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Experimental Investigation of the Effect of Fluid-Solid Mixture Flow by Pneumatic System in Textile Industry

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The transport of multiphase flows of slurry (fluid-solid) through pipelines is usually encountered through several hurdles in various industries such as cement, textile and chemical industries. The flow parameters such as solids concentration, pipe directions and so on, add to these complexities and concepts associated with transport of slurries seems to be uncertain which has resulted in significant research being conducted on flow of slurries through pipelines. The investigation has been carried out in Textile and garment factory at Ethiopia in eastern Africa. The objective of the investigation is to study the effects of transporting of fluid-solid mixture (air-cotton ball) through horizontal, vertical and inclined pipelines in a textile factory. For this purpose one generalized mathematical model developed by Shrivastava and Kar (SK Model) was applied to predict more accurate results of pressure drop. The results of pressure drop obtained using SK model were compared with experimental results. The results showed that the percentage of head losses is increased in the smaller diameter pipe line about 48% and 67% with air velocity 12 m/s and 24 m/s respectively as compared to that of larger diameter pipeline. In the proposed pipeline system, it was observed that the energy saving can be achieved about 65% and 77% with air velocity 12 m/s and 24 m/s respectively.

Keywords: Cotton seeds, Fluid flow, Pipelines, Pressure

Introduction

In many process industries, the slurry transport (two phase - liquid and solid flow) through pipelines is widely encountered due to interfacial interaction as well as friction which lead to pressure drops. The flow of slurry in the inclined pipe is more complex than both vertical and horizontal flow as separation and slippage of phases happened simultaneously.[1] Besides minimal research have been conducted on inclined flow as compared to horizontal and vertical flow even though the occurrence of inclined pipes in industry is unavoidable in particular places.[2,3]

The SK model can be applied in optimizing the pipeline system to convey of solid particles such as cotton seed, powders, fine stones and pulverized coal etc., along with various pipe orientations. In this present study SK model was utilized to determine the pressure reduction for the pneumatic conveying system for cotton seeds through pipelines of different diameters.[4–7] The SK model was also been found useful on designing and optimize the several factors of pneumatic transport with energy conservation point of view.[8] The experimental work has been conducted in MAA Garment & Textiles Factory in the northern part of Ethiopia wholly owned by Kebire Enterprises PLC. In this study the SK model was used to determine pressure drop for transporting mixture of various mass loading ratio and also an attempt was made to analyze the optimum particle size which would offers very less resistance to transport of solid mixture and results into minimum losses in the pressure drop.[9–11]

Theory of SK Model

The total head losses (h_t) for conveying heterogeneous fluid mixture through unit pipe length, head losses (h_f) due to friction in the fluid-pipeline and further head losses h_s due to occurrence of solid mixture particles in the transportation were obtained by mathematical SK model. The total head losses (h_t) per unit length can be calculated from the following mathematical relation:[7, 9]

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$$h_t = \frac{fV_f^2}{2gD} + \left\{0.5C_d\rho_f A_p V_T^2 + m_P g\left(1-\frac{\rho_f}{\rho_p}\right)sin\theta\right\}\frac{M_s}{M_f}\frac{1}{m_P g} \quad \ldots (1)$$

The Darcy-Weisbach factor for friction (f) of the above relation (1) can be calculated by applying the Blasius equation as mentioned below:

$$f = \frac{0.3164}{Re^{0.25}} \quad \ldots (2)$$

where, Renolds numbers (R_e) defined as$R_e = \frac{V_f D}{v_f}$. The terminal velocity values (V_T) and coefficient of drag (C_d) of the solid particles to be conveyed with a carrier fluid through a pipeline and mean equivalent diameter of spherical (d) of the particles can be calculated from the following Eqs (3–7):

$$V_T = \sqrt{\frac{4gd(\rho_p-\rho_f)}{3C_d\rho_f}} \quad \ldots (3)$$

$$C_d = 18.5{Re_p}^{-0.6}, 0.1 < Re_p < 500 \quad \ldots (4)$$

$$C_d = 0.44\ , 500 < Re_p < 2\times10^5 \quad \ldots (5)$$

where, Re_p- Reynolds number for particles is written as

$$Re_p = \frac{V_p d}{v_f} \quad \ldots (6)$$

$$M_s = C_v A\left(V_g - V_T\right)\rho_p \quad \ldots (7)$$

In order to calculate critical velocity (V_C), the mathematical expression from the SK model can be applied from the Eq. (8) as given below:

