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Alternative Design of a Pneumatic Conveying Machine for Rice Husk as A Coal Substitute for Rotary Kiln Fuel in Cement Factories

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Abstract

The reduced amount of coal transported to cement factories is being diverted to rice husk, which is biomass, to facilitate the use of increasingly expensive coal. This transition is necessary due to the different characteristics of rice husk compared to coal. Additionally, the combustion process in rotary kilns requires extremely high temperatures (1,400–1,500°C). However, a significant portion of the generated energy is lost through the kiln walls, exhaust gases, and heat radiation. These heat losses reduce thermal efficiency and increase fuel consumption. Coal, fuel oil, and natural gas are the primary energy sources for cement kilns, which are not only expensive but also have negative environmental impacts. The fluctuation in fossil fuel prices further affects overall cement production costs. To address these challenges, cement factories must design an efficient rice husk conveying system from storage to the rotary kiln. Transporting rice husks with air ensures no unintended reactions while allowing smooth flow through closed horizontal and vertical transport pipes commonly used in the industry. This study aims to design a pneumatic conveying machine with a closed air pressure system to transport biomass (rice husks) at a capacity of 7 tons/hour as an alternative fuel for rotary kilns in the cement industry. The design method follows several stages, including practical work experience, literature review, material selection, design considerations, conceptual design, calculations, and technical drawings. The proposed system utilizes the dilute phase method, with a blower power of 49.26523 kW pushing the rice husks toward the hopper. The pipeline flow parameter, measured as the pressure drop, is 132.9673 kPa. The selected materials include galvanized iron pipes with two elbows to connect horizontal and vertical sections.

Keywords: transport biomass, dilute phase method, selected material, capacity, closed air pressure.

INTRODUCTION

Indonesia, as one of the world's largest rice producers, produces significant agricultural waste, including rice husks. Rice husks are the outermost part of the rice grain which contributes around 20-23% of the total weight of the grain. The potential for rice husk waste in Indonesia is very large because national rice production reaches around 55-60 million tons of milled dry grain (GKG) per year. With this assumption, the rice husk waste produced ranges from 11-13 million tons per year (BPS, 2023). The abundant availability of biomass in nature has made the energy and chemical industries begin to switch to alternative bio-material fuels, considering the high demand for energy from fossil fuels until 2030 (Bajwa et al., 2018). The cement industry has replaced some of its coal needs to minimize fuel energy by using biomass material in a rotary kiln combustion system (Sandupama, 2019). This utilization not only supports reducing carbon emissions but also helps more efficient waste management and empowers local communities through a circular economy, thereby supporting the creation of a greener and more sustainable cement industry. Rice husks are a form of biomass that can be used as an industrial energy source (Olutoge and Adesina, 2019; Weldekidan et al., 2018). The abundant availability of rice husks in Indonesia also has the potential to be used as an alternative fuel.

In the cement industry, the coal fuel feed system which has undergone a grinding process will then be carried by an air flow driven by an air blower. The same thing is also used to feed biomass material as an alternative fuel in rotary kilns with a pneumatic conveying system. Pneumatic conveying is the process of transporting solid particles in air or gas (not reacting with the particles) through closed horizontal and vertical conveying pipes, and can be applied to almost all industries that deal with powder and granular materials (Tripathi et al., 2018). These system requirements consist of a compressed gas source (air), a feed device, a transport pipe, and a receiving device to release the material being carried (Mills, 2016).

When implementing a pneumatic conveying system, it is very important to maintain flow stability and pay attention to factors such as pipe diameter, operating conditions (gas velocity), and particle properties (size and shape) (Li et al., 2022). Most of the studies reported in the literature related to the handling of particulate materials have focused on particles with regular shapes. Thus, there is a lack of information regarding the feeding of materials with irregular particles, such as biomass. These particles pose considerable difficulties in the predictability of feeding and transport processes (Gomes et al., 2021). Different particle material properties cause different pressure drops in the pipe. One of the key parameters in conveyor system design is determining the pressure drop limit. Incorrect estimation of these parameters can result in serious operating problems such as greater power consumption, system wear, and flow blockages (Sharma, 2019).

