Effect of the thermal storage medium on non-dimensional numbers of a grain dryer

Dhananjay Kumar [a], Pinakeswar Mahanta [b], Pankaj Kalita[c]

[a] Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati-781039, India
[b] Department of Mechanical Engineering, Indian Institute of Technology Guwahati, Guwahati-781039, India & Department of Mechanical Engineering, National Institute of Technology Arunachal Pradesh, Itanagar-791112, India
[c] Centre for Energy, Indian Institute of Technology Guwahati, Guwahati-781039, India
Email: [a] tak5dhananjay@gmail.com, [b]pinak@iitg.ac.in, [c]pankajk@iitg.ac.in

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Abstract: This study deals with the evaluation of non-dimensional numbers such as Grashof numbers, Rayleigh numbers, and Nusselt numbers for the outer surface of the rectangular chamber of biomass operated natural convection crop dryer. This study is aimed to develop a grain dryer for agricultural products drying in the village areas of the developing countries, especially where electricity is not available. This study has been performed for the two cases; (i) without thermal storage medium in the rectangular chamber, and (ii) with thermal storage medium in the chamber. The purpose of this study is to analyze whether the thermal storage reduces the energy losses from the rectangular chamber. The non-dimensional numbers analysis has been performed for both the cases of studies. In the present study, variations in all the non-dimensional numbers with time were plotted. Relatively lower values of the non-dimensional numbers for the chamber outer surface were obtained for the case-II. Hence, the thermal storage medium reduces the energy losses from the chamber

Keywords: Natural convection, Heat transfer coefficient, energy analysis, exergy analysis

1. Introduction

In the present scenario of the energy crisis, the thermodynamic analysis of any energy consumable systems/dryers become the most essential tools to optimize the energy consumption in the systems. The thermodynamic analysis can provide a significant solution to the energy crisis in the world. In the present situation, energy consumption increasing rapidly in daily life and we have very limited energy resources. Hence, the thermodynamic study of the biomass-operated grain dryer can extend the self-life of the energy resources. Numerous researchers reported the thermodynamic study of the various types of dryers. Kumar et al. [1] performed the thermodynamic study of a biomass-operated grain dryer and found that the sensible thermal storage medium reduces the exergy destruction in the natural convection dryer. Guerraiche et al. [2] performed a performance analysis of a solar collector using thermal storage. The thermal storage medium was used as a mixture of Sodium Nitrate (NaNo3) and Potassium Nitrate (KNo3). During the study, the outlet water temperature of the collector was obtained 14.86–16.80 % higher in the case of the thermal storage medium. Kumar et al. [3] reported the analysis of the non-dimensional number of a dryer and relatively better performance of the dryer were observed in the case of sensible thermal storage material. Caliskan et al. [4] performed the first and second law thermodynamics study of a solar dryer using thermal storage for the ambient temperature of 8, 9, and 10 °C, respectively. This study was performed for the heating application of a building. In this study, the maximum value of the second law efficiency of the acquired thermal energy storage system was recorded as 88.78 % for the ambient temperature of 8 °C. Considering all components of the system, the maximum exergetic efficiency of the floor heating unit was obtained as 98.08%. Kumar et al. [5] studied the energy analysis in the rectangular chamber of a natural convection biomass-operated grain dryer and observed that the thermal storage medium reduces the energy losses from the wall. Kalaiarasi et al. [6] presented the thermodynamic study of a solar air heater coupled with sensible thermal storage. This study was performed for two air mass flowrates 0.018 kg/s and 0.026 kg/s. The maximum value of thermal and exergetic efficiency was recorded as 49.4–59.2% and 18.25–37.53%, respectively for the airflow rate of 0.026 kg/s. Adetifa and Aremu [7] performed the experimental and numerical study of a thermal energy storage material. In this study, two latent storage medium and one sensible thermal energy storage medium were used for the low-temperature application. During the study, it was observed that the thermal storage material is capable to sustain 1.5 kg of water above 50 °C for 3 hours and 20 minutes in the absence of solar radiation. Kumar et al. [8] performed the exergy analysis in the rectangular chamber of a natural convection dryer and found that the thermal storage reduces the exergy losses from the wall of the rectangular chamber. Hence, this study enhances the performance of the dryer. Abuska et al. [9] reported the thermodynamic study of a solar collector coupled with sensible thermal storage. This study was performed to continue the use of solar collector even in cloudy weather. This study was performed for the airflow rate range of 0.004–0.048 kg/s and the thermal efficiency was obtained in the range of 6.05–39.99 %. Senthil and Cheralathan [10] reported a study on the capacity enhancement of thermal storage for a solar collector. In this study, sugar alcohol was used as latent thermal storage and the thermal and exergetic efficiency were obtained as 66.7% and 13.8%, respectively.

