Drying Air Properties Investigation and Simulation Study of a Commercial Mixed-Flow Batch Type Paddy Seed Drying System

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Abstract

In Malaysia, numerous extensive research to gauge the performance and efficiency of paddy dryers were conducted by past researchers. These studies gave valuable insights into paddy drying and promoted further research oppurtunities, especially in engineering and technical studies. However, the study of commercial grain dryers performance for paddy seed drying still lacks in Malaysia. The absence of fundamental information, such as the static pressure requirement, the right volume of air (volumetric flow rate) and the drying air temperature profile requisite in regard to paddy seeds drying leads to ill-informed judgements and poor decision-making which can be detrimental, especially in regars to the design and plant installation. This study was therefore undertaken to investigate the three pertinent parameters i.e. static pressure, volumetric flow rate and the temperature profile of the drying air of a commercial, mixed-flow, batch type seed dryer at Loji Pemprosesan Benih Padi Sah (A) at Telok Chengai, Kedah using both field experimentation and computational fluid dynamics (CFD) simulations. Results from experimentation investigation suggested that in current operating condition and configuration, the drying system is producing 460 Pa (46.90 mmH_2O) of static pressure per 300 mm of grain bed depth which is lower than the recommended value of 500 Pa (51.00 mmH_2O) and 4 times lower than the actual required value due to higher grain bed depth (1,200 mm) at the top of the dryer. The volumetric flow rate of 15,699 m³/h (9,240 cfm or 577 cfm/mt) produced by the blower fan also indicated that it lacks volume of air to facilitate efficient drying rate as recommended value are as high as 1,589 cfm/mt. Thermal imaging of the drying system revealed that 8.88% losses in temperature occured from the blower fan (45°C) to the drying plenum (41°C). Computational Fluid Dynamics (CFD) simulations was performed through ANSYS-Fluent commercial software indicated that these results were acceptable as the disparity between the actual experimentation results and the simulated results were 10.0% and 7.3% for the static pressure and temperature profile respectively.

Keywords: Paddy Seed Drying, Commercial, Static Pressure, Volumetric Flow Rate, Temperature, Computational Fluid Dynamics, ANSYS-Fluent

Introduction

Syarikat Perniagaan Peladang MADA Sdn. Bhd. (MADACorp), a subsidiary of the Muda Agricultural Development Authority (MADA) operates a commercial seed processing plant, namely the *Loji Pemprosesan Benih Padi Sah* at Telok Chengai, Kedah, to supply certified seeds to farmers within the MUDA area and its vicinity. Seed integrity is one of the ultimate goals of the processing plant. High quality certified paddy seeds which are guaranteed in terms of their physical and genetic purity, possess important attributes, such as good germination and vigor, are crucial to increase the production yield by between 5% and 20% (Mat et. al., 2002; IRRI, 2013). The most effective and economical way of preserving seed quality is through drying. However, lately most of the 13 units of plant batch dryers , which have a total holding capacity of 130 metric tons, showed a decline in their performance efficiency. Being a commercial entity that accounted for approximately 40% of the total annual income of MADACorp., a dip in the overall effeciency in the drying plant can have a significant impact on the overall profitability. Considering a plant of almost 40 years in operation, a comprehensive review of the drying system and structrural integrity must therefore be carried out for immediate improvement. Drying is defined as the removal of moisture to moisture content (MC) in equilibrium with normal atmospheric air or to such an MC that reduces in activity of molds, enzymatic action and insects (Henderson & Perry, 1976). Convective type of drying is used extensively in grain drying such as paddy seeds. It is one of the most effective and economical type of drying with regards to grain conditioning. The principles of air movement especially its relationship to the static pressure of the air and the volume of air per unit time is crucial to the rate of drying of the paddy seeds. Sufficient volume of air per unit time and pressure must therefore be provided to affect optimum drying process effectively and efficiently in order to produce high quality of dried grain and seeds.

