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Performance analysis of Rotary Cotton Seed dryer with One and Three Segment Flights

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Abstract

This paper presents the performance analysis of rotary cottonseed dryer. Experiments were performed on cottonseeds, at inlet air temperatures of 100, 110, 120ºC, and drying air mass flow rates of 0.00563, 0.0064, 0.00709 kg/s by using two different flights. The performance of dryer was evaluated by checking effect of operating variable on weight loss of dried products, specific energy consumption (SEC) and pick-up efficiency. Image analysis method was used for determining design loading of drum. Weight loss of cottonseeds was found to be in the range of 0.446-0.788 kg. The pick-up efficiency and SEC varied between range of 7.19-19.52% and 0.219-0.399 kW-h/kg respectively.

Keywords: Specific energy consumption (SEC), Pick-up efficiency, moisture.

Introduction

Cotton is mainly cultivated for fiber production in textile industry. Cottonseed is byproduct of cotton left after ginning. It is processed into four main products; oil, meal, hull, and lint. Cottonseeds contain 15-16% moisture in it. For oil extraction process, cottonseeds are required to be dried. Generally, term drying means removal of relatively small amount of volatile material like moisture from solid or nearly solid or nearly solid material, which assures microbial stability and guarantees expected shelf-life of the product[1]. Generally, sun rays are used for drying products like cottonseeds. The main advantages of sun drying are low capital and operating cost. However, this method of drying has several disadvantages like contamination of products, no control over drying process, undesirable changes in quality of products and long drying time[2,3]. To overcome these disadvantages open sun drying should be replaced with industrial dryers. One way to do so is to use rotary dryer for drying cottonseeds. Utilization of high amounts of energy in the drying makes it one of the most energy-intensive operations with great industrial significance[4]. Thermodynamic analysis is an essential tool for system design, analysis and optimization of thermal systems. So, the objective of this work is to present performance analysis of rotary cottonseed dryer at different drying air temperatures, drying air mass flow rates.

Material and Methods

Drying equipment: Drying of cottonseeds was analyzed in rotary drum type dryer. It has horizontal drum having radius of 0.3 m and length of 1.5 m. Drum has flights attached to its inner periphery which were useful for tossing of seeds inside drum. Air was supplied with the help of blower and air flow was controlled by using valve. Air was heated by passing over the coils of nichrome wire. This hot air was passed over seeds in drum which was rotated with the help of 3 phase electric motor. Speed of the motor was controlled with variable frequency drive. Power of the motor was transmitted to drum through reduction gear box and chain drive. During experiments temperature, relative humidity of air at ambient, at inlet and outlet of drum were recorded.

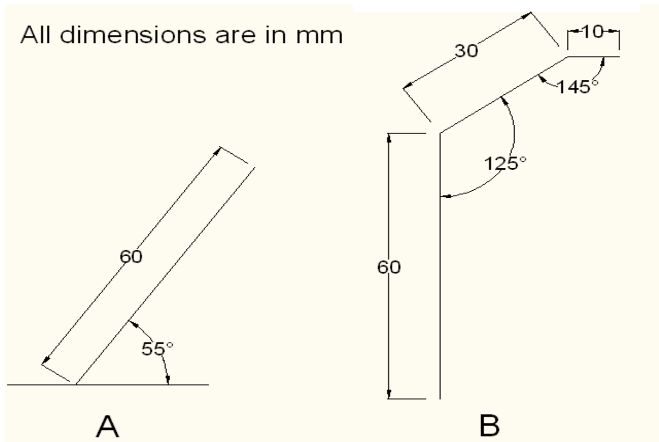

Figure-1
Geometry of flights used

Nomenclature: A=Surface area (m^2), C = Specific heat (kJ/kg^{o}C), H = Absolute humidity (kg/m^3), M = Mass flow rate (kg/s), m_v = Mass of moisture vaporized (kg), P = Atmospheric pressure (kPa), P_{vs} = Saturation pressure of vapour (kPa), φ = Relative humidity of air, Q = Heat rate (kJ/s), T = Temperature (^{o}C), T = Time (sec), W = Humidity ratio of air (kg water/kg dry air), $\dot{V}$ = Volume flow rate (m^3/s), U_d = Side heat loss coefficient from enclosed air of the rotating drum to the ambient air through the drum walls (kW/m2 ^{o}C), η_p = Pick-up efficiency (%), ψ = Dynamic angle of repose, μ = Dynamic friction coefficient

