Abstract

The production of jaggery is popular activity in rural sector of India. Though jaggery production process appears simple, it is a complex unit operation involving heat and mass transfer processes simultaneously. The design of the traditional jaggery making furnaces is evolved mainly through experience gained over the years. The thermal efficiency of the jaggery furnace system depends on the various parameters such as furnace diameter, its depth, pan design, chimney top and bottom diameters, chimney height, number of air holes for fresh air supply and their diameter and bagasse feed rate.

The present work is focused on experimental and CFD analysis of single pan jaggery making furnace including flue gas duct and chimney. The work is carried out in three phases. In the first phase, experimentation was performed on existing conventional jaggery making furnace to find out heat and mass balance for the jaggery furnace and to evaluate its thermal efficiency. The experimental results indicated that, out of total heat evolved from combustion of bagasse only 30% heat is utilized for jaggery production and 70% heat is lost through flue gas and wall heat loss. Further experiments were performed on two small jaggery making units developed consisting of modified pan design and furnace construction. It was observed that, the heat utilization efficiency with modified finned pan and riveted pan is 25.96% and 24.86% respectively. Thus 74.03% and 75.13% heat was lost through flue gas and wall heat loss out of total heat liberated from combustion of bagasse for modified finned pan and riveted pan jaggery plants respectively.

In second phase, CFD modeling and simulation of existing conventional jaggery furnace with chimney was carried out. The main objective of this CFD analysis was to validate the field data acquired with numerical results of simulation. It was found that CFD model analysis results of flue gas temperature and sugarcane juice temperature variation with time were in good agreement with each other with average error of 9.47% and 7.25% respectively. The measured velocity of the gas and predicted value of CFD analysis shown variation of 3.27% which is very small.

In the third phase, based on field data collected from visits to 34 jaggery making units and earlier research findings the dimensions of pan, furnace, flue gas duct and chimney were standardized. Two 3D CFD models using these standard dimensions were developed. The
difference between two models was in the design of pan. First model consisted of flat bottom pan and second model was provided with fins at the bottom of the pan. The CFD simulation was carried out for both models using ANSYS FLUENT software. The numerical results of CFD simulation predicted that the heat utilization efficiencies for jaggery furnace with flat bottom pan and finned bottom pan as 48.4% and 41.02% respectively. Thus use of fins at the bottom of pan have not resulted into increase in heat transfer from flue gases to pan, rather, the heat utilization efficiency value decreased by 7.38%.

Hence to increase the heat utilization efficiency of the jaggery furnace, the innovative pan with spiral coil heat exchanger was designed. The CFD model of jaggery plant using same dimensions for first and second model was prepared with modified pan with spiral coil heat exchanger. The CFD simulation of this model was carried out using ANSYS FLUENT software. The thermal heat zone figures show uniform distribution of heat around spiral coil with temperature of 389.7 K. The sugarcane juice temperature around the spiral coil predicted is 389.7 K indicating thermal equilibrium between spiral coil heat exchanger and sugarcane juice. Further velocity stream line flow diagram for jaggery plant with spiral coil heat exchanger shows increased turbulence of flue gases in the combustion chamber, spiral coil and chimney which is comparatively less for flat bottom pan model and negligible for finned bottom pan model. The velocity of flue gas obtained with spiral pan model at the entry of flue gas duct is 7.06 m/s which is higher than the value of 5.2 m/s for flat bottom pan & finned bottom pan. The estimated value of heat utilization efficiency of spiral coil heat exchanger pan model is 52.76%. This value is 4.36% higher than that for flat bottom pan model. Thus jaggery plant model with spiral coil pan model give 9.0% increase in thermal efficiency compared to flat pan bottom model.