

Research on Resistance Properties of Gas-Solid Flow in Y-shaped Branch Pipe

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ABSTRACT: In this paper, Y-shaped branch pipes are designed with one branch being unchanged and the other being changeable. Gas-Solid flow experiments of average particle diameter 2mm millet are carried out using compress air at horizontal Y-shaped branch pipe. Resistance properties of each branch and the mutual resistance characteristics are described. The results show when the superficial gas velocity reduces, the pressure drop on each branch and the pressure drop differential value of the two branches decrease firstly, but when the superficial gas velocity reduces to deposition velocity, the respective pressure drop begin to rise. With the differential value rising of the angle between the changing branch and the main pipe, it is found that the pressure drop curve of each branch and the pressure drop differential value of the two branch are away from each other in high gas velocity zone, while become near in low gas velocity zone. Meanwhile, principal component analysis method is adopted to explore the importance of influencing factors and their correlation. The experimental consequence shows that the angle between the changeable branch and the main pipe, superficial gas velocity and the solids loading ratio are chief influencing factors.

Keywords: Gas-solid flow, Branch pipe, Resistance properties, superficial gas velocity, Principal component analysis

NOMENCLATURE

1. INTRODUCTION

Two-phase gas-solid flow occurs in many processes, mainly in pneumatic conveying.^[1] This type of transport is widely used in heat energy engineering, food industry, production of building materials, chemical industry, metallurgy and other fields because of low energy consumption, low wear and flexible installation. Phenomena occurring in vertical, horizontal and lean pneumatic conveying are well known and they have been widely discussed in literature^[2]. But the flow property of branch pipe is little reported. As an important parameter of gas-solid two phase flow in

branch pipe, pressure drop can't be ignored^[3]. It influences the layout of pipe network and the dynamic requirement^[4]. A number of theoretically based models and empirical correlations haven been developed for calculating the pressure drop along the pipe^[5], but most research focused on horizontal and vertical cases^[6]. The present paper designs streamlined Y-shaped branch gas solid flow experimental bench and explains the resistance characteristics of the Y-shaped branch in gas-solids pipe flow experimentally. The results mainly described the flow pattern, pressure drop on each branch. The pressure drop differential value between the two branches is mentioned by principal component analysis too. The consequence and correlation

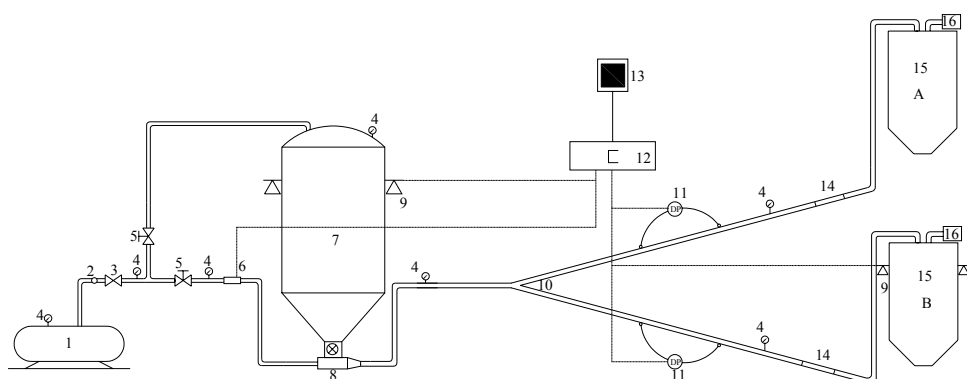


Figure 1: Schematic diagram of the experiment system

1. air supply 2. oil-and-moisture trap 3. gas flow control valve 4. static pressure apparatus 5. gas valve 6. gas flux apparatus 7. feeder 8. solid injector 9. weight balance 10. Y-junction 11. differential pressure cell 12. data collector 13. microcomputer 14. lucite pipe 15. collecting bin A, B 16. Dust collector

analysis on the differential value between the two branch pipes have demonstrated the chief influencing factors are the angle between the changeable branch and the main pipe, superficial gas velocity and the solids loading ratio.