Subscripts: a = Air, d = Drum, i = inlet air, o = Outlet air, P = Product, ∞ = Ambient

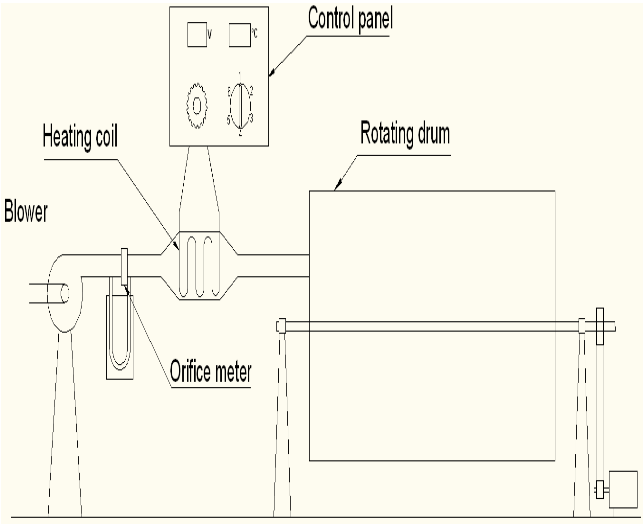

Figure-2
Schematic Diagram of experimental setup

Experimental procedure: For rotary dryers it is necessary to find out its design loading. For that, drum was loaded with the cottonseeds and rotated at different speeds to select the speed of rotation, where even distribution of airborne seeds across the cross-section of drum is obtained. Then images were taken at 120 fps with Nikon S6300. From the analysis of those images dynamic coefficient of friction (μ) for cottonseed at that particular speed of drum rotation was determined.

Then dynamic angle of repose at various flight positions can be obtained from equation 1[5, 6]:

$$\tan\psi = \frac{\mu + \upsilon(\cos\theta - \mu\sin\theta)}{1 - \upsilon(\sin\theta + \mu\cos\theta)} \quad (1)$$

Where, ψ is dynamic angle of repose, $\upsilon = r_e\,\omega^2/g$ is ratio of centrifugal to gravitational force acting on the cottonseeds and θ is the angle made by flight tip at the center of drum. If dynamic angle of repose is known one can find out the volume of drum occupied by seeds from which design load of dryer can be determined. For 1 segment flight and 3 segment flight design load comes out to be 7 kg and 11 kg respectively.

So, for experiments drum was loaded with 7 kg of cottonseeds. Dryer was operated for 20 minutes. After that seed were removed from drum and packed in plastic bag. Then they are weighed on electronic balance with the accuracy of 0.001 gm. Experiments were performed on the inlet air temperature of 100, 110, 120°C and air mass flow rate 0.00563, 0.0064, 0.00709 kg/s.

Experiment for determination of side heat loss coefficients: Before each experiment, the dryer was operated for one and half hour in order to achieve steady-state conditions. Then the temperatures at three different locations of the drum were recorded. Temperatures at inlet and outlet of drum and ambient air to were also recorded in order to determine side heat loss coefficient.

The heat loss due to the heat exchange of the inlet air to ambient through the drum of the dryer was calculated using equation 2[7]:

$$\dot{Q}_{aol} = \dot{m}_{ai} C_{ai} (T_{ai} - T_{ao}) \quad (2)$$

The equation 3 is also usable to calculate the heat loss by the frame of the dryer:

$$\dot{Q}_{dl} = U_d A_d (T_d - T_\infty) \quad (3)$$

By equalizing equations 2 and 3:

$$\dot{Q}_{dl} = \dot{Q}_{aol} \quad (4)$$

Consequently, the following equation was obtained for calculation the side heat loss coefficient:

$$U_d = \frac{\dot{m}_{ai} C_{ai} (T_{ai} - T_{ao})}{A_d (T_d - T_\infty)} \quad (5)$$

Three replications of experiments were performed to calculate the side heat loss coefficient at each air temperature and drying air mass flow rate.

