International Journal of Research in Engineering, Science and Management
Volume-3, Issue-3, March-2020
www.ijresm.com | ISSN (Online): 2581-5792

CFD Analysis for Tea Withering with and without Effect of Solar Radiation

Sunay Dev Pushan[1], Agnimitra Biswas[2]
[1]*M.Tech. Scholar, Department of Mechanical Engineering, NIT Silchar, Silchar, India*
[2]*Assistant Professor, Department of Mechanical Engineering, NIT Silchar, Silchar, India*

***Abstract*: To analyse the tea withering process of the existing withering trough of Rosekandi tea estate, Cachar Assam, using CFD Simulations with and without the effect of solar radiation. The systematic performance data including the construction details of the withering trough are collected from the tea estate and analysed for computational modelling of withering process. The model of withering trough has been built using Ansys 14.5 and finds various input wind speeds and validated with the experimental data. After that the validated model is modified incorporating radiant flux boundary condition due to solar energy on a semi-transparent material (Polycarbonate sheet) covering the top of the withering trough. Now the new CFD model has been built and is analysed for different solar radiation intensities and wind speed. The outcome indicates towards the improvement of the withering process as reduced temperature difference across the leaf layers compared with the existing design.**

***Keywords*: Withering trough, Humidity, Solar radiation, Porous media, Polycarbonate sheet.**

1. Introduction

Solar energy proves to be a promising alternative energy source in providing low grade heat required in many commercial and industrial applications, especially in countries where this source is abundantly available. The most widely studied solar radiation. A solar dryer is an enclosed unit which allows the solar insolation to pass through a glazing and get absorbed. The heated surface, in turn, heats up a draft of air which then flows across/through food items and leads to their drying. The drying temperature and relative humidity under solar drying continuously varied with increasing drying time. The results revealed that the drying temperature in solar drying was greater than the ambient temperature, whereas the relative humidity in this system was lower than the ambient relative humidity. The green tea leaves (the tip and two to three small delicate leaves) were picked. The collected tea leaves were spread out on wire trays and withered by passing the air at about 25°C to 29°C for pre-determined time. The increasing of drying capacity will increase the drying efficiency, therefore decreases the energy consumption to evaporate the moisture from the product. Drying air temperature and moisture content was distributed uniformly throughout the racks within the dryer.

A. Tea Leaf Processing Steps

Tea leaves and flushes, which include a terminal bud and two young leaves, are picked from bushes typically twice a year. The tea leaves will begin to wilt soon after picking, with a gradual onset of enzymatic oxidation. Withering is used to remove excess water from the leaves and allows a very slight amount of oxidation. The enzymatic process that takes a group of compounds called polyphenols and oxidizes these compounds to coloured products. On the basis of the degree of fermentation and manufacturing process. Drying is a simultaneous heat and mass transfer process, where heat is supplied to wet tea by heated air and the evaporated moisture is carried away by the air. The physical and chemical transformations during withering and the implication of these changes on subsequent manufacturing stages and on the overall quality of tea [Omaidze et al., 2014]. The drying is described by a deep bed procedure that includes conduction within the grain bed. The results show that temperatures at the top and bottom of the bed are higher than that in the middle resulting in two drying fronts one at the top and the other at the bottom of the bed and moving in opposite directions [Baruah et al., 2012].With a view to ensure uniform withering of leaf mass through its different layers, the direction of airflow through the trough bed is reversed at certain time intervals, conventionally each hour, by operating swing dampers and using alternate air-exits of upper and lower ducts [Gupta. R et al. 2012].