2. EXPERIMENT SYSTEM

The dividing flow branch pipes are often encountered in the pneumatic conveying engineering. One of the simplest devices used for this purpose is the Y-junction connected with the main channel and two branch pipes, which have symmetrical construction. In this paper, the transporting system (see Fig1) is made up of gas supply, feeder, collecting system, data acquisition system and pipeline. The transporting system is seamless steel pipes with the diameter of 32mm. Y-junction is designed well in this paper as shown in Fig2. One angle between branch and main pipe is 15° (angle α) which is unchanged, flowing in collecting bin A (A branch), while the other angle is changeable with their values being 10° , 15° , 20° , 30° (angle β), which connects with bin B (B branch). Note that in the context, angle α is defined the angle between unchanged branch and the main

pipe, while angle β stands for the angle between changeable branch and the main pipe. Y-junction is made of lucite, and was linked with seamless steel pipe by reinforced flange. Solid flow rate was controlled by the opening angle of the solid injector valve (see Fig.1). Differential pressure cell and static pressure apparatus were installed after the Y-junction in the branch pipes to measure the pressure drop and static pressure along the pipe. Electronic-weighting system was introduced to weight solid in the collecting bin B and feeder respectively.

Millet with the mean diameter of 2mm and solid density of 1340kg/m^3 was taken along with compressed air in transporting pipeline. In the experiment, gas volume flow ratio was controlled from $0.0097\text{ m}^3/\text{s}$ to $0.018\text{ m}^3/\text{s}$ and the solids loading ratio was from 15 to 25.

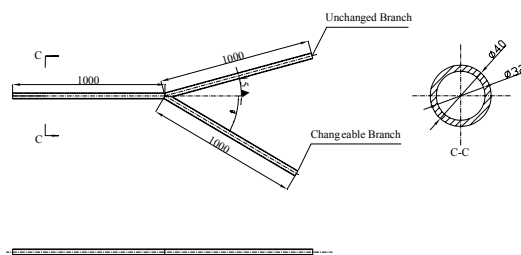


Figure 2: Schematic diagram of Y-junction



Figure 3: Flow style of the branch pipe with the angle $\beta = 10^\circ$

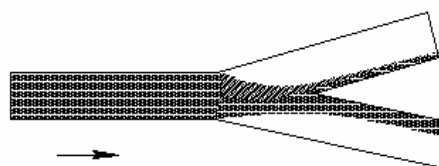
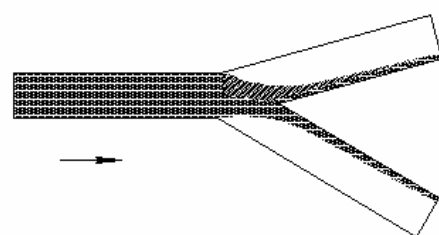


Figure 4: Flow style of the branch pipe with the angle $\beta = 30^\circ$



3. FLOW PATTERN ANALYSIS

At first, the gas-solid two phase fluid flows in the pipe before the Y-junction with homogenous suspension flow style, as shown in Fig3 and Fig 4. The collision frequency between the particles, particle and wall decreased because of the enlargement of pipe cross-sectional area when the two phase flow across the Y-junction. The gas velocity is high, according to Newton's second law of motion, the solids accelerate faster. It can be seen from lucite pipe that the two phase flow can not full all pipe at the beginning, but deviate inner side of pipe. This phenomenon belongs to Coanda effect. The flow becomes symmetrically again after redistribution in each branch pipe. By comparing Fig 3 and Fig 4, we can conclude that the solid mass flowing in branch pipe increased with the diminishing of the angle between main pipe and the branch. At the same time, the flow style is changing while the gas velocity becomes less. The solid will deposit when the gas velocity is low enough.

4. THE RESPECTIVE PRESSURE DROP ON EACH BRANCH PIPE

Thanks to the pressure drop measurements, we can see when the operation pressure keep to a constant value, the angle between the branch and the main pipe, the change of conveying velocity have some noticeable effect on the respective and mutual resistance properties of the branch pipe. Note that the resistance property was evaluated by the survey of the pressure drop per unit of length along pipeline.