Theoretical principle: Performance of the dryer can be characterized by specific energy consumption (SEC), pick-up efficiency of air and weight loss of seed after drying. SEC is defined as energy required per kg of moisture removed. The dryer is better performing if it has a lower SEC[8].

$$SEC = \frac{\dot{m}_{ai} C_a (T_{ai} - T_\infty) t}{m_v} \quad (6)$$

The specific heat of air was obtained by equation 7:

$$C_a = 1.005 + 1.88w \quad (7)$$

Where w is the humidity ratio of the air. Following equation was used to transform relative humidity to humidity ratio.

$$w = 0.622 \frac{\varphi P_{vs}}{P - \varphi P_{vs}} \quad (8)$$

Where, φ is relative humidity of air, P_{vs} is saturation pressure and P is ambient pressure.

Pick-up efficiency is defined as the ratio of actual mass of moisture removed to capacity of air to remove moisture. It is given by equation 9:

$$\eta_p = \frac{m_v}{\dot{V}_a t(H_{as} - H_{ai})} \quad (9)$$

Where, m_v is mass of moisture removed, H_{as} is absolute humidity of air entering drum at the point of adiabatic saturation, H_i is absolute humidity of air entering into drum.

Results and Discussion

Weight loss of cottonseeds: Figure 3 and figure 4 show the effect of air temperature and drying air mass flow rate with different flight geometry on the weight loss of cottonseed in rotary dryer.

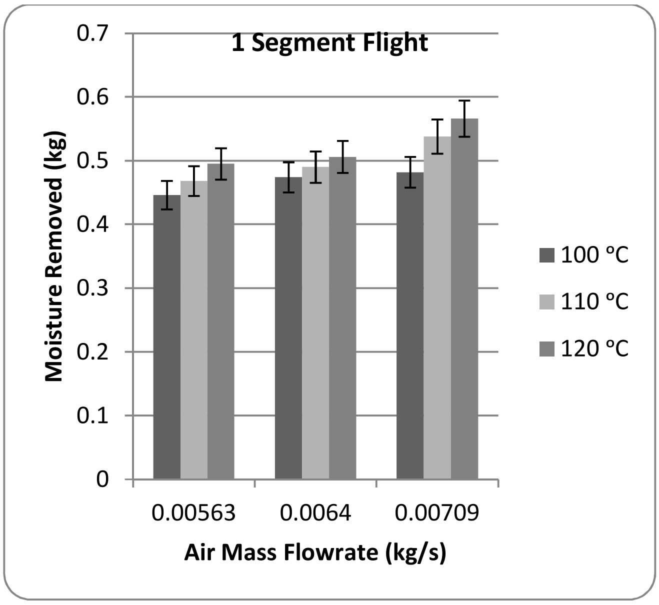

Figure-3
Effect of drying air inlet temperature and drying air mass flow rate on the weight loss of cottonseed for 1 segment flight

An analysis of variance showed that weight loss increased ($p < 0.05$) with increase in drying temperature for all drying air mass flow rates for both flight geometries. An analysis of variance showed that the weight loss increased ($p < 0.05$) with increase in drying air mass flow rate for all air temperatures for both flight geometries. The maximum value of weight loss in 20 minutes was 0.788 kg at drying air temperature of 120 ^{o}C, drying air mass flow rate of 0.00709 kg/s with 3 segment flight geometry. The minimum value of weight loss was 0.446 kg at drying air temperature of 100^{o}C, drying air mass flow rate of 0.00563 kg/s with 1 segment flight geometry.

Energy analysis: The experimental data was converted to specific energy consumption (SEC). Figure 5 and figure 6 show the effect of air temperature and drying air mass flow rate with different flight geometries on the SEC for drying of cottonseed in rotary dryer.