$V_c = \Big[\Big\{0.5 \times C_d \times pf \times A_p \times V_t^2 + m_p \times$
g1−ρfppsinθ{2×Ms×DC+1mp×K×VfC2−CA×ρ f}13−C … (8)

The value of particle density (ρ_p) and density of fluid can be determined by following equation as mentioned below:

$$\rho_p = \frac{m_p}{V} \quad \ldots (9)$$

$$\rho_f = \frac{P}{R_{specfic}T} \quad \ldots (10)$$

Experimental Work and Techniques

In MAA garment factory, the cotton seed of solid particles is transported by the FD fan in the mode of air-solid mixture through pipe flowing out as waste material. However it is difficult and expensive to predict the pressure drop and critical velocity using instruments as the flow is two phase mixture. In this investigation an attempt was made to apply the SK model with the help of MATLAB to solve this problem of prediction.[12] Experimental study have been performed to analyze on the effect of drop in pressure due to internal pipe diameter, mass flow rate of solid and various particle diameter. Results of all graphs are plotted for head loss versus velocity of air to the corresponding pressure drop of the pipelines. The head loss (h_t) per unit pipe length for transporting heterogeneous air and cotton seed mixture in the horizontal pipe were calculated by using stated in theory of SK model.

Further experiments were conducted to obtain the volume, density and mass of cotton seed to analyze the properties of cotton seeds. From the experimental results the average volume of one particle was found as $2.33\times10^{-8}m^3$ and radius of cotton seed was calculated as 1.8 mm. The average mass and density of one cotton seed particle was determined around 0.0358 g and 1537 kg/m^3 respectively. The input data used for pressure drop prediction were collected from MAA garment and Textile factory manual.[13]

Structure of Existing Pipeline System

The existing pipe network in the knitting and spinning department consists of two different internal diameters, i.e. 0.25 m and0.65 m as shown in Fig. 1**.** The pipe diameter 0.65 m with flow rate of 0.167 kg/s starts from the pre-filter machine. After that it is extended and connected with another

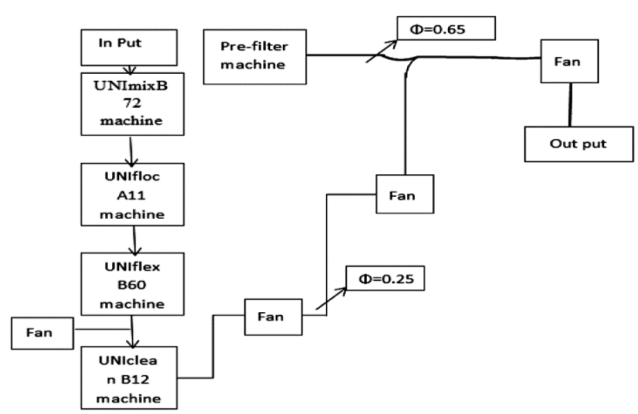

Fig. 1 — Existing pipelines for pneumatic conveying cotton seeds

pipe having diameter of 0.25 m that has flow rate of 0.75 kg/s which comes from the UN clean machine. Finally it is connected to 0.65 m diameter pipe that conveys cotton seed at mass flow rate of 0.95 kg/s.

Proposed pipeline system

The existing pipe lines for pneumatic conveying of cotton seeds shows greater pressure drop on the pipelines due to different geometric sections and thus leads to more energy loss. In order to reduce pressure head loss and energy savings purpose the new pipeline system have been suggested. In the proposed layout, internal diameter of 0.65 m pipe with flow rate of 0.95 kg/s has been suggested throughout the structure and eliminated two bends in the existing structure.

Results and Discussion

The results found from the SK model and experimental study of existing system for fluid-solid mixture flow through pipelines is discussed in this section.

