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# Gas flow through vertical pipe and perforated vertical pipe

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**Abstract:** In this study major and minor energy loss in vertical pipe and vertical perforated pipe were investigated. Bernoulli's principle can be derived from the principle of conservation of energy. This states that, in a steady flow, the sum of all forms of energy in a fluid along a streamline is the same at all points on that streamline. This requires the sum of kinetic energy, potential energy and internal energy remains constant. Thus an increase in the speed of the fluid – implying an increase in both its dynamic pressure and kinetic energy – occurs with a simultaneous decrease in the sum of its static pressure, potential energy and internal energy.We have developed and classified all equations of energy loss that effect on gas flow through pipe and perforated pipe. Constant uniform flow out of perforated pipe was investigate.it showed that uniform fluid distribution along the perforated pipes can be achieved by proper selection of pipe diameter, size of perforations, and spacing between perforations.
**Keywords:** pressure drop, perforated pipe, orifice, friction factor.

## Introduction

Vertical perforated-pipe distributor has difference usage for efficient operation of chemical processing equipment such as contactors, reactors, mixers, burners, heat exchangers, extrusion dies, and etc. The design of perforated pipes for fluid distribution is a problem encountered in many fields. Such distributors are used in reaction vessels in chemicalengineering, spray and irrigation lines in agriculture, and heating and cooling ducts in environmental control.

In some cases it is required to provide uniform distribution of fluid, as in irrigation; while in others the distribution must vary along the pipe in some prescribed way, as with an uninsulated hot-air duct where uniform heat output is required.

The amount of fluid being discharged from any opening in a pipe is dependent on the discharge coefficient for the hole and the static pressure difference which exists across it, if both of these quantities remain constant along the distributor then uniform discharge will occur.

It is increasingly evident that to obtain an optimal design, engineers must give proper consideration to three conditions:

1. Flow behavior in the distributing unit. Optimum design can be obtained only through full understanding of the flow behavior involved in the distributing unit itself. An undesirable alternate solution is through expensive trial and error design on each piece of equipment.
2. Upstream flow conditions. Many distributor designs have failed because the mechanism of flow upstream of the distributor was either not taken into account or elsenot fully understood.

3. Downstream flow conditions. A unit giving excellent distribution ofa fluid may actually be detrimental to theprocess because intolerable downstream flow phenomena are created.

## Literature review

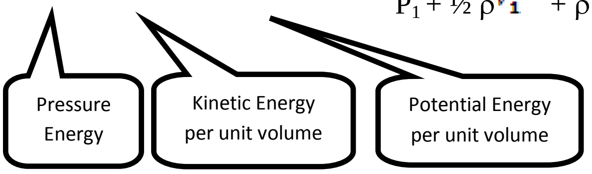
### A. Bernoulli Equation

Bernoulli's principle can be applied to various types of fluid flow; there are different forms of the Bernoulli equation for different types of flow. The simple form of Bernoulli's principle is valid for incompressible flows (e.g. most liquid flows and gases moving at low Mach number).

Bernoulli's principle can be derived from the principle of conservation of energy. This states that, in a steady flow, the sum of all forms of energy in a fluid along a streamline is the same at all points on that streamline. This requires that the sum of kinetic energy, potential energy and internal energy remains constant.[1]

The Bernoulli Equation can be considered to be a statement of the conservation of energy principle appropriate for flowing fluids.

$$P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2$$




### B. Macroscopic Fluid Distributors

The perforated pipe is a common type of distributor used in a wide variety of piping configurations such as ion exchange beds, absorption towers, and packed towers, as well as furnaces and reactors. It may either distribute or collect fluids in towers ranging from 1 to 30 or more feet in diameter. Figure l shows a single manifold, which is generally one lateral of a many branched feed system. Here, the arrows depict ideal distribution over the length of the unit-that is. The discharge arrows, being of equal height, indicate that the same amount of fluid comes out of each hole in the manifold. This ideal distribution is realized when a proper balance exists between kinetic energy and momentum of the inlet stream, friction losses along the length of the pipe, pressure drop across the outlet holes, and various interactions between these factors.