The character of the dilute phase mode has characteristics in the form of a higher air speed of >20 m/s when compared to dense phase mode (1–5 m/s). The low-pressure drop for each pipe length in the transportation flow is less than 5 mbar/m. The feed uses a preferred rate of less than 10 tons/hour and the solid particles are fully suspended in the air. The particles in question are rice husks and are carried in the airflow.

The aim of this project is to design a pneumatic conveying tool with a closed air pressure system to distribute rice husks with a capacity of 7000 kg/hour using a calculation of the energy required by the blower so that the rice husks as fed fuel flow in distribution pipes to the combustion furnace to heat the rotary kiln.

METHOD

The research method for this project is to design using calculations with the stages shown in the work scheme in Figure 1. The method for carrying out conveyor design goes through several stages, namely: literature study, needs analysis, determining the design concept, design calculations, and working drawings. Designing conveying rice husks to the rotary kiln is done by looking for data on the distance from the rice husk storage location to the source of ignition of the cement raw material. The characteristics of rice husks and air such as density, viscosity, and gravitational force are supporting components in designing pneumatic conveying systems. Pipe length, material capacity per hour, particle and pipe diameter according to conditions in the field at the Cement factory

Pneumatic Conveying Method Dilute Phase

In the flow that occurs in the pipe there is contact between the material being transported and the pipe, especially at bends, so action is needed given to the delivery of brittle and abrasive materials. The use of dilute phase transportation is very common in the energy industry with the handling of coal and fly ash. Many materials naturally need to be carried in a low-velocity solid phase flow, but can also be carried in the dilute phase. If high speed is used to deliver any material that is suspended in air, then the material will be delivered in the dilute phase (Raj et al., 2017). The study design of the dilute phase is shown in Figure 2.

The design system is used to design pneumatic conveying systems, the design criteria must be in accordance with the requirements mentioned in the previous section such as design diameter, length and pipe material. Determining pressure drop parameters in the pipe due to friction and at the elbow. Selection of air moving system, material feeding system and air drying system.

All the criteria above were designed and selected using standard design calculations from the 'Pneumatic Conveying System Design Guide' by David Mills with the following equation 1.

Airspeed in the pipe

$$Vsalt = \left(\frac{4m_s 10^{\alpha} g^{\frac{\beta}{2}} D\left(\frac{\beta}{2}-2\right)}{\pi\rho f}\right)^{1/\beta+1} \quad (1)$$

Where, $\dot{m}s$ is mass flow rate of solids (kg/s), $Vsalt$ is superficial gas velocity at saltation (m/s) g is gravity (m/s2), D is pipe diameter (m), x is particle diameter (m), α=1440x+1,96; β=1100x+2,5 α=1440(0,002)+1,96; β=1100x+2,5; α=4,84; and β= 4,7

Pressure drop acceleration

$$\Delta PA = \frac{m_s V_{salt}}{A} \quad (2)$$

Where is the mass flow rate (solid) ' ms ', air speed ' Vsalt ', pipe cross-sectional area 'A'

Pressure drop due to friction

Known:

Elbow, n = 2

Efficiency = 60%

K = 1.2

Finding the F value:

$$F = \frac{0,25}{(\log\left(\frac{1}{3,7\left(\frac{D}{\varepsilon}\right)}\right)+\frac{5,74}{Re^{0,4}})^2} \quad (3)$$

Reynold number

$$Re = \frac{\rho_g V_g L_c}{M} \quad (4)$$

Where is the air density 'ρg', air speed 'Vg ', pipe diameter 'Lc', and viscosity 'M'

So, the pressure drop value due to friction :

$$\Delta P_{fg} = \left(\frac{FL}{D} + \sum K\right)\frac{\rho V^2 salt}{2} \quad (5)$$

