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NON-DIMENSIONAL NUMBERS ANALYSIS OF A BIOMASS OPERATED GRAIN DRYER COUPLED WITH THERMAL STORAGE

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ABSTRACT

In this study, non-dimensional number analysis has been performed for the rectangular chamber (brick wall) outer surface in a natural convection grain dryer. For the study, biomass is burnt in the conical furnace for three hours at a rate of 1.6 kg/h. The study has been performed for two cases; (i) without sensible heat storage medium (pebbles), and (ii) with sensible heat storage medium in the rectangular chamber. In the present study, Grashof number ( ), Rayleigh number ( ), and Nusselt number ( ) have been evaluated. The value of Grashof number and Rayleigh number was obtained in the range of 2.59×108□9.56×109 and 1.9×108□7.84×109 for the case-I and 1.48×109□579×109 and 1.08×109□4.23×109 for case-II, respectively. The value of Nusselt numbers was obtained in the range of 85.6□284.23 and 152.99□240.8 for the cases-(I&II), respectively

1. Introduction

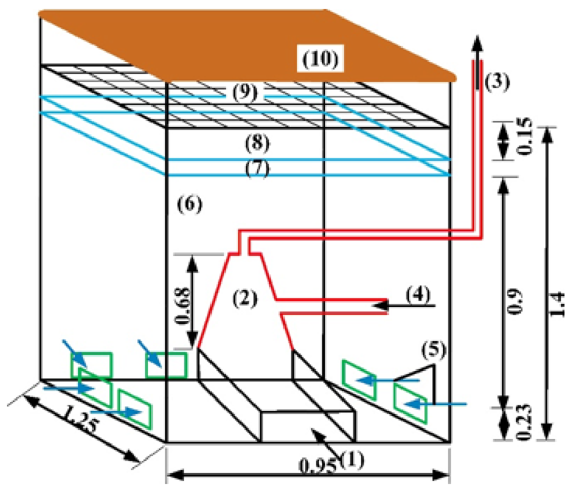
The balance of food in the increasing population of the world is a major issue. From the literature, it has been found that developing countries lose 10% to 40% of food due to improper post-harvesting. From the study, it has been observed that 1/3 of the world population depends on rice as the main source of food [1]. Hence to preserve food for the entire world population food security is a challenging issue at present. The open sun drying of the agricultural products is a commonly used drying process in developing countries like India but this drying process does not give a good product quality due to insects, birds, etc. Hence designing a proper dryer for agricultural product drying is a challenging issue. Pangavhane et al. [2] designed a solar dryer and performed the drying analysis of grapes. The SAH and the drying chamber performance analysis was carried out in the natural convection mode under no-load condition. The performance of the dryer was also tested for the grapes drying process. During the study, the thermal efficiency of the solar collector varied from in the range of 48□56%. Prasad and Vijay [3] dried the agricultural products (ginger, turmeric, and Guduchi) in a solar dryer. To continue the drying process of the products, the solar dryer was coupled with a biomass burner. The products were also dried in a solar dryer only and open sun in the same ambient condition. During the study, it was observed that the drying is relatively faster in the hybrid dryer. Kumar et al. [4] reported the non-dimensional and heat transfer coefficient analysis for a conical furnace of a grain dryer and the found that the use of energy storage medium enhances the performance of the dryer. Bala and Woods [5] studied the simulation of the rough rice drying process in an indirect type natural convection solar dryer. The temperature along the collector was analyzed by a numerical solution. The drying behavior of the product was analyzed with the help of deep-bed solution procedure. Due to variation in temperature in the collector and across the air bed thermal buoyancy effect was observed. It was observed that over-drying takes place in a bottom layer so, continuous mixing is essential. Bena and Fuller [6] studied the performance of a solar dryer integrated with a biomass burner. In this study, a natural convection dryer was coupled with a simple biomass burner. During the study, the drying behavior of the agricultural products was analyzed. The main objective to design this dryer is the suitability of small scale farmers for the agricultural product drying process in the developing countries. The drying efficiency of the dryer unit was obtained at 9%. The thermal efficiency of the dryer and the burner was obtained at 22% and 27%, respectively. Kumar et al. [7] performed the exergy analysis of a dryer and found that the thermal storage medium reduces the exetgy destruction in the chamber. Jain and Tewari [8] performed the performance analysis of a solar dryer coupled with a latent thermal energy storage medium working under natural convection. During the study, the thermal storage (PCM) works as back up energy sources, it stores thermal energy during sunshine hours and supplies in the evening (when the sunshine is not present). In this study, the thermal efficiency were reported as 28.2%. Sekyere et al. [9] reported the performance analysis of a hybrid mixed-mode natural convection solar dryer coupled with a biomass burner. In this study, the drying characteristics of freshly prepared pineapples was analyzed. Kumar et al. [10] performed the first and second law analysis of a biomass operated grain dryer and observed that the sensible thermal storage medium enhances the performance of the dryer. Syahrul et al. [11] performed the drying analysis of the moist products with the help of first and second law analysis of a fluidized bed dryer. Midilli and Kucuk [12] analyzed the first and second law of thermodynamics of the pistachios drying process in a solar dryer. In this study, the energy analysis was performed to estimate the energy gained by the air in the solar air heater and the energy utilization ratios.