In the literature, many researchers performed the thermodynamic analysis of solar dryers. The literature related to the biomass operated dryer with thermal storage medium is found to be very limited. Hence, the objective of this study is to analyze the effect of the sensible storage medium on non-dimensional numbers of the natural convection biomass operated grain dryer. In the present analysis, the study is performed for the two cases; (i) without thermal storage medium, and (ii) with thermal storage medium in the rectangular chamber.

2. Experimental setup and procedure

The experimental set up has been designed for the agricultural products drying process. The dryer consists of a rectangular chamber, paraffin wax tray, and drying tray having a dimension of 1.25 m × 0.95 m × 0.9 m, 1.25 m × 0.95 m × 0.12 m, and 1.25 m × 0.95 m, respectively. Multiple holes in the conical furnace of dimension 0.6 m × 0.3 m × 0.68 m is kept in the rectangular chamber. Holes are made at the conical surface to flow the flue gases into the rectangular chamber. The flue gas exhaust pipe having a diameter of 6.35 cm is attached for the exhaust of flue gas. A provision of fresh air entry in the conical furnace is also made for the proper combustion of the biomass. The principle of this dryer working is buoyancy force. When the biomass burns in the furnace, hot air from the conical furnace flow into the rectangular chamber. This creates negative pressure in the furnace, which makes the cause of ambient air enters into the furnace, and combustion of the biomass continues. The experimental studies have been performed for the two cases; (i) There is no sensible storage medium (pebbles) in the rectangular chamber, (ii) sensible storage is present in the rectangular chamber. Fig. 1 shows the photograph of the natural convection crop dryer and Fig. 2 shows the schematic of the dryer.

Fig. 1 Photograph of the dryer.

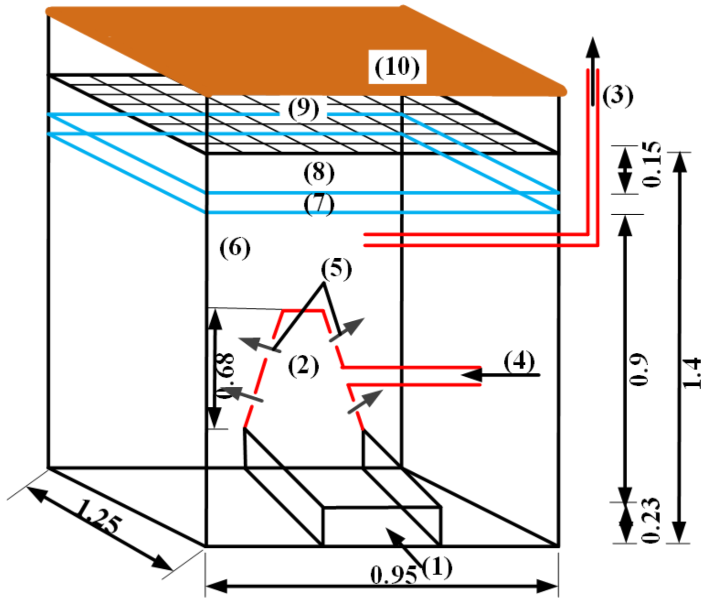

Fig. 1 Schematic of the experimental setup.

(1) Fresh air enters into the furnace (2) Conical furnace (3) Exhaust pipe (flue gas outlet) (4) Biomass feeding pipe (5) Flue gas enters into the chamber (6) Rectangular chamber (sensible storage) (7) Paraffin wax tray (8) Drying chamber (9) Drying tray (10) Mild steel cover.