Fig5~Fig8.show the trend of pressure drop on each pipeline being transported at different gas velocity. Not that the points are our experimental data, whereas the curves are the interpolation on these points. In order to contrast, twice of the pressure drop per unit of length of purity air is added into the figures. These diagrams illustrate pressure drop on each branch reduces greatly with the compressed air velocity becoming smaller. But when the gas velocity is diminished to a definite value, continuing to reduce the air velocity, the pressure drop will increase on the contrary. The gas velocity is defined deposition velocity. And at the same time, inflection point will appear on the resistance property curves.

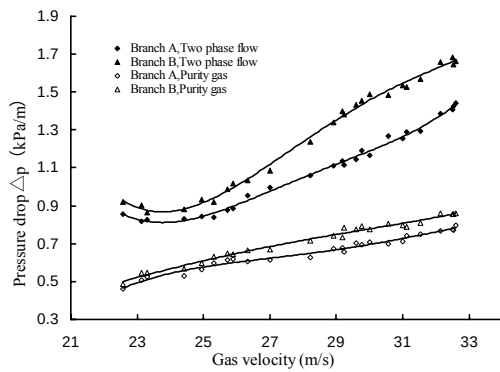


Figure 5: Pressure drop curve for $\beta = 10^0$

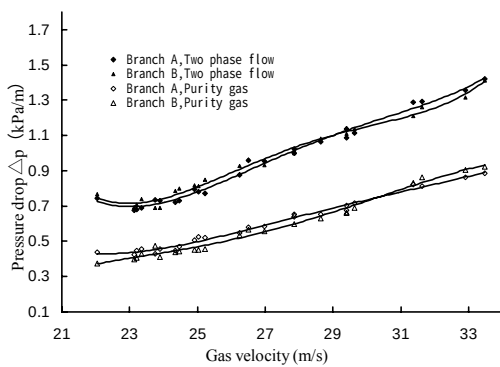


Figure 6: Pressure drop curve for $\beta = 15^0$

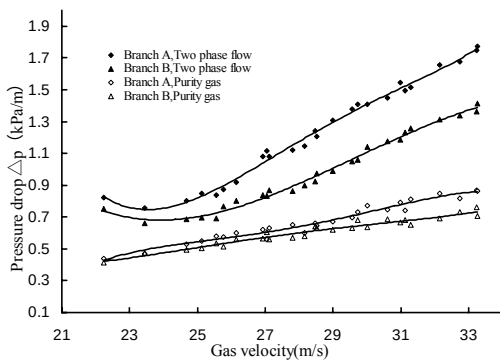


Figure 7: Pressure drop curve for $\beta = 20^0$

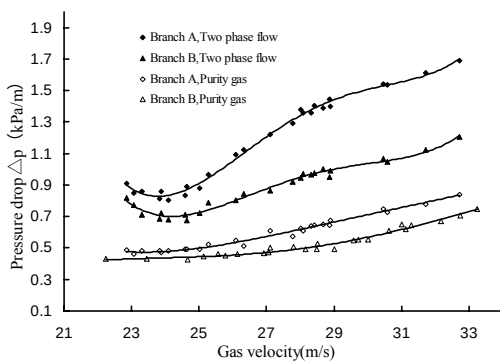


Figure 8: Pressure drop curve for $\beta = 30^0$

When the air velocity is bigger than the deposit velocity, the chief influencing factors are the two phase velocity and slip velocity between gas and solid. The particles accelerate more quickly with the gas impetus getting bigger. This improves the particles' turbulent kinetic energy. At the same time, the superficies frictional force between the fluid and wall and the inter-particle collision strengthen. All factors lead to the increasing of pressure drop. But if we decrease the air velocity under the deposit velocity, the concentration of solid prevail all other factors on the pressure drop. Pressure drop on each branch increases with the gas velocity going down. Thus, the inflection point is defined. At this point, the pressure losses are minimum and the particle begin to settle on the bottom of pipe. From these diagrams, we also concluded that the deposit velocity of each branch on one Y-shaped branch pipe is different. This means the deposit in each branch isn't synchronous.