Present work deals with the non-dimensional number analysis of the rectangular chamber (Brick wall) outer surface in natural convection biomass operated grain dryer for the two cases of studies; (i) without sensible heat storage medium in the chamber, and (ii) sensible heat storage material present in the chamber.

2. Experimental set-up and procedure

For the developed experimental set up, the study has been performed for biomass operated grain dryer having a brick wall rectangular chamber inside dimension $1.25 \times 0.95 \times 0.9$ m, conical furnace (MS) $0.6 \times 0.3 \times 0.68$ m, exhaust pipe (MS) 0.635 m diameter, paraffin wax tray (MS), drying chamber, drying tray (MS wire mesh), biomass feeding pipe (MS) 0.1 m diameter, etc. as shown in Fig. 1. Fig. 2 shows the schematic of the dryer. The present work deals with the non-dimensional number analysis of the rectangular chamber outer surface. This study has been done for two cases; (i) with sensible energy storage material, and (ii) without sensible energy storage material in the rectangular chamber. For the proper analysis, the study has been performed by measuring the temperature at the outer wall surface of the rectangular chamber with the help of a laser light temperature sensor (temperature gun). In the present work, locally available biomass is burnt at the rate of 1.6 kg/s for three hours in the conical furnace. Due to heat generation in the conical furnace, the surface of the furnace gets heated-up, surrounding air/pebbles in the chamber which is in contact with the furnace gain heat from the furnace's outer surface. Due to buoyancy force, hot air from the chamber below the wax tray flows into the drying chamber through the hollow tubes in the tray and once the paraffin wax melts in the tray it supplies uniform heat to the product in the drying chamber.

Fig. 1 *Natural convection grain dryer*.



(1) Fresh air enters into the furnace (2) Conical furnace (3) Exhaust pipe (4) Biomass feeding pipe (5) Ambient air enters into the rectangular chamber (6) Rectangular chamber (7) Paraffin wax tray (8) Drying chamber (9) Drying tray

Fig. 2 *Schematic of the experimental setup (all dimensions are in meter).*

3. Theoretical analysis

In this study, Non-dimensional numbers have been calculated to analyze the loss of energy from the brick wall of the rectangular chamber. Non-dimensional numbers such as Gr, Pr, Ra, and Nu are evaluated in the present study. Grashof number for the outer surface of the brick wall can be evaluated by using Eq. (1) [10], [13]:

$$Gr = \frac{g \times \beta \times \Delta T \times L^3}{\vartheta^2} \quad (1)$$

Prandtl number is calculated with the help of Eq. (2):

$$\Pr = \frac{\mu \times c_p}{k} \quad (2)$$

Rayleigh number is evaluated in Eq. (3) [14]:

$$Ra = Gr \times \Pr \quad (3)$$

Nusselt number in the natural convection mode of heat transfer for a Rayleigh number range of $10^9 \leq Ra \leq 10^{13}$ [15] is calculated by using Eq. (4):

$$Nu = 0.10 \times Ra^{0.333} \quad (4)$$

4. Results and discussion

This study was performed in November 2019. In the study, subscripts 1&2 represent the cases-(I&II) and w represents the the rectangular chamber outer surface (brick wall). During the study, all the experimental data have been recorded at an interval of 30 minutes. Fig. 3 presents the outer surface temperature of the rectangular chamber (brick wall). From the results, it can be seen that the outer surface temperature of the brick wall is relatively higher for the case-I. The higher values of the outer surface temperature indicates that the case-I allows relatively more heat through the brick wall of the rectangular. Hence, energy loss through the wall is higher for the case-I as compared to case-II. Fig. 4 shows the Grashof number variations of the rectangular chamber outer surface. From the results, it is observed that the Grashof number is higher for the case-1 as compared to case-II. The cause of the higher Grashof number in the case-I is the higher value of the wall outer surface temperature. The value of Grashof numbers was ranged from 2.59×10^8□9.56×10^9 and 1.48×10^9□579×10^9 for the cases (I&II), respectively. The variations of the Rayleigh numbers are shown in Fig. 5. From the figure, it is clear that the Rayleigh numbers for the case-I are relatively higher as compared to the case-II. Its value ranged from 1.9×10^8□7.84×10^9 and 1.08×10^9□4.23×10^9 for the cases (I&II), respectively. Fig. 6 presents the variations of the Nusselt number with time. In the study, it is observed that the value of the Nusselt number is higher for the case-I and its variation with time is similar to that of the Rayleigh number. Its value ranged from 85.6□284.23 and 152.99□240.8 for the cases□□I&II), respectively.