Pressure Drop due to Solid Friction

$$\Delta P_{fs} = ks\Delta P_{fg} \quad (6)$$

Where Solid loading(s)

$$S = \frac{m_s}{\rho_g V_{salt} A}$$

$$S = \frac{2{,}222 kg/s}{(1{,}2\frac{kg}{m^3})(18{,}28935 m/s(0{,}00810321 m^2)}$$

$$S = 12{,}4954$$

$$F_s = \frac{(55{,}5)D^{1{,}1}}{Vg^{0{,}64}dp^{0{,}26}\rho s^{0{,}91}} = 0{,}0391$$

$$k = \frac{F_s V_{salt}}{F_g V_g} = \frac{0{,}03916}{0{,}02233} = 1{,}7533$$

Pressure Drop due to Lift Gas

$$\Delta P_{Lg} = \rho_g gh \quad (7)$$

Where is the air density 'ρg', gravity 'g', vertical pipe length 'h'

Pressure Drop due to Lift Solid

$$\Delta P_{LS} = \frac{hm_s g}{AV_{salt}} \quad (8)$$

Where is the length of the vertical pipe 'h', mass flow rate (solid) '$\dot{m}s$', gravity 'g', pipe cross-sectional area 'A', and airspeed 'V'.

Flow rate (Q) value in the pipe

$$Q = AV_g \quad (9)$$

Where is the cross-sectional area of the pipe 'A' and the air velocity 'Vg'

Energy or power of the drive system

$$P_{req} = \Delta PQ \quad (10)$$

Where is the pressure drop 'ΔP' and the flow rate 'Q'

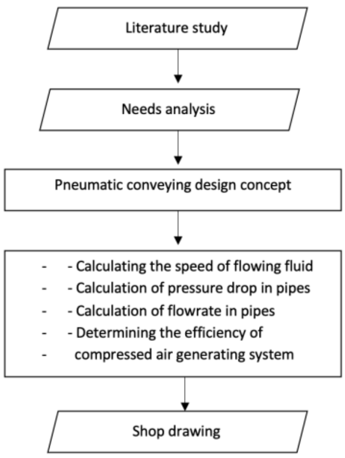

Figure 1. Working scheme of the conveyor design project

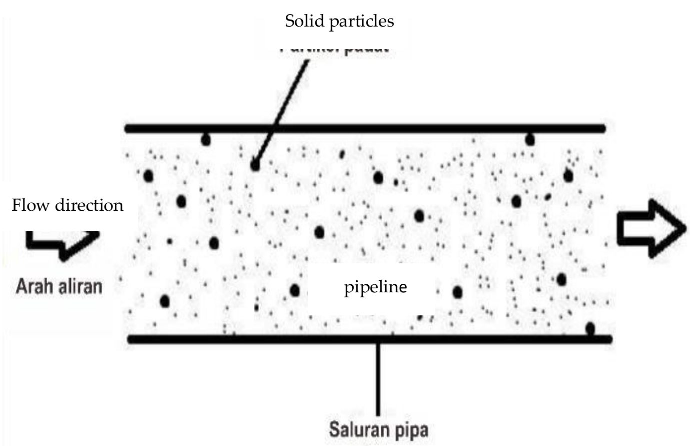

Figure 2. Dilute phase flow is a mixture of particles or solid materials with airflow in a pneumatic conveying piping system. (Raj et al., 2017)

RESULTS AND DISCUSSION

Conveying design calculations starts from designing the piping. When designing a pipe that carries a mixture of rice husks and air from the starting point to the delivery point, it is necessary to consider two pipe sections that are constructed horizontally and vertically.

