Design and Development of a Bio Coal Pelletizer for Application in Solid Waste Management Technologies

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Abstract

The need for efficient solid waste management to value added products like bio coal is increasingly becoming important. Bio coal generated from biomass. This work focused on the design and development of a bio coal pelletizing machine to enhance the energy efficiency of bio coal produced from biomass. A bio coal pelletizing machine with potential to pelletize 69 tons/day bio coal was developed with stainless steel as the material of construction. The mode of operation was batch wise and a residence time of 2.5 hours is required. Health and safety consideration during the operation of the bio coal pelletizer were considered through a detailed HAZOP analysis and establish a process control around the pelletizer. A bio coal pelletiser was designed and developed for optimum energy efficiency in the bio coal sector. The pelletiser was made up of stainless steel and a design stress of 45 N/mm^2. The design pressure of the pelletiser was 1.3 atmospheres and had a cross sectional area of 8.8 m^2. Optimum operation of the pelletiser was achieved through a HAZOP and process control analysis

Keywords

Bio coal pelletizer, carbonisation, HAZOP, pelletiser design, solid waste management.

1. Introduction

The need for efficient solid waste management to value added products like bio coal is increasingly becoming important. Bio coal generated from biomass such as brewers spent grain has been reported to be renewable, sustainable and also burns at the same intensity as coal (Monzon 2000). For this value to be achieved from the bio coal there is need to consider pelletization of the bio coal. The process of pelletization involves the production of larger bodies from smaller bodies through the process of agglomeration (Dmitrienko et al. 2018). Pelletization promotes dust control, decreases transportation costs due to the densification and any losses from breakages. The need for an optimally designed pelletiser then becomes important. This study looked at the design and development of a bio coal pelletizer for the production of 70 tons of bio coal per day.

2. Design of a bio coal pelletiser

2.1 Material of construction

Mild steel of 0.3% carbon was selected as it has high strength, good ductility, moderate hardness and good machinability (Hu et al. 2010).

Volume of pelletiser

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\text{Volume} = \frac{\text{Mass of raw materials}}{\text{Density of the raw material}}$$

Assuming constant density of raw materials throughout the process
Mass of raw materials = 10 624.64 kg and the density of the raw materials at 25 ^{0}C is 320 kg/m^3.

$$\text{Volume} = \frac{10\ 624.64\text{kg}}{310\text{kg/m}^3} = 33.20\text{m}^3$$

In cooperating a safety factor of 5%

$$\text{Volume} = 34.2\text{m}^3$$

Diameter and height of pelletiser

The pelletiser is cylindrical in shape.

$$\text{Volume} = \frac{\pi D^2}{4} \times H$$

But D = 0.5H

$$\text{Volume} = \frac{\pi(0.5H)^2}{4} \times H$$

$$h = \sqrt[3]{\frac{34.2 \times 4}{\pi \times 0.5^2}} = 5.58 \text{ m}$$

Since D = 0.5 H
D = 0.5(5.58) m=2.79m

Cross sectional area

Cross sectional area of the pelletiser = π × D= π × 2. 79 m =8. 77 m^2

Design pressure

Operating pressure is 1atm
Operating temperature is 25 °C
Design pressure at 30% above the absolute operating pressure

$$\text{Design pressure} = \frac{130}{100} \times 1 \text{ atm} = 1.3 \text{ atm}$$

1 atm = 101325 Pa

$$\text{Design pressure} = 1.3 \times 101325\text{Pa} = 132\text{KPa} = 0.132\text{N/mm}^2$$

Design stress of stainless steel at 25 °C is 45 N/mm^2.

Thickness of the pelletiser (t)

$$\text{Thickness} = \frac{P_i D_i}{2f - P_i}$$

Where P_i = Design pressure
f_i = Design stress
D_i = internal diameter

$$\text{Thickness} = \frac{0.132 \times 2.79 \times 1000}{2 \times 45 - 0.132} = 4.10 \text{ mm}$$

Allowing 2.0 mm for corrosion the required thickness =6.10mm

Stress Analysis

Pressure stresses:

Circumferential stress
Stresses in the circumferential direction due to internal pressure

$$\text{Circumferential stress} = \frac{PD_i}{2t}$$

$$\text{Circumferential stress}, \delta_H = \frac{0.132 \times 2.79 \times 1000}{2 \times 6.10} N/mm^2 = 30.19 \text{ N/mm}^2$$

Longitudinal stress
Stress in the longitudinal or axial direction

$$\text{Longitudinal stress} \qquad = \frac{\mathrm{PD_i}}{4\mathrm{t}}$$

$$\text{Longitudinal stress}\,,\delta_{\mathrm{L}} \qquad = \frac{0.132 \times 2.79 \times 1000}{4 \times 6.10} N/mm^2 \qquad = 15.09\mathrm{N/mm^2}$$

Both the longitudinal stress and longitudinal stress are less than the permissible tensile stress of 45 N/mm^2 hence the design is acceptable.