Materials and methods

Seed dryer system

The experiments were conducted by using one of the commercial scale Louisiana State University (LSU) batch mixed-flow seed dryer systems (Figure 1), which was available at the *Loji Pemprosesan Benih Padi Sah* at Telok Chengai, Kedah. The seed dryer had a holding capacity of 15 metric tons. The cross-sectional area of the dryer was 3.65 m x 2.55 m and the height of dryer was 7.90 m. The dryer was connected to an 11.0 kW, 15.0 HP backward-curved centrifugal blower fan. The atmospheric air was heated through the use of a diesel-fired burner, with a burning capacity of 320,000 BTU or 80,000 kcal.

Measurement of air flow properties

Air properties, such as its velocity, volumetric flow rate and pressure components were measured by using a pitot tube anemometer/differential manometer (CEM 0001). The measurement was carried out by using log-Tchebycheff for a transverse circular duct method. The readings were recorded at 10 different points and the average value was calculated. These data were collected at the inlet for heated air and outlet for exhausted air and carried out at a specified time interval. The pitot-tube anemometer/differential manometer was calibrated before use.

Measurement of temperature

The drying air temperatures were measured on an hourly basis at two different locations by using a thermal hygrometer data logger (RIX 670). This data along with the air properties will be used in the simulations. An investigation of temperature distribution profile on the dryer plenum was also conducted using a thermal imaging scanner in order to validate the actual results with the CFD simulations.

ANSYS-Fluent Simulation

The temperature regime, static pressure distributions and the volumetric flow rate of the drying air in the drying plenum of the seed dryer at *Loji Pemprosesan Benih Padi Sah* at Telok Chengai, Kedah was simulated using commercial CFD software, ANSYS Fluent Ver. 15. The 3D geometry modelling of the drying plenum was done through another commercial software called Solidworks. The modelling of the drying plenum was "cut" into half, as analysing was done based on the concept of symmetrical model. Its dimension was given by 1,255 mm in length x 480 mm in width x 4,490 mm in height. An extension of the air outlet was done to the fluid domain to avoid fluid's "backflow" error. This method of extending and moving the outlet further away from its original location by modelling in an additional length of outlet surface is on one of the common tactics with CFD modelling to minimize backflow behavior (Wong, 2017). A total of 6,031,348 number of elements and 1,135,607 nodes were produced in the discretization of the drying plenum. The simulation was carried out for a steady-state condition. The k-ε was used to represent the turbulence model for this simulation. The turbulence specification method was based on the turbulence intensity and its hydraulic diameter. Two materials was defined for this analysis; the air for fluid and the steel for the solid walls. The thermo-physical properties for air was determined from the experimental analysis, while the properties for the steel was taken from the pre-set ANSYS-Fluent configuration. Three domain were defined in this simulation; the air inlet, the air outlet and the wall. For this simulation, the properties of the fluid (drying air) was used to define the air inlet. The bottom of the drying plenum was set as the air inlet, the outlet of the air was set to be the drying air channels out which was extended 500 mm to cater for backflow of air and the rest of the domain was set as walls. The walls were set as stationary and the condition of the solution was set to be in no-slip condition. The default SIMPLE scheme algorithms were used for the analysis of the problem. Hybrid Initialization was chosen as the solution initialization for this problem, due to the general in nature of the problem itself.

Results and discussion

Air flow properties

From the experimentation investigation, the centrifugal backward-curve blower fan produced a total of 15,699 m^3/h (9,240 cfm) of air. The corresponding volumetric flow rate per tonnage for the dryer system was approximately 933.35 m^3/h per mt (549.31 cfm/mt). The resultant static pressure which responsible for the "push" of the drying air across the drying bed depth was approximately 460 Pa (46.90 mmH_2O). According to Brooker, Bakker-Arkema & Hall (1992), mixed-flow types of dryers require an operating static pressure as high as 51.00 mmH_2O (500 Pa) and a minimum air delivery of 1,589 cfm/mt dried materials (45 $m^3/min.mt$). From the result of the experimentation investigation, it was noted that the fan does not produce enough static pressure to provide enough "push" for the drying air to penetrate and conversely does not produce enough volumetric flow rate to increase the drying rate.