Total pipe length = 118 m

Horizontal pipe length = 98 m

Vertical pipe length = 20 m

The next step is to determine the flow velocity based on the characteristics of the material and pipe. Required mass (solid) flow rate, $\dot{m}s$ = 7000 kg/hour (theoretically). But to ensure maximum performance, $\dot{m}s$ is taken as 8000 kg/hour (2.222 kg/second). The required pipe diameter, D = 10.16 cm = 0.1016 m (theoretically). Material and pipe characteristics are shown in Table 1. Based on the data in Table 1, the flow velocity in the pipe can be calculated. The air velocity value in the pipe can be determined from equation 1:

$$Vsalt = \left(\frac{(4)\left(2{,}222\frac{kg}{s}\right)(10^{4{,}84})\left(9{,}8\frac{m}{s^2}^{\frac{4{,}7}{2}}\right)\left(0{,}1016m\left(\frac{4{,}7}{2}-2\right)\right)}{(3{,}14)\left(\frac{1{,}2kg}{m^3}\right)}\right)^{\frac{1}{4{,}7}+1}$$

$$Vsalt = 18{,}2893\ m/s$$

The phenomenon that occurs when a flow moves along a pipe path certainly experiences a pressure drop due to the frictional force of the flow with the pipe, changes in flow direction when turning, friction between air and solid materials, and the presence of gravitational forces (Pandey and Patil, 2015). Calculation of the pressure drop value can be determined from the factors below.

Pressure Drop Acceleration (ΔPA)

Pressure drop acceleration is a factor that inhibits flow due to the frictional force of the flow with the pipe (Lyu et al., 2022). Research by Syahputra et al. (2018) also emphasized that the pressure drop in the flow pipe is influenced by several parameters, including the type of pipe connection, bends, valves, diffusers, and other components installed in the piping system. The fluid flowing in the pipe experiences friction along the flow pipe and the diameter of the pipe.

Mark pressure drop acceleration can be determined from equation 2.

$$\Delta PA = \frac{(2{,}222\frac{kg}{s})(18{,}2893\frac{m}{s})}{(\frac{(3{,}14)(0{,}1016m)^2}{4})}$$

$$\Delta PA = 5015{,}6679\ Pa$$

Pressure Drop due to Friction (ΔPfg)

Jalaluddin (2019) observed that the pressure drop is caused by head loss that occurs due to fluid friction on the pipe wall (major losses) and the presence of joints or bends in the pipe (minor losses). This causes a decrease in pressure, velocity, and Reynolds number at the same pipe cross-section. Pressure drop due to friction is a factor that inhibits flow, especially when there is a change in flow direction at a pipe bend. To determine the value of the pressure drop, it is important to know the change in force that occurs in the flow and the Reynolds Number value. To determine the value of the pressure drop due to friction, it is necessary to know the change in force (F) that occurs in the flow and the Reynolds Number value (Junianto and Hendrarsakti, 2021). The F value can be determined from equation 3.

$$F = \frac{0{,}25}{(\log\left(\frac{1}{3{,}7\left(\frac{0{,}1016}{0{,}00015}\right)}\right) + \frac{5{,}74}{Re^{0{,}4}})^2}$$

Table 1. Material and Pipe Characteristics

Specification	Symbol	Value
Average capacity	$\dot{m}_s$	7 *tonnes/hour*
Design capacity		8 *tonnes/hour* (2,222 Kg/s)
Particle diameter	dp	0,002 m
Rice husk density	ρ_s	140 Kg/m^3
Air density	ρ_g	1,2 Kg/m^3
Gravity	g	9,8 m/s^2
Air viscosity	μ	0,0000185 N.s/m^2
Pipe diameter	D	0,1016 m
Pipe roughness	ε	0,00015 (*galvanis iron*)
Area (πr^2)	A	0,00810321 m^2

Next, look for the Re value (Reynold number) which can be determined via equation 4.

$$Re = \frac{(1{,}2\frac{kg}{m^3})(18{,}2893\frac{m}{s})(0{,}1016m)}{0{,}0000185\ kg/ms}$$

$$Re = 120531{,}7846$$

So, the pressure drop value due to friction can be determined by equation 5.

$$\Delta P_{fg} = (\frac{0{,}02233(118m)}{0{,}1016m} + 1{,}2)\frac{(1{,}2\frac{kg}{m^3})(18{,}28935\frac{m}{s})^2}{2}$$

$$\Delta P_{fg} = 5446{,}707\ Pa$$

Pressure Drop due to Solid Friction (ΔPfs)

Pressure drop due to solid friction is a factor that inhibits flow due to friction between air and solid materials (Al-Kayiem et al., 2016).