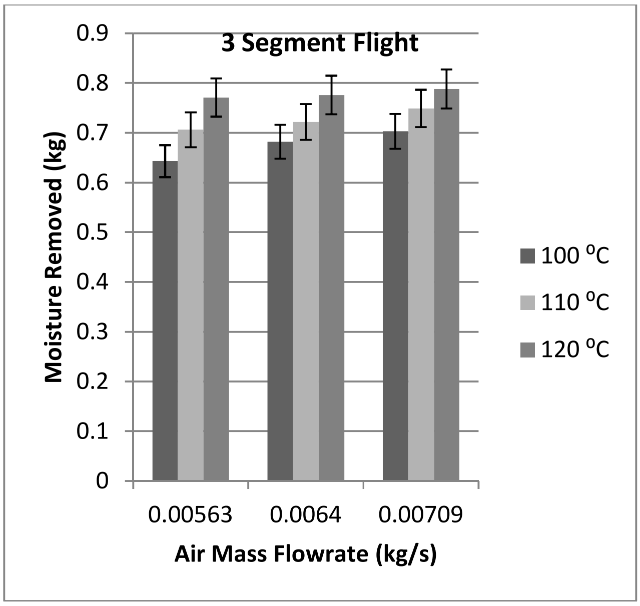

Figure-4
Effect of drying air inlet temperature and drying air mass flow rate on the weight loss of cottonseed for 3 segment flight

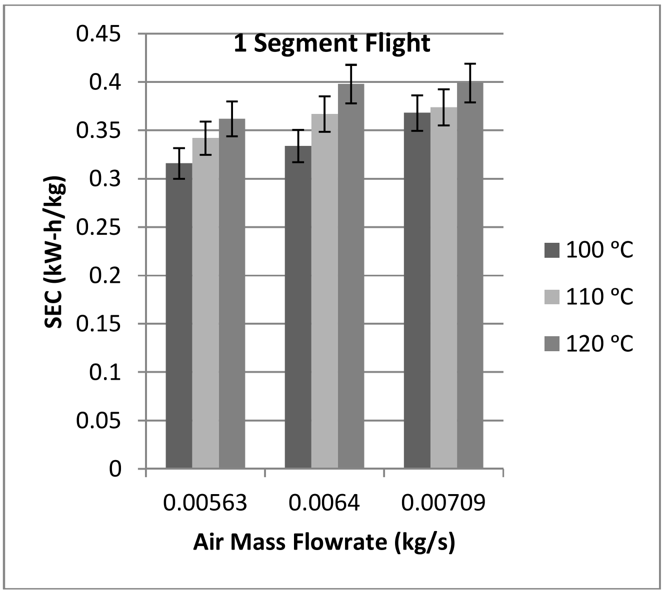

Figure-5
Effect of drying air inlet temperature and drying air mass flow rate on SEC for 1 segment flight

An analysis of variance showed that the SEC increased ($p < 0.05$) with increasing in air temperature for all drying air mass flow rates for both flight geometries. An analysis of variance showed that the SEC increased ($p < 0.05$) with increasing in drying air mass flow rate for all air temperatures for both flight geometries. An analysis of variance showed that the SEC is reduced ($p < 0.05$) with 3 segment flight than that for 1 segment flight at all drying air mass flow rates and all air temperatures.

The maximum value of SEC was 0.399 kW-h/kg at air temperature of 120 °C, drying air mass flow rate of 0.00709 kg/s with 1 segment flight. The minimum value of SEC was 0.217 kW-h/kg at air temperature of 100 °C, drying air mass flow rate of 0.00563 kg/s with 3 segment flight.

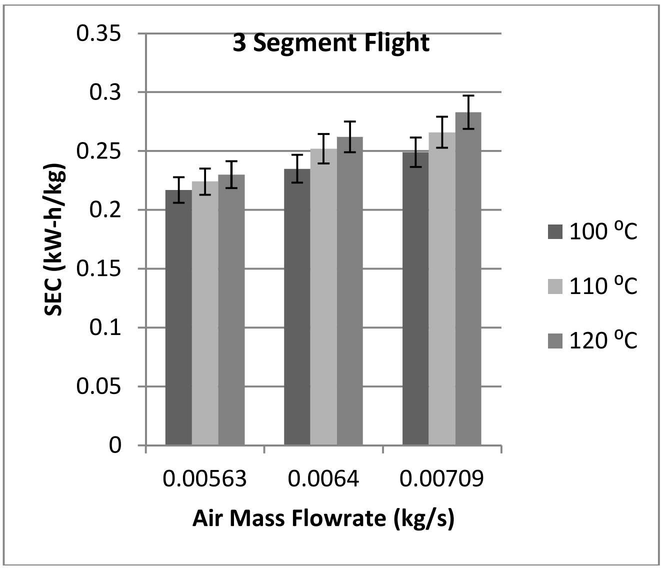

Figure-6
Effect of drying air inlet temperature and drying air mass flow rate on SEC for 3 segment flight