Temperature distribution profiles

Temperature distribution profiles investigation revealed that the highest temperature distribution recorded was localized at the fan's casing which was the closest section to the heat source, the burner. The surface temperature of the fan metal housing registered a temperature ranged from 36 to 46°C. The average temperature was recorded at 45°C, as indicated in Figure 1.0 As the drying air moves farther from the heat source, its temperature began to drop. The temperature distribution at the ducting's wall ranged from 33 to 45°C with an average value of about 40°C as in Figure 2.0. The decreased in the drying air temperature can also be attributed to the presence of turbulence in this section of the duct. As the velocity of the drying air inside the ducting increased as a result of the change in the ducts cross sectional area, the fluctuations in the temperature gradient became higher thus causing the average temperature to drop. As the air moves into the drying plenum, which acts like a diffuser, the velocity of the air slowed, reducing the fluctuations of the temperature, in contrast with the ducting section. From Figure 3.0, the temperature at the dryer's wall suggested that the drying air temperature at this section ranged from 33 to 42°C and its average was approximately at 41°C. From the above observation, an approximately 8.88% of total temperature losses can be traced from the temperature difference from the fan's casing to the drying plenum.

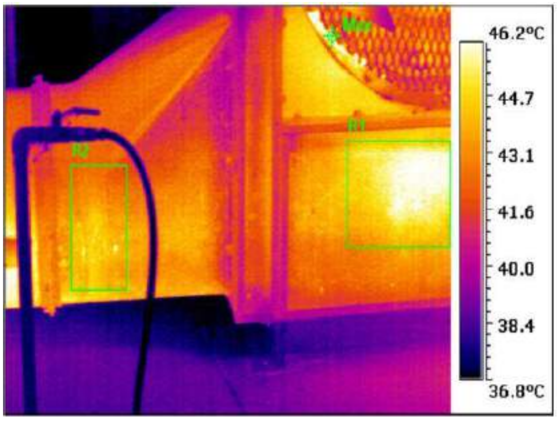

Figure 1.0: The thermo imaging of the temperature distribution at the fan's casing

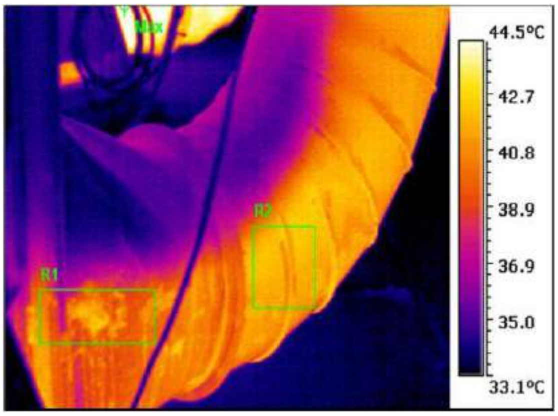

Figure 2.0: The thermo imaging of the temperature distribution at the ducting

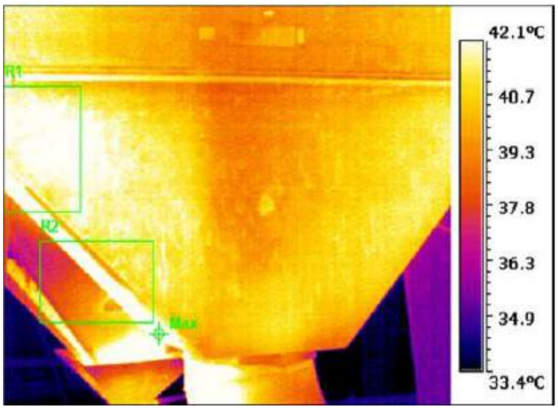

Figure 3.0: The thermo imaging of the temperature distribution at the entrance of drying plenum