Bending stresses
Bending stresses result from the bending moments to which the pelletiser is subjected (Kaliyan and Morey, 2009).
Second moment of area of the pelletiser, Iv:

$$\mathrm{I_v} = \frac{\pi}{64}(\mathrm{D_0^4} - D_{\mathrm{i}}^4)$$

But $\mathrm{D_{i}} =$ 2790 mm
$\mathrm{D_0}$= 2796.1mm

$$\mathrm{I_v} \qquad = \frac{\pi}{64}(2796.1^4 - 2790^4) \quad = 2.61 \times 10^{10}\mathrm{mm^4}$$

Bending stress, δ_b:

$$\delta_{\mathrm{b}} = \pm\frac{\mathrm{M_V}}{\mathrm{I_V}}\left[\frac{\mathrm{D}_i}{2} + t\right]$$

Assuming that the applied bending moment $\mathrm{M_V}$ is 1.87 × 10^8N/mm^2

$$\delta_{\mathrm{b}} \qquad = \frac{1.87 \times 10^8}{2.61 \times 10^{10}}\left[\frac{2790}{2} + 6.1\right] \quad = 10.04\mathrm{N/mm^2}$$

Design of square key sunk
W=T=D/4
W=width of key
T=thickness of key
D= diameter of key
Assume 20 mm diameter of the shaft because of its rigidity and loading.

$$W = \frac{20}{4}mm = 5mm$$

Design of step turned transmission shaft
Assume allowable shear stress as 42 MPa, shaft rotation at 400 rpm and transmitting 18 KW.

$$T = p \times \frac{60}{2\pi N} = 18 \times 10^3 \times \frac{60}{2\pi \times 400} Nmm^{-1}$$

But $T = 16\pi \times \tau \times d^3$

$$d = \sqrt[3]{\frac{430 \times 10^3}{16 \times \pi \times 42}} mm = 5.8\,mm$$

Design of mould
From experiments, each mould should have a diameter of 0.0227m.
Surface area of mould

$$Surface\ area = 4\pi r^2 = (4 \times 0.0136^2 \times \pi\,)m^2 = 2.32 \times 10^{-3}m^2$$

Volume of mould

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi 0.0136^3 m^3 = 1.05 \times 10^{-5}m^3$$

Diameter of mould plate
Assume 90% of pelletiser diameter

$$d = \frac{90}{100} \times 2.79m = 2.51m$$

Number of moulds
Assume moulds cover 90% of mould plate

$$Number\ of\ moulds = \frac{Diameter\ of\ mould\ plate}{Diameter\ of\ mould} \times 90\%$$

$$N = \frac{2.65m}{0.0227m} \times 0.9 = 105.07 \approx 105$$

Table 1. Summary of design of a balling disk pelletiser

Item	Description
Material of construction	Mild steel
Design stress of material at 25 °C	45 N/mm^2
Volume	34.20m^3
Height	5.58m
Diameter	2.79m
Residence time	2.5 hours
Cross sectional area	8.77 m^2
Design pressure	1.3 atm
Thickness	0.0041m
Circumferential stress	30.19 N/mm^2
Longitudinal stress	13.09 N/mm^2
Bending stress	10.04 N/mm^2
Width of key	0.005m
Shaft diameter	0.0058m
Surface area of mould	2.32×10^{-3}m^2
Volume of mould	1.05×10^{-5}m^3
Diameter of mould plate	2.51m
Number of moulds	105

3. HAZOP analysis and process control

3.1 HAZOP analysis

HAZOP is a formal way of identifying potential deviations from the way a design is expected to work, their causes and problems associated with these (Kim et al. 2001). It identifies potential hazards to people, process plant and the environment. It provides a considerable amount of useful material for inclusion in the process operating instructions, thus resulting in better-informed operations, personnel and safer operations. Awareness and prevention of these hazards is vital. Corrective and emergency measures are also of importance.