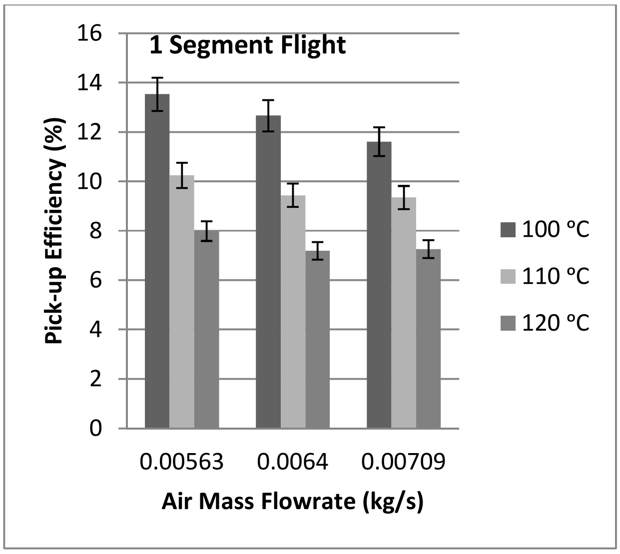

Figure-7
Effect of drying air inlet temperature and drying air mass flow rate on the pick-up efficiency for 1 segment flight

Figure 7 and figure 8 show the effect of air temperature and drying air mass flow rate on the pick-up efficiency for drying of cottonseed in rotary dryer with different flight geometries.

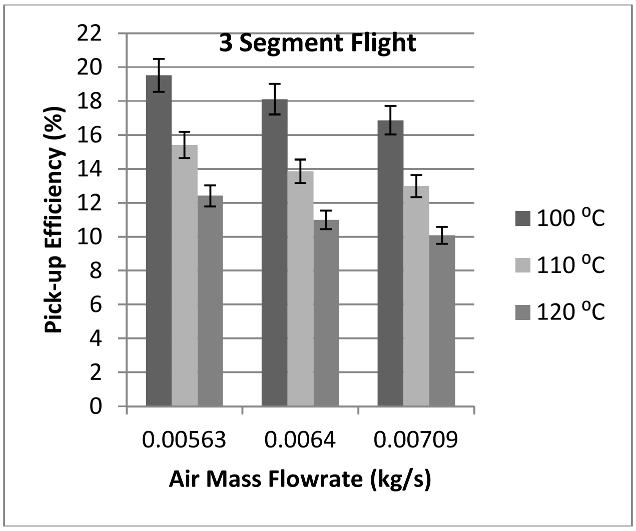

Figure-8
Effect of drying air inlet temperature and drying air mass flow rate on the pick-up efficiency for 3 segment flight

An analysis of variance showed that the pick-up efficiency decreased ($p < 0.05$) with increasing in air temperature for all drying air mass flow rates for both flights. The pick-up efficiency decreased ($p < 0.05$) with increasing in drying air mass flow rate for all air temperatures for both flights. An analysis of variance showed that the pick-up efficiency is more ($p < 0.05$) for 2 segment flight as compared to 1segment flight at all drying air mass flow rates and for all air temperatures. The maximum value of Pick-up efficiency was 19.52% at air temperature of 100 °C, drying air mass flow rate of 0.00563 kg/s with 3 segment flight.

Conclusion

Energy analysis of cottonseed drying in rotary dryer was investigated. Significant amount of moisture was removed in short time of 20 minutes. Weight loss of outlet dried product and SEC increased with increase in inlet air temperature while pick-up efficiency decreased with increase in inlet air temperature. Weight loss of outlet dried product and SEC increased with increase in mass flow rate of air while pick-up efficiency decreased with increase in mass flow rate of air. From the results of Weight loss of dried product in 20 minutes, SEC and pick-up efficiency, 3 segment flight is more suitable than 1 segment flight for rotary cottonseed dryer.

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