Prediction of Pressure Drop for Horizontal Pipe

The variation of drop in the pressure against the velocity of air is shown in Fig. 2 (a) and Fig. 2 (b) for diameter of 0.25 m pipe and diameter of 0.65 m pipe, respectively. The properties of fluid for calculated values of $C_d$and V_t for both pipe diameter were calculated (Table 1 and Table 2). As shown in the both figures the actual critical velocity is not appeared in the graph of head loss against velocity of air. The reason may be due to the terminal velocity is less than the theoretical critical velocity. From the figure it can also be observed that in the diameter of 0.25 m pipe line, the percentage of head loss is increased about 48% with air velocity 12 m/s and 67% with air velocity 24 m/s when compared with diameter of 0.65 m pipe line.

Analysis of Proposed Pipeline System

The proposed pipeline system for pneumatic conveying of cotton seeds gives more energy saving by installing pipeline into horizontal and minimized bends in the system. Therefore internal diameter of 0.65 m pipe with flow rate of 0.95 kg/s has been suggested throughout the structure. The variation of pressure drops between existing pipeline and proposed pipeline for transporting of air-cotton seed by pneumatic system is depicted in Fig. 3. It is to be observed that the existing pipe diameter of 0.25 m with flow rate of 0.167 kg/s and other one is 0.65 m diameter pipeline with mass flow rate of 0.783 kg/s shows more pressure drop due to different geometric sections and thus leads to more energy loss as compared to proposed pipeline of 0.65 m diameter

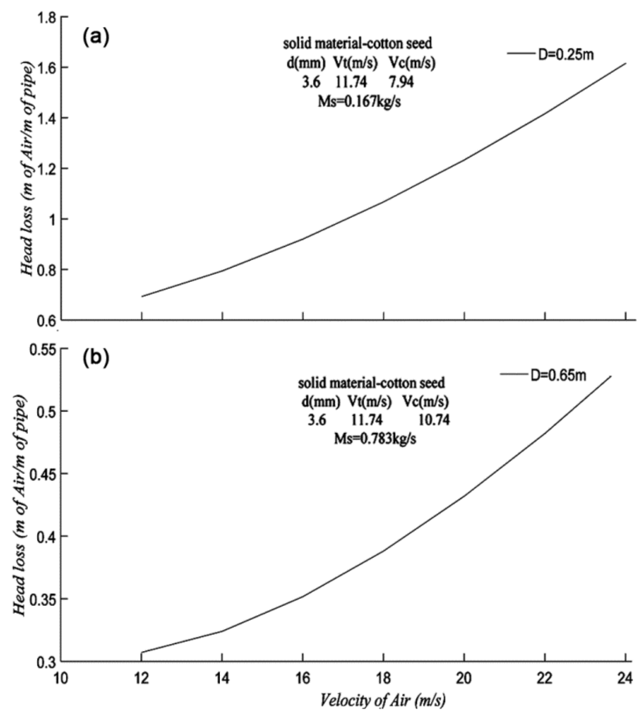

Fig. 2 — Pressure drop for horizontal pipe (a) diameter 0.25 m and M_s= 0.167 kg/s
(b) diameter 0.65 m and M_s=0.783 kg/s

Table 1 — Properties of fluid velocity for diameter 0.25m &M_s=0.167 kg/s

Parameters (Cottonseed)	Cd	ρ_p (kg/m^3)	ρ_f (kg/m^3)	D (mm)	V_T (m/s)	V_c (m/s)	h_f	h_s	h_t
Properties	0.44	1537	1.1919	3.6	11.7430	7.94	0.4431	0.2493	0.6924

Table 2 — Properties of fluid velocity for diameter 0.65m &M_s=0.783 kg/s

Parameters (Cottonseed)	ρ_p (kg/m^3)	ρ_f (kg/m^3)	D (mm)	V_T (m/s)	V_c (m/s)	h_f	h_s	h_t
Properties	1537	1.1919	3.6	11.7430	10.7349	0.1342	0.1729	0.3071

with mass flow rate of 0.95 kg/s. The percentage of energy savings for proposed pipeline of 0.65 m diameter at the flow rate of 0.95 kg/ are plotted in Fig. 4. It was noticed that the percentage of energy savings can be achieved about 65.58% and 77.15% at minimum air velocity of 12 m/s and at maximum air velocity of 24 m/s respectively. The increase in energy savings may be due to maintaining constant diameter pipeline and elimination of several bends throughout the structure in the pneumatic system.