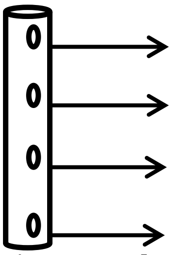


**Figure 1: Ideal distribution**

### C. Pressure Loss in pipe

In order to have flow in a pipe system, a pressure difference is needed, as fluids flow from a high-pressure point to a low-pressure point. One can identify three components that define this pressure difference:

1) Hydrostatic pressure loss, 2) Frictional pressure loss, 3) Kinetic pressure loss

In upward (or “uphill” in the context of pipelines) flow, fluids must overcome the backpressure exerted by the effective column of fluid acting against the direction of flow. They must also overcome friction losses due to the interaction of the fluid with the pipe wall.

In downward (or “downhill” in the context of pipelines) flow, friction effects act against the direction of flow, but in this case, the effective hydrostatic column helps the fluid to overcome such friction losses.

Hydrostatic pressure losses are a function of the density of the fluid in the pipe. Frictional losses depend on the fluid properties and flowing conditions within the pipe.

There are numbers of calculation methods used to account for hydrostatic and frictional fluid losses under a variety of flow conditions.

**C-1 Hydrostatic Component**

This component is of importance only when there are differences in elevation from the inlet end to the outlet end of a pipe segment. (In horizontal pipes this component is zero.)

$\Delta P_{HH} = (g\mathbf{h}$

Where: ρ, density of the fluid. g, acceleration of gravity. h, vertical elevation (can be positive or negative).

**C-2 Kinetic Component**

Although we often account for a major portion of the head loss, especially in process piping, the additional losses due to entries and exits, fittings and valves are traditionally referred to as minor losses. These losses represent additional energy dissipation in the flow.

$$\frac{(V]^2}{2g}$$

Where: V, flow rate. K, the loss coefficient and (0 < K < 1).

Maldistribution in manifolds with effect of momentum and kinetic can show up in Fig 2, When effects associated with momentum and kinetic energy predominate, higher flows occur from holes near the closed end of the distributor.

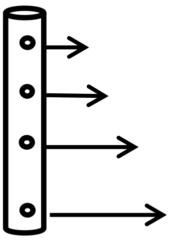


**Figure 2: Distributor with effect of momentum and kinetic energy. (Downward flow)**

**C-3 Friction Component**

During pipe flows, friction results from resistance of the fluid to movement. Friction can be thought as energy that is "lost" or "dissipated" (transformed into non-useful thermal energy) in the system. In single-phase flow scenarios, the frictional component can be found by the general Fanning equation:

$$\Delta P_f = \frac{2f\ (v^2 L}{g_c D}$$

This correlation can be used either for single-phase gas or for single-phase liquid pipe flows.

Maldistribution in manifolds with effect of friction can be shown up as Fig 3, when the friction term dominates, the first hole discharge more than their proper share.

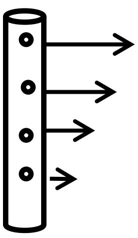


**Figure3: Distributor with effect of friction. (Downward flow)**

**D. Fanning friction factor (f):**

The Fanning friction factor is a dimensionless number used in fluid flow calculations. It is related to the shear stress at the wall.

Laminar and Turbulent flows can be characterized and quantified using Reynolds Number established by Osborne Reynolds, and is given as:

$$\frac{\square}{\mu} = \frac{VD}{\upsilon}$$

$N_R < 2100$ Laminar flow, $N_R > 4000$ Turbulent flow

Fanning friction factor for laminar flow can be obtained from Hagen-Poiseuille equation.[2]

$$f = \frac{16}{N_R}$$

For turbulent regime the roughness of pipe itself comes into play. Colebrook and White equation can be used to estimate fanning friction factor for turbulence. This correlation is available as a graph (Moody graph) and shown in Fig 4.The Colebrook formula gives a good approximation for the *f*-Re-(e/*D*)data for rough pipes over the entire turbulent flow range.[3]

$$\frac{1}{\sqrt{f}} = -4log\left[\frac{\varepsilon}{3.7D} + \frac{1.256}{N_R\sqrt{f}}\right]$$