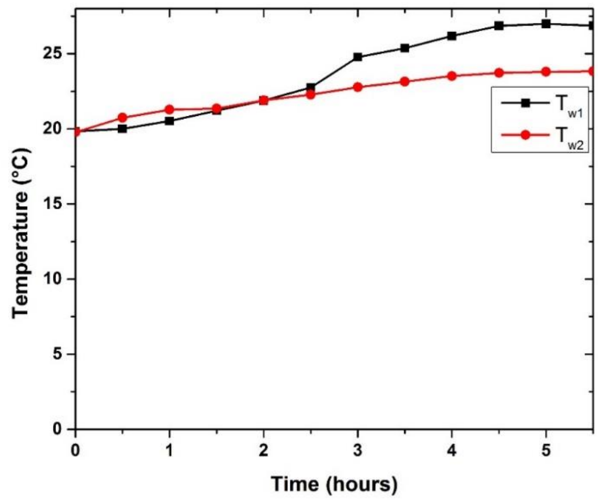


Fig. 3 *The variations of rectangular wall outer surface temperature.*

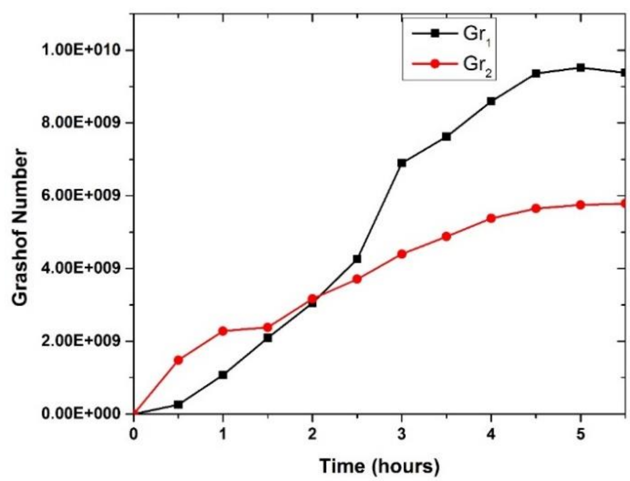


Fig. 4 *Grashof number variations with time.*

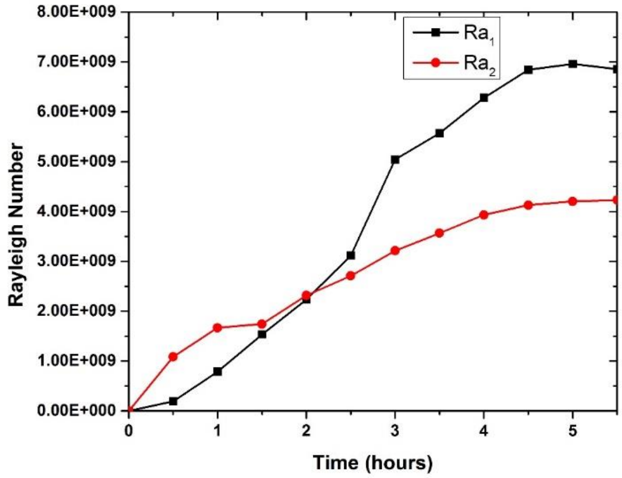


Fig. 5 *Rayleigh number variations with time.*

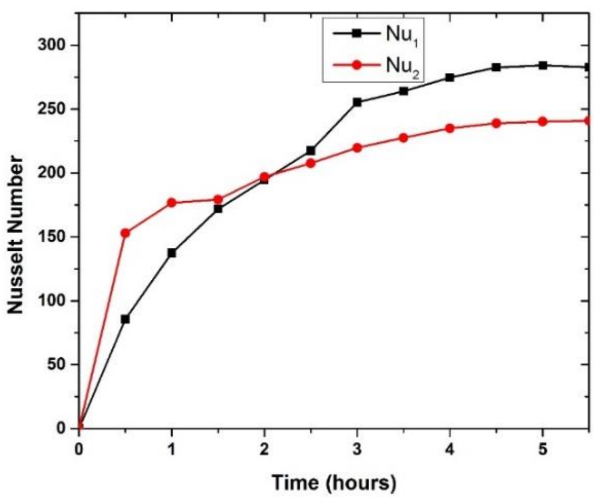


Fig. 6 *Nusselt number variations with time.*

5. Conclusions

From the study, it is found that the temperature of the outer surface of the rectangular chamber and all three non-dimensional numbers values is higher for the case-I. Hence, it leads to relatively high losses of energy through the brick wall. This indicates that the energy losses through the rectangular chamber is lower in the case-II (when sensible heat storage material is present in the rectangular chamber). Hence, the use of sensible heat storage material (pebbles) in the rectangular chamber reduces the losses of energy I,e enhances the performance of the dryer.

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