Effects of Pipe Diameter

To investigate the effect on the various pipe diameters on the pressure drop, an additional pipe diameter of 0.45 m was introduced for comparison purpose with existing pipe diameter of 0.25 m and 0.65 m. In Fig. 5 the variation of head losses against different air velocities for various pipe diameters is depicted. It can be observed from the graph that as the pipe diameter increases (from diameter of 0.25 m to 0.65 m), the head loss decreases progressively throughout the various velocity of air. Therefore it is recommended to use the larger size pipe that could save considerable amount of energy.

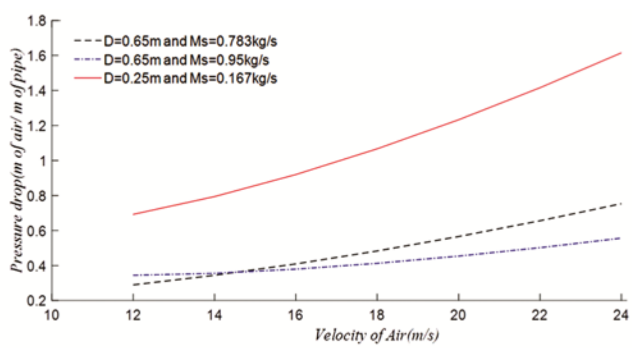

Fig. 3 — Pressure drop for existing and proposed pipeline

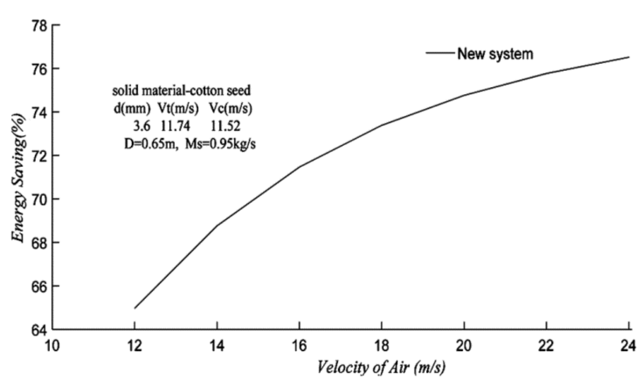

Fig. 4 — Energy savings for the proposed pipeline system

Effect of Particle Size

The comparison of pressure drop on various particle sizes (3 mm, 4 mm and 3.6 mm) for two different pipe diameters of 0.25 m and 0.65 m with flow rate of 0.167 kg/s are portrayed in Fig. 6 and Fig. 7 respectively. From the graphs it can be noticed that for both pipe diameters of 0.25 m and 0.65 m with constant mass flow rate of 0.167 kg/s, the head loss gradually decreases from larger particle size 4 mm to smaller particle size 3 mm. Therefore it is