Hazard

Anything that has the potential to cause harm or injury to a person or damage to plant or property is a hazard. Hazards can result from the bio coal work environment include: the use of machinery and substances, poor work design and inadequate systems and procedures (Muazo and Stegemann 2015). Common types of workplace hazards can be categorised as follows: physical (noise, lighting, temperature), chemical (poisons, dusts, vapours, fumes, hazardous substances) biological (viruses, plants, parasites, blood, other body fluids), mechanical (slips, trips and falls, manual handling, plant and equipment), electrical (shock, ignition, plant and equipment) and psychological (stress, repetitive work, shift work, violence/aggression). Some hazards are more specific to the event environment, these may include: temporary structures (construction, stability, crowd capacity, and collapse), dangerous or flammable materials (projectiles, fireworks, vehicles, exhaust fumes, open fires, gas cylinders), movement of heavy equipment (uneven sites, vicinity of other personnel, scheduling), spectators (public access, egress, behaviour) and weather (rain, hail, wind, heat, thunderstorms).

Harm

Harm refers to physical injury or damage to human beings, the environment or property. It is something that adversely affects or threats the humans and their environment.

Operability

Operability is any operation inside the design envelope that would cause a shutdown that could possibly lead to a violation of health or safety regulations, environmental, or negatively impact profitability.

General measures to reduce risks

Risk assessment at a company is very important because it reduces operational costs and injuries to workers. The methods used in reducing risks that are associated production are:

Training of workers

Basic knowledge of the process, correct operating practice, emergency procedures and provision of frequent refresher training courses.

Control of hazards
The prevention of hazards deviation is done by provision of automatic control systems, alarms, control valves, together with good operating practices and management.

Causes for Deviations
The three basic types of the causes for deviation are:

Human error
These are hazards caused by the operator, designer, manufacturer or any other person could be a danger to the environment and to the people within that working area.

Equipment failure
Mechanical, structural or operating failure results in release of hazardous material such as carbon dioxide emissions.
The HAZOP Procedure followed for the bio coal pelletizer is given in Table 2.

Table 2. Standard HAZOP guide words

Word	**Meaning**
No or not	Design intent does not occur or the operational intent is not attainable
More	There is a quantitative increase in the design intent
Less	There is a quantitative decrease in the design intent
Reverse	The opposite of the design intent occurs
Other than	There is the complete substitute of design.
Also/as well as	Although design intent is achieved, there are additional occurrences.
Other	Activity occurred but not in the way intended.
Early	Activity occurred before time intended by design.
Late	Activity occurred past the time intended by design
Fluctuation	Design intent is not consistently achieved.
Part	System composition difference from what it should be
More than	More "components" present than there should be for example, extra phase, impurities
More of	*e.g.* More Flow caused by reduced delivery head ; surging ; suction pressurized ; controller failure ; valve stuck open leak ; incorrect instrument reading
Before/after	The step (or part of it) is effected out of sequence
Faster/slower	The step is done/not done with the right timing
Where/else	Applicable for flows, transfer, sources and destinations

The HAZOP analysis for the bio coal pelletiser is shown in Table 3.

Table 3. HAZOP analysis on the bio coal pelletiser

Guide word	Parameter	Deviation	Possible cause	Consequences	Corrective measures
NO	Flow	No flow of bio coal paste to the pelletiser	Pipe blockage Pipe leakages Valve fails to open (control valve failure) Pump failure	Low product quality Less production Dust production (hazardous to healthy)	Install low flow alarms Maintenance (repairing the control valve) Check valves regularly Feedback control system
More	Flow	High flow rate of bio coal paste	Valve does not close Pump failure Pump increases the rate of pumping the	Low product quality	Install sensors to detect and provide feedback Install level meters

			fluid		
Less	Flow	Low flow of bio coal paste	Control valve failure Pump failure Leakage	Low yield	Install flow meters Alarms

3.2 Process control on the bio coal pelletiser

The process and instrumentation (P&I) line diagram is examined, process line by process line (Rezania et al. 2016). Guide words are used to generate deviations from normal operation corresponding to all conceivable possibilities covering every parameter i.e. flow rate and quality, pressure, temperature, viscosity and the equipment components. The pelletizing rate is affected by the paste flow rate (Sanchez et al. 2015; Staples et al. 2017). The pelletizing rate transmitter measures the pelletizing rate and sends a signal to the pelletizing rate controller (PRC). Comparison of the process variable to flow rate occurs; a signal is computed and sent to the flow controller. The flow controller signals the valve to close or open.