The pressure drop value due to solid friction can be determined from equation 6

$$\Delta P_{fs} = (1{,}7533)(12{,}4954)(5446{,}707\ Pa)$$

$$\Delta P_{fs} = 119330{,}8819\ Pa$$

Pressure Drop due to Lift Gas (ΔPLg)

Pressure drop due to lift gas is a factor that inhibits flow due to the gravitational force on air movement. Pressure drop due value to lift gas can be determined from equation 7

$$\Delta P_{Lg} = \left(1{,}2\frac{kg}{m^3}\right)\left(9{,}8\frac{m}{s^2}\right)(20m) = 235{,}2Pa$$

Pressure Drop due to Lift Solid (ΔPLs)

Pressure drop due to solid lift is a factor that inhibits flow due to the gravitational force on the movement of solid particles (Dabirian et al., 2016). The pressure drop value due to solid lift can be determined from equation 8

$$\Delta P_{LS} = \frac{(20m)(\frac{2{,}222kg}{s})(\frac{9{,}8m}{s^2})}{(0{,}00810321m^2)(\frac{18{,}2893m}{s})}$$

$$\Delta P_{LS} = 2938{,}9224Pa$$

Based on the factors explained above, the total pressure drop (Δ$\boldsymbol{P}$) that occurs in the flow over the length of the piping path is as follows.

$$\Delta P = \Delta P_A + \Delta P_{fg} + \Delta P_{Fs} + \Delta P_{Lg} + \Delta P_{Ls}$$

$$\Delta P = 5015{,}66792 + 5446{,}707 + 119330{,}8819 + 235{,}2 + 2938{,}92243$$

$$\Delta P = 132967{,}3793\ Pa$$

$$\Delta P = 132{,}9673793\ kPa$$

This pressure drop is still in line with Syahputra's research (2018) which analyzed the pressure drop due to friction in two gas wells, PUT-2 and PNN-D9D. The calculation results show that in the PUT-2 well, with a pipe length of 226.14 m and a gas flow velocity of 59.805 m/s, there was a pressure drop of 104283,204 kPa. Meanwhile, in the PNN-D9D well, with a pipe length of 236.16 m and a gas flow velocity of 19.788 m/s, the pressure drop that occurred was 28309,873 kPa.

In a pneumatic conveying system, the flow can move with the energy provided by the drive system. To determine the amount of energy needed, it is necessary to know the volume of fluid flowing in the pipe per unit of time (Bhatia, 2019). The flow rate (Q) value in the pipe can be determined from equation 9

$Q = (0{,}00810321 m^2)(18{,}2893 m/s)$

$Q = 0{,}1482\ m^3/s$

From previous calculations, the pressure drop and flow rate values in the pipe serve as the basis for calculating the energy required by the drive system. The energy or power of the drive system is determined from equation 10.

$P_{req} = (132{,}9673\ kPa)(0{,}1482 \frac{m^3}{s})$

$P_{req} = 19{,}7060\ kW$

By considering the safety factor in the drive system, it is necessary to add 1.5 design strength (Acar et al., 2006) to

$P_{req} = 19{,}7060\ kW x 1{,}5 = 29{,}5591\ kW$

The power that will be supplied to the drive system input will be the ratio of output power to efficiency (Demirel, 2018). To ensure optimal and achievable performance, the drive system efficiency was chosen to be 60%

$P_{in} = \frac{P_{req}}{Blower\ efficiency} = \frac{29{,}5591}{0{,}6}$

$P_{in} = 49{,}2652\ kW$

To avoid power variations due to fluctuations, the motor value needs to be taken beyond the calculated results.