Comparing Fig5, Fig7 and Fig8, we can realize that, the pressure drop per unit of length curve of the branch with bigger angle between the branch and main pipe is below that of other branch. It means the pressure drop on the branch with bigger angle is smaller. Note that, whatever the branch, the general style of curves looks similar. Moreover, we notice that the pressure drop curves of each branch are away from each other in high gas velocity zone, while become near in low gas velocity zone.

Fig 6 shows the pressure drop on each branch pipe with the same angle between branch and main pipe ($\beta = \alpha = 15^0$). The curves are close in the whole gas velocity domain, which mean the resistance properties on each branch are the same.

From Fig5 to Fig8, we can achieve that to purity gas, pressure drop on each branch also decrease with the reduction of gas velocity, which has same trend with that of gas-solid flow in high gas velocity zone.

5 THE MUTUAL RESISTANCE PROPERTIES OF BRANCH PIPE

5.1 Experimental Investigation

The mutual resistance properties was expressed by differential value for the pressure drop between the unchanged branch and changeable one.

From the result on the Fig5~Fig8, we traced the evolution of the differential value for the pressure drop between the two branches, according to the gas velocity ,for values of β ($10^\circ, 15^\circ, 20^\circ, 30^\circ$ respectively) on Fig.9.

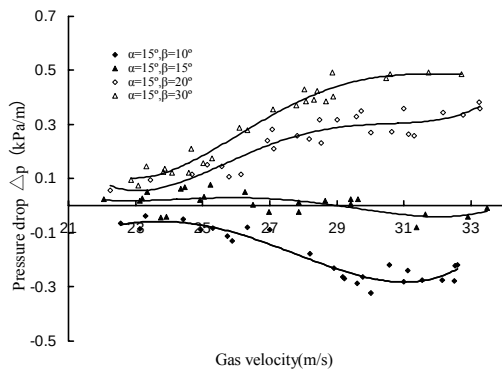


Figure9: Differential value curve between the unchanged branch and changeable branch

As shown in Fig.9, the absolute value of the pressure drop differential value between branch A and branch B reduces as the air velocity decreases. It will be obvious to the branch pipe with high absolute value of $(\alpha - \beta)$. As the absolute value of $(\alpha - \beta)$ increases, under the same air velocity consequence, the pressure drop differential value becomes larger. Fig.9 also shows that the curve of the pressure drop differential value becomes far away in high gas velocity zone while draws near when the gas velocity decrease. It is because the chief influencing factors of the pressure drop differential value are the value of $(\alpha - \beta)$ and the gas velocity in high gas velocity zone, while in low gas velocity zone, the flow style in each branch changes non-synchronously. As $\alpha = \beta$,

the pressure drop differential values fluctuate near 0.

5.2 Application of Principal Component Analysis on the Mutual Resistance Properties

Principal component analysis is a statistical method, which is widely used in many fields. It concentrates the reducing of the parameters' amount by reconstructing experimental data to gain new variables which are irrelevant.

As we all know, original data matrix can be decomposed into two parts. One is called score matrix, the other is loading matrix. The correlations have been realized with the following function:

$$X = TL^T \quad (1)$$

Where X, T, L are original data matrix, score matrix and loading matrix respectively. X matrix is made up of n lines and p rows, where n stands for sample and p is characteristic. T matrix is made up of n lines and d rows, where d is the amount of principal components. L matrix is made up of p lines and d rows.

The amount of principal components is determined on the basis of maximum variance rule. Most variances can be involved by the first and second principal component. And the data is displayed by the relation figures of the principal components.

