}\lambda - \frac{3}{8}\lambda + \frac{1}{3} - \frac{3}{8}\lambda + \frac{18}{5}\lambda - \frac{6}{5} - \frac{4}{5} \mp \frac{6}{5}\lambda + \frac{6}{5} - \lambda$$

$$+ \frac{1}{3} - \lambda + \frac{2}{7}\lambda$$

$$0 = 6\lambda - 2 + \frac{3}{8}\lambda - 9\lambda + 3\lambda + 6\lambda - \frac{9}{2}\lambda + 2\lambda$$

$$+ \frac{2}{7}\lambda - 1 + \frac{4}{3} + \frac{3}{2}$$

$$0 = -\frac{1}{8}\Lambda + \frac{2}{7}\Lambda - \frac{1}{6}$$

$$\frac{9}{56}\Lambda = \frac{1}{6}$$

$$\Lambda = \frac{f\,L}{3\,D_m} = \frac{56}{54}$$

$$= \frac{28}{27} \simeq 1$$

## CONCLUSION

From the proceeding analysis, it may be concluded that the pressure rise due to deceleration in a closed end dividing flow manifold with equal and uniformly spaced laterals, can be balanced by frictional pressure losses by making $f L/3D_m$ term equal to 1. The term f means suitable selection of pipe material, i.e., f, its length, L, and its diameter $D_m$.

## NOMENCLATURE

| | |
|---|---|
| D | Diameter of dividing flow manifold |
| f | Dimensionless friction factor |
| g | Acceleration due to gravity |
| L | Length of dividing flow manifold |
| P | Pressure in dividing flow manifold |
| x | Distance along dividing flow manifold |
| V | Velocity in dividing flow manifold |

*Subscripts*

| | |
|---|---|
| i | Inlet |
| m | Dividing flow manifold |
| x | Horizontal in flow direction |

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