In both the cases of studies, biomass (lebbeck) has been burnt at the rate of 1.6 kg/h for three hours in the furnace. During the study, the temperature at the outer surface of the rectangular chamber (brick wall) is measured with the help of a Temperature Gun (GM-300).

3. Mathematical formulation

This study has been performed to analyze the variations of non-dimensional numbers at the outer surface of the rectangular chamber. To evaluate the non-dimensional numbers of the rectangular chamber, the following equations have been used. The Grashof number (Gr) for the brick wall outer surface can be evaluated with the help of Eq. (1) [11,12]:

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

Prandtl number can be written as in Eq. (2):

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

Rayleigh number is evaluated with the help of Eq. (3) [5]:

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

Nusselt number is calculated with the help of Eq. (4) [13]:

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

4. Results and Discussion

In the present study, all the experimental data have been recorded at an interval of 0.5 hours. The subscripts 1 &2 represent the case-1 and case-II, respectively. Fig. 3 shows the Grashof numbers variations for the case-I and case-II. From the results, it was found that the values of Grashof numbers were higher for the case-I. The average values of the Grashof numbers were obtained as 4.09×10^9 and 3.08×10^9 for the case-I and case-II, respectively. The Rayleigh numbers variations is shown in Fig. 4 and the Nusselt number is shown in Fig. 5. From the Figs. (4 & 5), it was found that the Rayleigh numbers and the Nusselt numbers are higher for the case-I and these curves follow the same trend as Grashof numbers. The average value of the Rayleigh and Nusselt numbers are obtained as 2.89×10^9 and 132.17 for the case-I and 2.17×10^9 and 121.94 for the case-II, respectively.

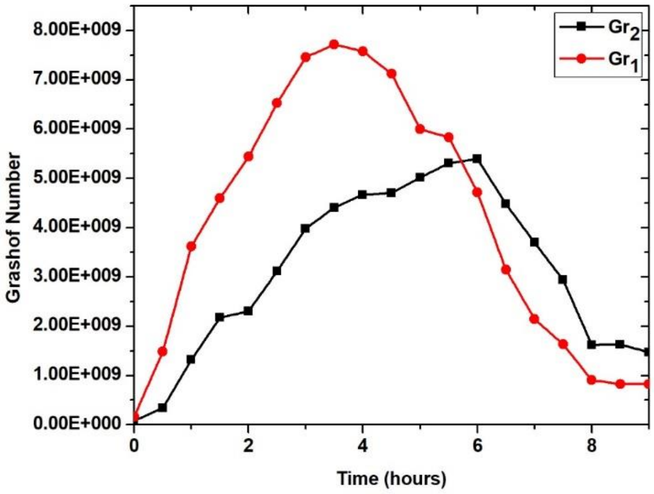

Fig. 3 Grashof numbers variations.

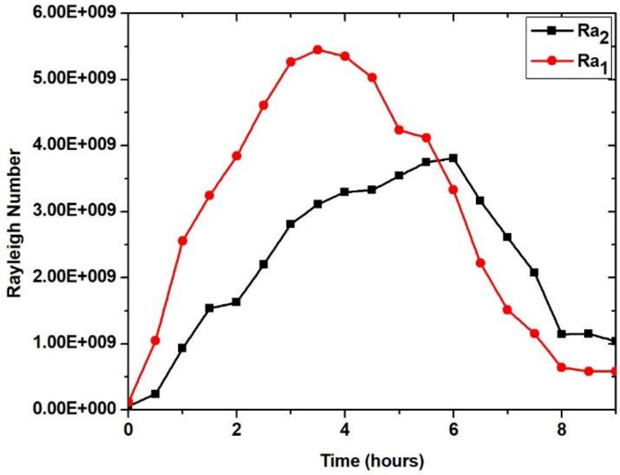

Fig. 4 Rayleigh numbers variation curve.