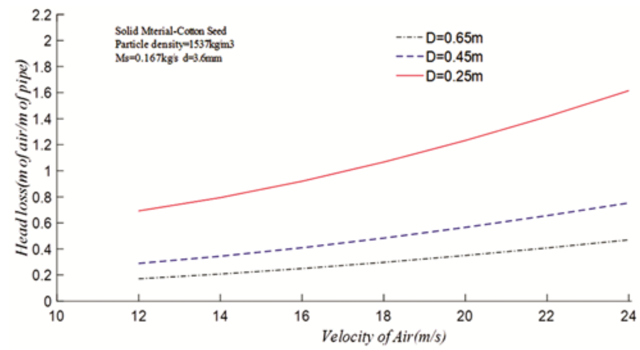

Fig. 5 — Pressure drop for horizontal pipe with various pipe diameter

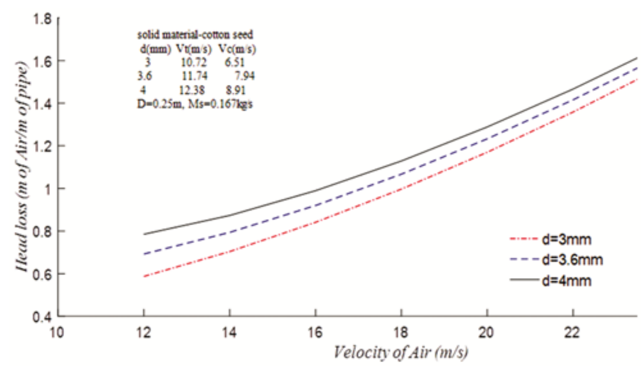

Fig. 6 — Head loss for horizontal pipe with diameter 0.25 m and M_s= 0.167 kg/s

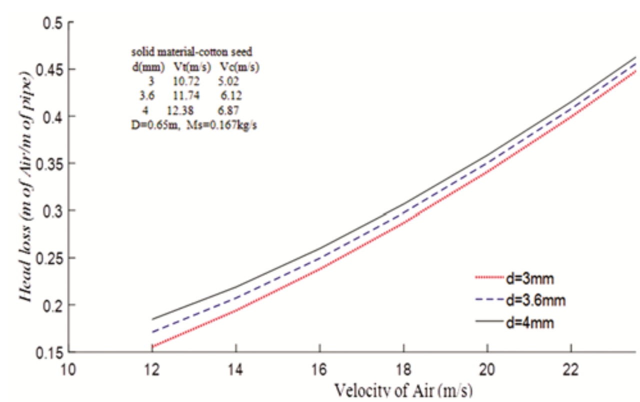

Fig. 7 — Head loss for horizontal pipe with diameter 0.65 m and M_s= 0.167 kg/s

recommended to optimize the particle sizes in order to reduce head loss in the textile industries.

Conclusions

1. In the 0.25 m diameter pipe line, the percentage of head loss was increased about 48% and 67% with air velocity of 12 m/s and 24 m/s respectively when compared with diameter of 0.65 m pipe line.
2. It is recommended to install pipeline of 0.65 m diameter with mass flow rate of 0.95 kg/s to minimize the head loss. The percentage of energy savings can be achieved about 65.58% and 77.15% for minimum air velocity at 12 m/s and maximum air velocity at 24 m/s respectively.
3. The head loss for horizontal pipe decreases as the pipe diameter increases with constant mass flow rate of mixture.
4. The head loss is gradually decreases from larger particle size of 4 mm to smaller particle size of 3 mm for constant mass flow rate of mixture in the pipeline

References

1 Gilliese R G, McKibben M J & Shook C A, Oil, water and sand flow experiments in a model horizontal well, *Proc 3rd North Am Conf Multiphase Tech* (BHR Group, Cranfield, U.K) 2004, 117–131

2 Bartosik A S and Shook C A, Prediction of vertical liquid solid pipe flow using measured concentration distribution, *sPart Sci Technol*, **13** (2007) 85–104.

3 Raveleta F, Bakira F, Khelladia Reya R, Experimental study of hydraulic transport of large particles in horizontal pipe, *Exp Therm Fluid Sci*, **21** (2012) 102-112

4 Saha A K, Das D, Srivastava R, Panigrahi P K, Muralidhar K, Fluid mechanics and fluid power-contemporary research, *Proc 5th In 41st Nat Con FMFP*,14–17, July 2014.

5 Shrivastava K K, Determination of optimum particle size for economical hydro transport", *ASME Fluids Eng div Summer meeting, (*Texas, USA) 2005, 913-918.

6 Shrivastava and Kaushal K, Pneumotransport of grains through a pipeline, *ASME Fluids Eng. Div, Summer meeting*,(Texas, USA) 2002.

7 Shrivastava K K, *Investigation on hydo and pneumotransport*, Ph.D Thesis, Mech Eng. Dept, Bombay, Inda, 1990.

8 Shrivastava K K and Kar S, Genera analytical relation for pressure drop for hydro and pneumotransport of solids in vertical, horizonta land, inclined pipelines, *Proc ASME 5th Int fluid eng Conf on gas -particle flows* (British Columbia, Canada) 1993, 146–154.

9 Shrivastava, Kaushal K, Determination of optimum particle size for economical hydro transport, *ASME Fluids Eng div Summer Meeting (*Texas, USA) 2005, 913–918.

10 Shrivastava K K, *Investigation on hydro and pneumotransport*, PhD Thesis, Mech Eng Dept, Bombay, Inda, 1990.

11 Shrivastava K K, Pneumotransport of grains through a pipeline, *ASME Fluids Eng Div Summer Meeting,* (Texas, USA) 2002.

12 ANSYS Version:15.2, *User guide manual, Software release 15.0*, Inc., Southpointe, 275 Tech Drive, Canonsburg, PA 15317, 2009.

13 MAA Garment manual and textile, Guidelines of measurments and control, Mikelle, Ethiopia, Quiha, 2017.