B. Solar Radiation Effect on Withering of moisture

Radiation always exists and can strongly interact with convection in many situations of engineering interest. The influence of radiation on natural or mixed convection is generally stronger than that on forced convection because of the inherent coupling between the temperature and flow fields. A. Sinha, et al. [2] al investigated that the direct exposure to solar radiation of the products and the heated drying air enhance the drying rate of the products. The drying efficiency, is determined as the ratio of amount of water evaporated to incident solar radiation intensity for a given period of time [Bena and Fuller; Ekechukwu et al,]. Although the use of solar radiation for drying has existed since antiquity, it has not yet been widely commercialized, particularly in the industrial sector. Brenndorfer B. et al. [12] has been studied with the consideration of the rapid depletion of natural fuel resources and because of the rising fossil fuel cost, solar drying is expected to become indispensable in the future [1985]. Low mass flow rates are able to utilize the maximum capacity of the storage system and to supply heat for a longer duration. El-Sebaii et al. [10] has been investigated experimentally and constructed an indirect type natural convection solar dryer. Natural circulation greenhouse dryers often called tent dryers, these are essentially modified greenhouses. They are equipped with vents sized and positioned appropriately to control the air flow. They are characterized by extensive glazing on their sides. Insolent panels may be drawn over the glazing at night to reduce heat losses and heat storage facilities may be provided. S T et al. [9] has been designed greenhouse dryers allow a greater degree of control over the drying process than the cabinet dryers and are more appropriate for large scale drying. A numerical approach to model the flow in porous media using homogenisation theory. Wang et al. [8] has been reported the homogenisation method adopts an asymptotic expansion of velocity and pressure through the micro-structures of porous media. Heat transfers and pressure drops for porous-ring turbulators in a circular pipe. Numerical calculations are conducted with the Fluent 6.1.22 code, using the shear-stress transport (SST) k-ω model [Akansu, 2006]. The heat transfers and flow friction of a porous body using modified maximum slope method. The heat transfer coefficients of compact heat exchangers are estimated using transient testing methods [Krishnakumar and Nair, 2010]. In the present work, following objectives have been obtained: CFD analysis for tea withering of (a) The existing trough without consideration of solar radiation (b) The modified trough with consideration of solar radiation. And comparison of performances between the modified withering trough and the existing withering trough.

Table 1
Mesh Details of modified trough

No. of Nodes	94422
No. of Element	214254
Minimum Edge length	0.15 m
Minimum Orthogonal Quality	0.48
Minimum Aspect Ratio	0.92
Maximum Skewness	0.73

2. Theoretical and formulation

A. CFD Modelling of Withering Process

Three dimensional computational model of the existing open trough was built in Fluent 14.5 package. The dimensions of various parts of the trough like input blowers, wooden structures, wire and nylon meshes, leaf bed length, thickness and width were taken exactly same as the existing trough. The computational mesh was built to the Grid independent limit mesh, which means independency of result with respect to any mesh size increase from that limit. In the enclosed troughs the bed is kept in an enclosed environment by raising the sides of the withering troughs and using a cover on the top of the bed. This is designed to create a plenum chamber at the top of the trough as well.

In this case the fan is always made to blow air only in the forward direction and the air can be made to pass either from top to bottom or from bottom to top with damper and shutter controls at the air entry and exits respectively. The model diagram of the existing open trough in Rosekandi tea estate is shown in figure 3 and It is fitted with two blowers which in duct the drying air into the trough for flow through the leaf mass. The rated capacity of each blower is 40 cubic feet per minute (CFM) per square feet and 960 rpm. The existing trough is 28.35 m in length and 4.87 m in width, which is fitted with a wire mesh at the bottom face. The wire mesh is usually covered with nylon netting on which the leaf is spread at a rate of 1.8 to 2 kg per sq. ft., which results in a leaf layer thickness of approximately five to eight inches. The wire mesh is 3″ × 1″ in size, and there are 36 nylon meshes per square inch of wire mesh. In the table 2 describe the dimension and material used for manufacturing of the existing trough. The bottom face of the trough, which rests on the floor is slightly tapered by 0.30° to match the design with the existing trough.

The velocity of air on the bottom leaf layer was considered as the parameter for which grid independence limit (GIL) was determined. The various levels of refinement used for the grid independence study of the existing trough. The various levels of refinement used for the grid independence study of the existing trough. The refinement level consisting of 24,441 nodes and 1114254 cells was used for final simulation.