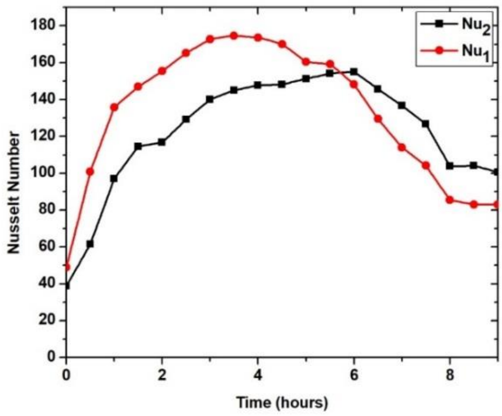

Fig. 5 Nusselt numbers variation curve.

Figs. (6&7) shows the variations of Grashof and Nusselt numbers for the cases-(I&II), respectively. From the figures, it was observed that the Grashof and Nusselt numbers vary with similar trends, and relatively lowers values of both non-dimensional numbers were obtained in the case-II. From the results, it was found that the maximum values of the non-dimensional numbers for the case-I were obtained at the 6 hours of the study, while the same was obtained at 4 hours for the case-II.

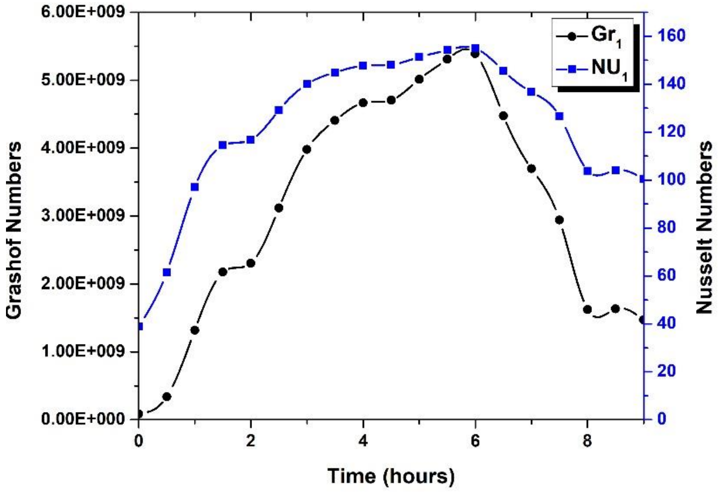

Fig. 6 Grashof and Nusselt numbers variations for case-1.

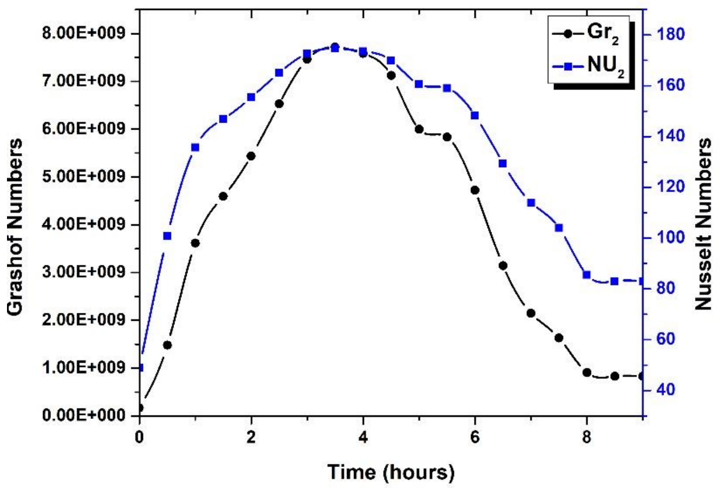

Fig. 7 Grashof and Nusselt numbers variation with time for case-2.

5. Conclusions

This study has been performed to analyze the performance of the developed dryer with the use of a sensible thermal storage medium in the rectangular chamber. From the results obtained in the present study, it has been found that the sensible energy storage material reduces the values of the non-dimensional numbers at the surface of the rectangular chamber. The lower values of the Nusselt numbers indicate that the sensible storage medium reduces the energy losses from the brick wall of the chamber. Hence, the use of a sensible storage medium (pebbles) is highly recommendable for the application.

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