ANSYS-Fluent Simulation Results

Static Pressure and Volumetric Flow Rate

ANSYS-Fluent simulated result showed the distribution of the static pressure ranged from as low as -734.5 Pa (-75.0 mmH$_2$O) to as high as 820.2 Pa (84.0 mmH$_2$O) as indicated in Figure 4.0. Based on the simulation, the static pressure distribution can generally be divided into 2 distinctive sections where the bottom section of the plenum's static pressure ranged from as low as 509.3 Pa (52.0 mmH$_2$O) to 664.7 Pa (68.0 mmH$_2$O) and the top section's static pressure ranged from 664.7 Pa (68.0 mmH$_2$O) to as high as 820.2 Pa (84.0 mmH$_2$O). Other sections such as the lower side of the entrance of the air channels and inside the air channels have a much lower range of static pressure. The accuracy of the simulated static pressure was confirmed through cross examination with the experimentation results. It was found that the average static pressure measured at the bottom section of the dryer was 46.90 mmH$_2$O (460 Pa); was relatively close (approximately 10% difference) to the average simulated static pressure of 52 mmH$_2$O (509 Pa) at the bottom of the dryer section (taken from the average of static pressure ranged from 36 mmH$_2$O (353.8 Pa) to 68 mmH$_2$O (664.7 Pa)). These regimes of static pressure distributions can be attributed to the drying air's velocity. As the bottom section of the dryer is closer to the air inlet of the drying plenum, it registered higher velocity of air thus possessed lower ranged of static pressure. As the drying air moves up the drying plenum, its velocity was reduced, therefore registered higher ranged of static pressure. The same correlation of static pressure-velocity of drying air was observed at the entrance and inside of the air channels; where lower static pressure was observed as a result of higher ranged of air velocity around those regions. In an ideal condition where the losses of the generated static pressure would be as minimum as possible, the simulated results predicts that the drying system (the blower fan) could generate as high as 820 Pa or 84.0 mmH$_2$O of static pressure, localized at the top section of the dryer, a region where the formation of relatively high static pressure was considered more critical compared to the lower sections of the dryer as the top section of the dryer required the largest "push" to overcome the high static-pressure drop due to thicker grain bed depth. The usual practice at the plant to over fill the top section to the brink of the drying chamber (heaping to an average of 1200 mm) can be counter-productive and adversely affect the overall drying performance.

From the findings, the static pressure requirement at the top of the dryer were at least 4 times the static pressure needed for the rest of the dryer's volume (that accounted almost 90% of the dryer's volume). Since the average static pressure measured during the experiment were 46.9 mmH_2O (460 Pa) and were sufficient for a standard 300 mm grain bed depth, then the theoretical static pressure requirement for the top part of the dryer that has a 1200 mm grain bed depth, would amount to an approximately 188 mmH_2O (1,844 Pa). Such a high static pressure requirement is impossible to achieve under current drying system configuration thus adversely affecting the dryer performance. However, positive outcomes could be anticipated if the current optimum fan speed configuration and the ideally simulated static pressure values be used as a guidelines to reduce the level of the filling to 1,000 mm and below, then the theoretical requirement for static pressure at the top of the dryer would be reasonably low (approximately 140 mmH_2O) and the disparity between the simulated static pressure of 84 mmH_2O (820 Pa) would be reduce from 55% (comparison between 188 mmH_2O) to 40%. The reduced from the theoretical static pressures of 188 mmH_2O to 140 mmH_2O would result in a reduction of approximately 48 mmH_2O (470 Pa) or is equivalent of reducing 1 layer on grain bed depth of static pressure. This could significantly boost the efficiency of the dryer system and hence reducing both the drying rate and as well as the drying period. The analysis of volumetric flow rate of the drying air is closely related to the characteristics of the air's velocity. Since the cross sectional area are constant, therefore the volumetric flow rate is directly proportional to the air's velocity. As the drying air moves upward towards the top section of the dryer, its velocity decreased thus reducing its volumetric flow rate. The opposite reactions could be viewed at the bottom sections of the dryer where the velocity is high hence a higher volumetric flow rate is expected at that section as in Figure 5.0.