Unfortunately, the Colebrook equation is implicit in *f* (since *f* appears on both sides of the equation), and the equation must be solved by iteration. An approximation to the Colebrook equation was created by Haaland, accurate to ± 2% compared to the Colebrook equation:

The Haaland equation.[4]

$$\frac{1}{\sqrt{f}} = -1.8log\left[\frac{6.9}{N_R} + \left( \left[\frac{\varepsilon}{3.7\mathbf{D}}\right]\right)^{1}.11\right]$$

For turbulent flow in smooth tubes, the Blasius equation gives the friction factor accurately for a wide range of Reynolds numbers $4000 < N_R < 10^5$:

$$f = \frac{0.079}{{N_R}^{0.25}}$$

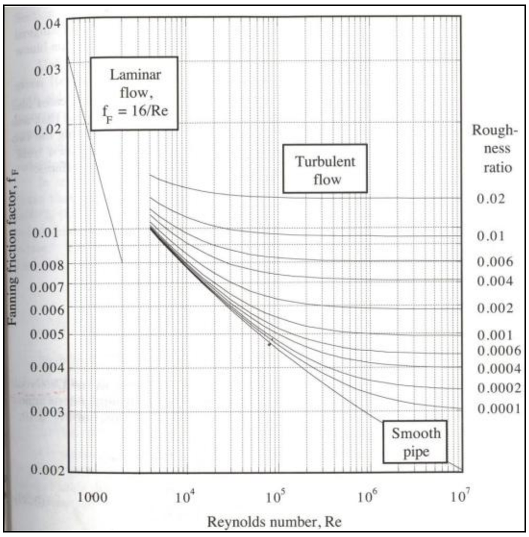



**Figure 4: Moody chart**

Swamee and Jain converted the moody graph into an equation.[5]For the turbulent portion - (less than 1% error)

$$f = 0.25\left[\log\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{{N_R}^{0.9}}\right)\right]^{-2}$$

*Pressure Loss in vertical pipe:*

Pressure loss in vertical pipe show in below equation:

$$\Delta P_T = (gh + \frac{2f\,(v^2 L}{gD} + K\,[(V]^2/2g$$

*E.* **Pressure loss in perforated vertical pipe**:

Pressure loss due to friction effects for n number of holes

$$(P]_f = \frac{2f\,(LV_1^2}{Dg_c}\sum_{i=1}^{n}\frac{\left[\frac{n-(i-1)}{n}\right]^2}{n}$$

Above equation has the unique advantage over other equations reported in the literature for calculating frictional losses in pipe distributors that it is a function of the number of holes, *n*

If the summation term is taken and plotted with respect to the number of holes, an asymptote of 0.33 exists for large values of *n* (Figure 5).[6]

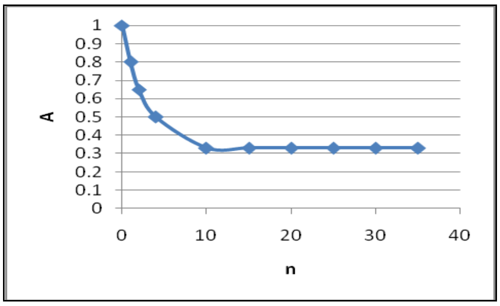



**Figure 5: Summation term plotted as a function of the number of holes**,

$$A = \sum_{i=1}^{n}\frac{\left[\frac{n-(i-1)}{n}\right]^2}{n}$$

Pressure loss due to kinetic energy effects for n number of holes:

$$\frac{k}{g_c}\left[1 - \frac{1}{n^2}\right]V_1^2$$

$0 < k < 1$

When *n* is sufficiently large, $[1 - \frac{1}{n^2}]$ in above Equation goes to 1.[6]

$$\Delta P_T = \frac{2f\,(LV_1^2}{Dg_c}\,(0.33) + (k/g_c\ V_1^2 + (gh$$

Simplified:

$\Delta P_T = (4fL/D - 2K)(V_1^2 \; + (gh$

**F. Uniform distribution:**

To obtain a desirable uniform distribution, the average pressure drop across the inlet holes $(P)_{hole}$ would have to be larger as compared to the pressure variation over the length of pipe ΔP. When the area of an individual inlet hole is small as compared to the cross-sectional area of the pipe, inlet hole pressure drop may be expressed in terms of discharge coefficient $C_o$(orifice discharge coefficient usually taken as 0.62), and the velocity across the inlet hole $V_{hole}$ as Perry and Green.[7]

$$(P)_{holes} = \frac{1}{C_0^2}\frac{(V_{hole}^2}{2}$$

Provided that $C_o$ is the same for all the inlet holes, the percent mal distribution, defined as the percentage variation in flow between the first and last inlet holes may be estimated reasonably well for small mal-distribution by Senegal.[8]

$$\text{percent mal distribution} = 100[1 - \sqrt{((P)_0 - |(P|)/(P)_0)}]$$

Above equation shows that for a 5% mal distribution, the pressure drop across the inlet holes would be about 10 times the pressure drop over the length of the pipe ($\Delta p_{hole} = 10\Delta p$).

For discharge manifolds with $K$=0.5, and with $4fL/3D$ <<1, the pressure drop across the holes should be 10 times the inlet velocity head, $(V_i^2/2$ for 5% mal distribution. This leads to a simple design equation.

Discharge manifolds, $4fL/3D$<<1, 5% mal distribution.[9]

$$\frac{V_{hole}}{V_i} = \frac{A_c}{A_h} = \sqrt{10}C_o$$

**Orifice Configuration (Blockage Ratio):**

Flow pattern and discharge angle tends to change when there are changes in number of orifices and also the configuration of orifices. Due to the long length of perforated tube, the flow between orifices is not uniform due to changes in pressure. Besides, the discharge angel of stream released tends to change from each location. Sangkyoo and team discovered that the flow rate distribution between orifices could be adjusted by varying aspect ratio of orifices.[10]Before Sangkyoo and team, Ahn ever fixed the diameter of orifices with low Reynolds number. Flow rate distribution characteristics depend on the Reynolds number that obtained (to ensure laminar flow).[10]In addition, Foust discovered that the velocity change between orifices seems to be small when a high speed air was injected inside the tube. Besides, another phenomena been discovered that the discharge angle turns perpendicular with respect to perforated tube length as it gets closer to the end of orifices. To conclude the findings of three researchers above, the flow rate characteristics in perforated tube can be controlled by the configuration of orifices. The flow pattern around orifice exit shown in Figure 6 and velocity was expressed in colors.

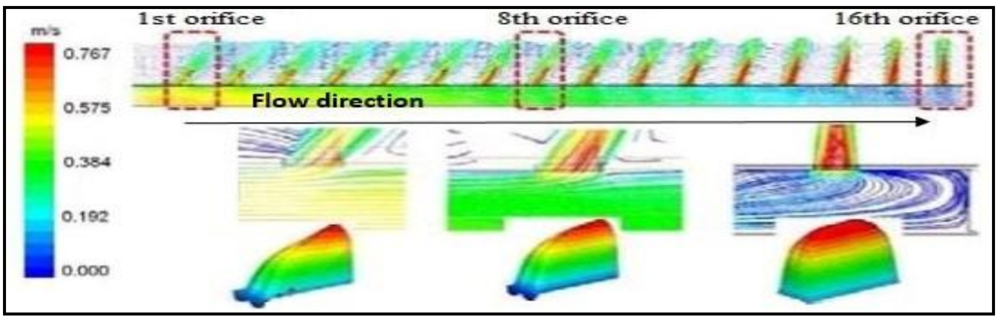



**Figure 6: Velocity vector plots and streamlines around orifices exit when BR = 0.957 and Re = 7 x 10$^4$**

## Conclusion

Uniform fluid distribution along the perforated pipes can be achieved by proper selection of pipe diameter, size of perforations, and spacing between perforations. As long as the clogging potential is avoided, smaller perforation sizes are preferred for better fluid distribution. Unit discharge rate can be determined based on the entrance pressure and the perforation size. Most distributing systems can be designed with a reasonable degree of accuracy where maldistribution of about ± 5 % can be tolerated. The trend in the chemical industry, however, is to recognize desirability of designs which provide essentially uniform distribution. Uniform distribution should be obtained on an optimum design basis, keeping the original investment such as equipment size and operating expense such as power requirements to a minimum.

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