Technical Specifications

The tool specifications used for designing working drawings, based on suitability for field conditions, appear in Table 2.

Table 2. Conveying Distance Specifications

Specification	Symbol	Value
Elbow	n	2
Horizontal pipe	$L_{Horizontal}$	98 m
Vertical pipe length	$L_{Vertical}$	20 m
Total pipe length	L_{total}	118 m

The transport system used is pneumatic conveying, which relies on an air blower as the drive system. This device is chosen because the flow system operates under normal pressure, ensuring efficient material transport. For feeding the powder into the system, a rotary valve is utilized. This type of valve is commonly used in pneumatic conveying due to its low cost, ease of construction, and simple operation (Mills, 2016). Since the rice husk material is non-corrosive, the recommended pipe material for the system design is galvanized iron, which provides durability and resistance to environmental factors.

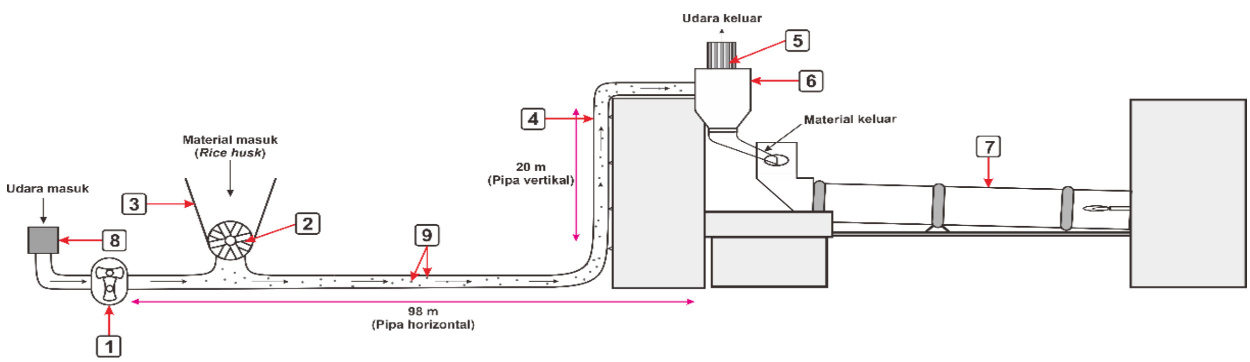

Figure 3. The pneumatic conveying system is equipped with (1) Air blower, (2) Valve (Rotary valve), (3) Supply hopper (incoming material), (4) Pipe, (5) exit air filter, (6) discharge hopper (outgoing material), (7) rotary kiln, (8) inlet air filter, and (9) solid particles.

Process Information

The incoming air uses a drive system (air blower) to push the rice husk particles that enter through the supply hopper as far as the length of the pipe (horizontal and vertical) with the presence of 2 elbows. The material fed to the rotary kiln as fuel will first be stored in the discharge hopper. The air that comes out of the pneumatic conveying system will undergo a filtering process before being released into the environment.

CONCLUSION

The pneumatic conveying machine is designed to transport rice husk biomass as an alternative fuel to the rotary kiln combustion furnace, with a capacity of 7000 kg/hour and a blower power of 49.27 kW. The system, with a total pipe length of 118 m, has an air velocity of 18.29 m/s, a pressure drop of 132.97 kPa, and a flow rate of 0.1482 m^3/s. The design uses galvanized iron pipes and a rotary valve as the feeder system. To accommodate field conditions, two elbows connect the horizontal and vertical pipes. This closed system minimizes material spillage, making it a more efficient and advanced technology. Further analysis of operational costs and initial investment is needed to assess its economic benefits.

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