Temperature Distribution Profiles

The simulated temperature readings from the analysis showed that as the hot drying air enters the plenum from the bottom and moves upwards before making a perpendicular turn into the drying bed, there exist a temperature gradient between the bottom and the top section of the plenum. It was found that the bottom plenum section to be the highest (45.01°C) and reduced as it moved upwards where the lowest was 41.3°C. The reduction in the drying air temperature seemed uniformly distributed across the longitudinal-section of the plenum. As in Figure 6.0, the average drying air temperature inside the drying plenum from the simulations was found to be 44°C. The existence of the temperature gradient of about 4˚C showed a distinctive heat loss occurred in the drying air as it moved up the dryer chamber. The loss in the heat from the drying air is gained by the metal housings of the dryer system as indicated by the thermal image captured by a thermal camera as discussed earlier. Therefore, it can be inferred that the simulation gave a sound result of the ideal temperature of the drying air would be if the control system is efficient and accurate.

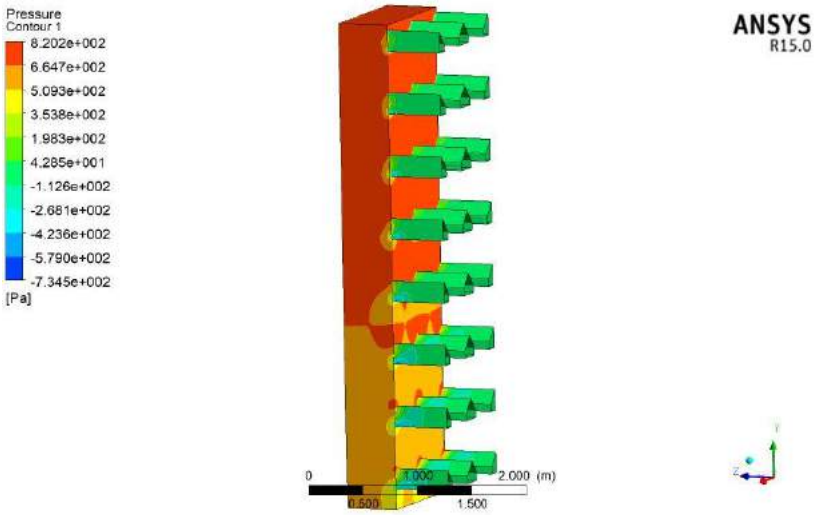

Figure 4.0: The pressure distribution inside the drying plenum

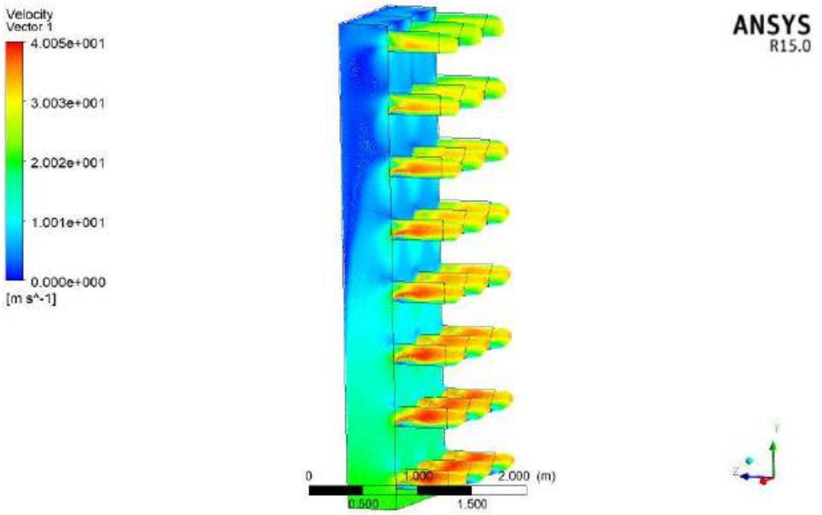

Figure 5.0: The velocity distributions inside the drying plenum

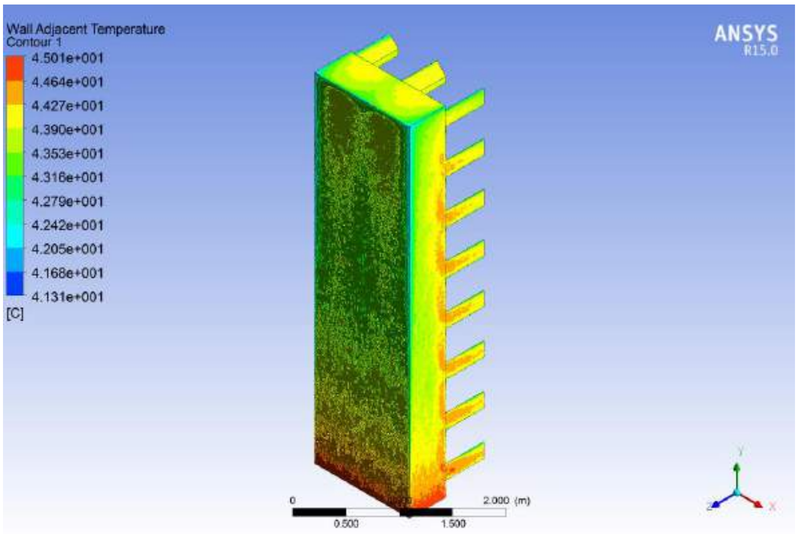

Figure 6.0: The temperature distribution inside the drying plenum

Conclusions

The performance of the LSU Batch Mixed-Flow Seed drying system *at Loji Pemprosesan Benih Padi Sah (A) Telok Chengai* was needed to be assessed and evaluated in order to determine its operating form and also to provide a basis for improvements and modifications in the future. Cross examination of the performance of the