With independence and correlation of all factors being considered, four major factors of the mutual resistance properties were confirmed in this paper. They are the angle between the changeable branch and the main pipe (angle β , X_A in Fig10), the gas velocity (v_g , X_V in Fig10), the solids loading ratio (k , X_K in Fig10), and the differential value of static pressure on the two branches (P_m , X_P in Fig10). At the same time, pressure drop differential value is regarded as the target. In this paper, excellent sample was set when the accumulative contribution rate is more than 85%. Standardized matrix was obtained after standardizing the original

Table1Eigenvalue & The Accumulative Rate of Variance

component	Characteristic number λ	Contribution rate (%)	Accumulative contribution rate(%)
1	0.2943	67.883	67.883
2	0.1315	30.318	98.201
3	0.0078	1.799	100.000
4	0.000	0.000	100.000

Table 2 Loading Matrix of Standard Data

Code number	Loading vector			
	PC1	PC2	PC3	PC4
β	0.829	-0.184	0.171	0.500
Vg	-0.251	0.675	0.481	0.500
k	-0.493	-0.687	0.1867	0.500
Pm	-0.085	0.197	-0.839	0.500

experimental data. Thus principal component analysis was carried out. The results were shown in Table.1 and Table.2. Note that PCi (i=1,2...)stands for the principal component.

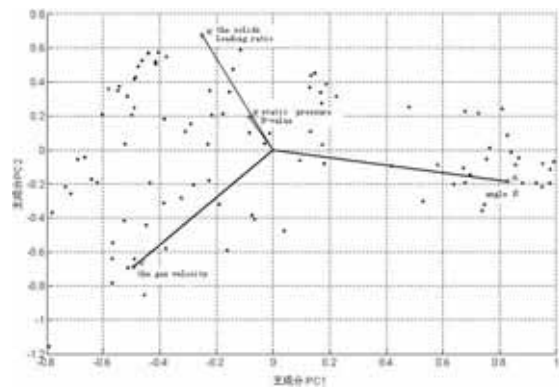
From Tab.1 and Tab.2, we can mention that the accumulative contribution rate of PC1、PC2 arrives at 98.201%, which is more than 85%. Consequently, the two principal components consist of most experimental sample information. Then the equations of PC1 and PC2 can be described as the following:

$$PC1 = 0.829X_A - 0.251X_V - 0.493X_K - 0.085X_P \quad (2)$$

$$PC2 = -0.184X_A + 0.675X_V - 0.687X_K - 0.197X_P \quad (3)$$

In the equation of PC1, the loading coefficients of X_V , X_P are -0.251,-0.085, and their absolute value is much less than that of X_A and X_K (the values are 0.829 and -0.493 respectively). It illustrates that in all influencing factors of the principal component PC1, the factors of X_A and X_K are the chief ones. Also, judged by the absolute value of all factors loading

coefficients, X_K and X_V affect PC2 obviously.

**Figure10:** Score and Loading Biplot of PCi

As shown in Fig.10, the score plot describes the linear projection which represents the main portion of experimental samples. PC1 and PC2 summarizes most experimental sample information. The excel sample mostly concentrates the plot of $-0.8 < PC1 < 1, -0.8 < PC2 < 0.8$. The loading plot can be used to explore the importance and correlation of the influencing factors. According to this plot, the distance between the grid origin and point A, point V is longer than others. So we can achieve that the chief influencing factors are the angle between the changeable branch and the main pipe, the

gas velocity, and the solids loading ratio is the secondary factors. The results agree with the experimental conclusion well.

6 CONCLUSION

This paper sets up an experimental pneumatic conveying bench with Y-junction being used. A combination of theoretical and experimental techniques for characterizing and predicting the resistance properties of Y-shaped branch pipe has been proposed and developed.

Firstly, this study presents the trend of respective pressure drop on each branch pipe and the mutual resistance properties. At the same time, the deposit velocity is confirmed. The relationship of flow style and the pressure drop is achieved too. The variation curves of respective pressure drop and mutual resistance properties are analysed in different gas velocity zone. Finally, principal component analysis method is adapted to evaluate the main affecting factors of the differential value between the unchanged branch and changeable branch. The results show that the chief factors are the angle between the changeable branch and the main pipe, the gas velocity and the solids loading ratio, which have good agreement with the experimental conclusion.

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