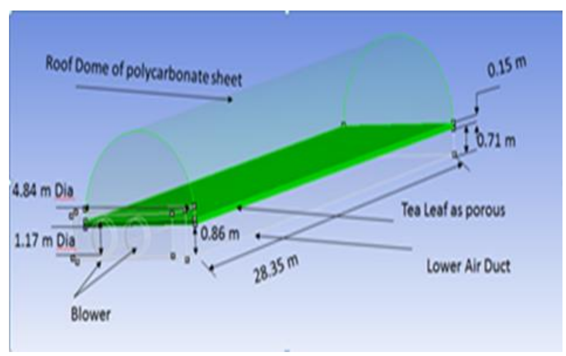

Fig. 1. Modified trough

B. CFD formulations

In this study, steady state, incompressible three-dimensional air flow was assumed. The numerical simulations were carried out by solving conservation equations for mass, momentum and energy using an unstructured grid finite volume methodology. The sequential algorithm, semi-implicit method for pressure-linked equation (SIMPLE) was used for pressure-velocity coupling of the flow. For the convective terms of the momentum equations and also for the turbulence equations, the second order upwind interpolating scheme was applied in order to achieve accurate results.

Air flow through the tea leaf particles is modelled as flow in porous media. Porous jump conditions are used to model a thin 'membrane' (leaf layer) that exhibits velocity/pressure-drop characteristics. This simpler model was used because it is more robust and yields better convergence.

C. Analysis the modified model using solar energy

The validated model is modified incorporating radiant flux boundary condition due to solar energy on a semi-transparent material (Polycarbonate sheet) covering the top of the withering trough of the existing design. With this the new CFD model has been built (shown in figure 2) and its performances are analyzed for different solar radiation intensities and wind speeds.

Air flow through the tea leaf particles is modelled as flow in porous media. Porous jump conditions are used to model a thin 'membrane' (leaf layer) exhibits velocity/pressure-drop characteristics. This simpler model was used because it is more robust and yields better convergence. The flow was overall turbulent with laminar in the porous medium. The porous media characteristics are derived as Continuity equation for porous flow.

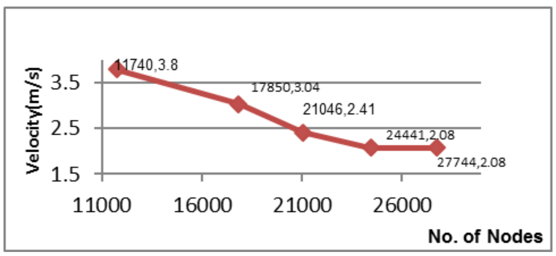

Fig. 2. Grid Independence Limit

3. Results and Discussion

Using solar radiation effect, the post CFD outcomes are shown in Figures in which the range of temperature variations end to end of the trough for bottom and top leaf layers are 1 ^{O}C and 1.16 ^{O}C respectively. Since tea leaf layers is taken as porous medium that is why if there is less deviation in temperature over the two surfaces causes more to be heat transfer over the surface. This results uniformity in temperature through its thickness. Below the graph also represent the comparative study of these models.

Table 2
Temperature and velocity of the air flow over the length of the trough on bottom leaf layer

Trough Length (m)	7.08	14.17	21.25	28.3
Temperature (Kelvin)	300.8	299.6	299.5	300
Velocity (m/s)	0.35	0.29	0.23	0.15

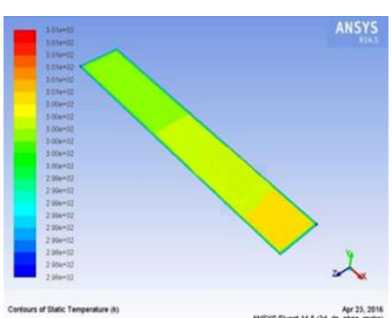

Fig. 3. Variation of temperature with velocity of the air flow over the length of the trough on bottom leaf layer