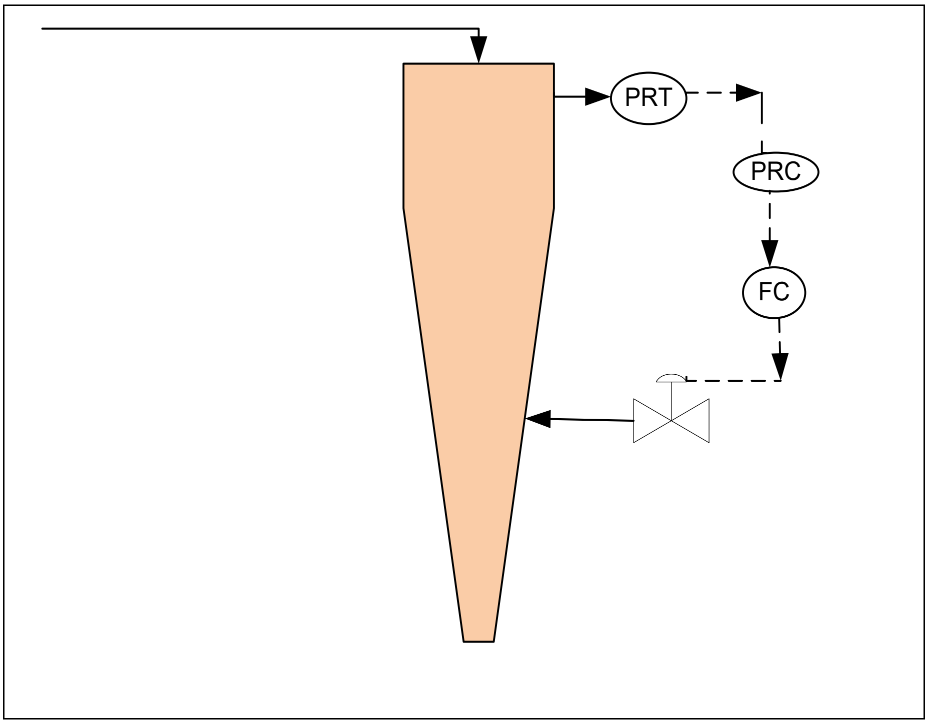

Figure.1. Cascade control on pelletiser

The symbols are represented in Table 4.

Table 3. HAZOP Symbols key

Symbol	Meaning
PRC	Pelletizing rate transmitter
PRC	Pelletizing rate controller
FC	Flow controller

4. Conclusion

A bio coal pelletiser was designed and developed for optimum energy efficiency in the bio coal sector. The pelletiser was made up of stainless steel and a design stress of 45 N/mm^2. The design pressure of the pelletiser was 1.3 atmospheres and had a cross sectional area of 8.8 m^2. Optimum operation of the pelletiser was achieved through a HAZOP and process control analysis.

References

Dmitrienko, M. A., Nyashina, G. S., and Strizhak, P. A. "Major gas combustion for combustion of slurry fuels based on coal, coal waste, and coal derivatives", *Journal of Cleaner Production*, vol. 177, pp. 284–301, 2018.

Hu, B., Wang, K., Wu, L., Yu, S. H., Antonietti, M. and Titirici, M. M. "Engineering carbon materials from the hydrothermal carbonization process of biomass,"*Advanced Matter*, vol. 22, pp. 813–828, 2010.

Kaliyan, N. and Morey, R. V. "Factors Affecting Strength and Durability of Densified Biomass Products", *Biomass and Bio-Energy*, vol. 33, pp. 337-359, 2009.

Kim, H., Kazuhiko, S. and Masayoshi, S. "Biomass Briquette as a Technology for Desulphurizing and Energy Saving", *Renewable Energy Journal*, vol. 8, pp. 33-75, 2001.

Monzon, J. E. "The cultural approach to telemedicine in Latin American homes (Published Conference Proceedings style)," in *Proc. 3rd Conf. Information Technology Applications in Biomedicine*, *ITAB´00*, Arlington, VA, pp. 50–53.

Muazo, R. and Stegemann, J. "Effects of operating variables on durability of fuel briquettes from rice husks and corn cobs", *Fuel Processing Technology*, vol. 133, pp. 137–145, 2015.

Rezania, S., Din, M. F., Kamaruddin, S. F., Taib, S. M., Singh, L., Yong, E. L. and Dahalan, F. A. "Evaluation of water hyacinth (Erichhornia crassipes) as potential raw material source for briquette production", *Energy*, vol. 111, pp. 768–773, 2016.

Sanchez, D. L., Nelson, J. H., Johnston, J., Mileva, A. and Kammen, D. M. "Biomass enables the transition to a carbon-negative power system across western North America", *National Climate Change*, vol. 5, pp. 230–234, 2015.

Staples, M. D., Malina, R., and Barrett, S. R. H. "The limits of bioenergy for mitigating global life-cycle greenhouse gas emissions from fossil fuels", *National Energy*, vol. 2, pp. 16202, 2017.

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