dryer system was done between experimentation investigation and CFD simulation using ANSYS-Fluent commercial software on three (3) drying air properties; static pressure, volumetric flow rate and temperature distribution profile. From the experimentation investigation, it was evidenced that the current blower fan produced a relatively low static pressure (460 Pa or 46.90 mmH_2O) and volume of air (15,699 m³/h or 9,240 cfm or 577 cfm/mt) compared to the proposed which were 500 Pa (51.00 mmH_2O) for static pressure and 45 m³/min.mt (1,589 cfm/mt) for the volume of air. These lack of drying air and the amount of “push” needed to overcome a greater grain bed depth at the top of the drying chamber has reduced the drying rate and consequently increased the drying period from 24h to approximately 30h. Validation for the static pressure generated using ANSYS-Fluent revealed a 10.0% disparity between the two results which indicates a very close approximation to the actual situation. From the simulation, under ideal condition, the drying system are producing as high as 820 Pa (84.00 mmH_2O) at the top of the dryer which are still insufficient to cater 4 times the normal requirement which are currently at 460 Pa (46.90 mmH_2O) per 300 mm of grain bed depth. Furthermore, validation on the drying air temperature distribution profile inside the drying plenum suggested a 7.3% disparity between the actual (41°C) and the simulated results (44°C). This result suggested that there was actual losses occurred in the drying system and one of the way to overcome this issue is to improve on the configuration of the drying system, such as to increase the effective length of the ducting and to maximize the pre-set temperature to 45°C, the maximum allowable safe drying temperature for seeds.

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