Table 3
Temperature and velocity of the air flow over the length of the trough on top leaf layer

Trough Length (m)	7.08	14.17	21.25	28.30
Temperature (Kelvin)	301.	301.2	300.9	300.48
Velocity (m/s)	1.74	1.05	0.95	0.84

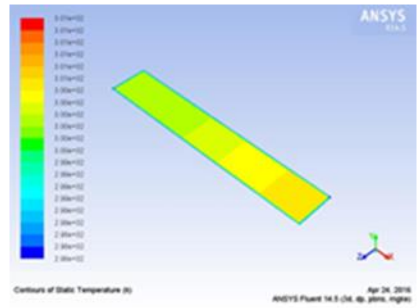

Fig. 4. Variation of temperature with velocity of the air flow over the length of the trough on bottom leaf layer

4. Conclusion

In this work, CFD simulations of tea withering process of an existing withering trough and a modified withering trough with consideration of solar energy has been performed. The CFD model of the withering trough has been validated with the experimental within limit ±2.9 % of error. Without Solar Radiation Application the heat transfer rate is 47.78 W/m^2, Moisture removal rate from tea leaf is 0.175 kg/min, withering time is about 15 hours but with solar radiation application the heat transfer rate is 58.28 W/m^2, Moisture removal rate from tea leaf is 0.214 kg/min, withering time is About 12 hours.

References

[1] Ayensu, A. 1997. Dehydration of food crops using solar dryer with convective heat flow. Solar Energy, 59 (4-6): 121–126.
[2] A. Sinha; Computational Fluid Dynamics Study of Tea Withering Trough Considering Leaf Layer as Porous Medium; NIT, Silchar, Assam.2014; Ph. D. Thesis.
[3] Baruah, D., Bhuyan, LP. & Hazarika, M. Impact of moisture loss and temperature on biochemical changes during withering stage of black tea processing on four Tocklai released clones. Two and a Bud. 59(2): 134-142, (2012).
[4] R. Gupta, A. Sinha and K. M. Pandey; Computational Fluid Dynamics Study of Tea Withering Trough Considering Leaf Layer as Porous Medium; Progress in Computational Fluid Dynamics, Vol. 14, No. 5, 2014.
[5] Sharma S, Sharma V, Jha R, Ray R. Evaluation of the performance of a cabinet type solar dryer. Energy Convers Manag; 30:75–80(1990).
[6] Krishnakumar, K. and Nair, A.R. 'Determination of heat transfer and flow friction of a porous body using modified maximum slope method', Proceedings of the 37th International & 4th National Conference on Fluid Mechanics and Fluid Power, IIT Madras, Chennai, India, (2010).
[7] Omiadze, NT., Mchedlishvili, NI., Rodrigez-Lopez, JN., Abutidze, MO., Sadunishvili, TA. & Pruidze, NG, Biochemical processes at the stage of withering during black tea production. Applied Biochemistry and Microbiology. 50(4): 394-397, (2014).
[8] Wang, J.G., Leung, C.F. and Chow, Y.K. 'Numerical solutions for flow in porous media', International Journal for Numerical and Analytical Methods in Geomechanics, Vol. 27, No. 7, pp.565–583, (2003).
[9] Sadykov TA, Khairiddinov B. A year-round double-block greenhouse-dryer. Appl. Solar Energy (Geliotekhnica) 1982;18(1):69-72.

[10] El-Sebaii AA, Aboul-Enein S, Ramadan MRI, El-Gohary HG. Experimental investigation of an indirect type natural convection solar dryer. Energy Convers Manage; 43(2002); 2251–66.
[11] Bena, B., Fuller, R.J., 2002. Natural convection solar dryer with biomass back-up heater. Solar Energy 72 (1), 75–83.
[12] Brenndorfer B, Kennedy L, Bateman COO, Mrema GC, Wereko-Brobby C. Solar dryers & their role in post-harvest processing. London: Commonwealth Science Council (Commonwealth Secretriat Publications), 1985.