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# Design, Fabrication and CFD Analysis of Jet Impingement Solar Dryer for Copra

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**Abstract**

*This Paper attempts to study the variation of simulation and fabricated jet impingement dryer to define how to increase efficiency, temperature and best quality of the dryer. The jet impingement is helps to increase the overall temperature of the exhaust air. where increasing the temperature slightly and velocity ranges of drying time as been reduced. The experimental process has been carried in the copra.*

*From the CFD analysis end results establish the flow jet impingement processing on the absorber where a strong function of heat transfer enhancement. The present process concludes that the mass flow ranges of air as been influence the heat transfer rates. At solar radiation 500-1000 ($W/M^2$), 348K ambient temperature and 0.048(Kg/S) mass flow ranges has been get at the end analysis.*

*Now a day the new model innovations are needed in solar dryer to fulfil the requirements of drying industrial and agricultural products. The new design process analysis and assumptions are very necessary to design any system. By comparison solar drying fulfil the requirements than sun drying processing. Under the such process and conditions Effect of mass flow ranges of air, solar radiation on exit air temperature, and efficiency has been analyzed.*

**Key-word:** Collector, Dryer Temperature, Absorber Plate, CFD Analyszing, Etc.

## 1. Introduction

The Solar drying technology which exposes the food to sunlight, where they used to reduced the moisture content from the food naturally[1]. In drying process two process has been taken placed such as heat transfer of the product and mass at interior region, the product to surface and surfaces to surrounding air. For agricultural drying process the formers used both open sun drying or natural drying, which drying process achieves by humidity of air, ambient temperature, solar radiation and wind. From the sun drying analysis and nowadays solar dryer needs easy to use, economic drying, faster drying rate. Drying which involve on all three process, transfer of heat, convection, radiation and conduction for enhanced drying. The some of disadvantages from the natural or sun drying techniques involved suffer from the dirt, dust, pollutions, rodent attacks, etc. These disadvantages are removed by using a solar dryer[2].

The active dryer are unnatural convections dryers and the hybrid solar dryers. Required air flow rate is used to provide in drying overall the whole ranges to control the temperature and moisture ranges[3]. By using forced convection the drying time reduced to three times and half of the area reduced for collector surfaces. The some of disadvantages from the natural or sun drying techniques involved suffer from the dirt, dust, pollutions, rodent attacks, etc. These disadvantages are removed by using a solar dryer [4-5]. The air circulation for solar air heater been split into two stages such as primary type air may flows over the absorber or behind the plates[6].

**Nomenclature**

| | |
|---|---|
| $A_c$ | Collector area ($m^2$) |
| $C_p$ | Specific heat of the air |
| $H_A$ | Solar radiation ($W/m^2$) |
| m | Moisture content (%) |
| Tamb | Ambient Temperature(°C) |
| Ti | Collector Temperature at entry stage (°C) |
| To | Collector Temperature at outlet stage (°C) |
| ΔT | Change in temperature difference (°C) |
| t | Time(h) |
| ma | Air flow rate (kg/s) |
| L | Collector Length(m) |
| W | Collector Width (m) |
| UL | Heat losses coeifficient ($W/m^2$°C) |
| ηC | Overall efficiency of collector (%) |
| Va | Wind velocity(m/s) |
| G | Global radiation ($W/m^2$) |
| Qu | The Overall heat losses at the collector (W) |
| Ib | Direct usual beam radiations ($kwh/m^2$/day) |
| Id | Diffused parallel radiations ($kwh/m^2$/day) |


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## 2. Methods and Materials

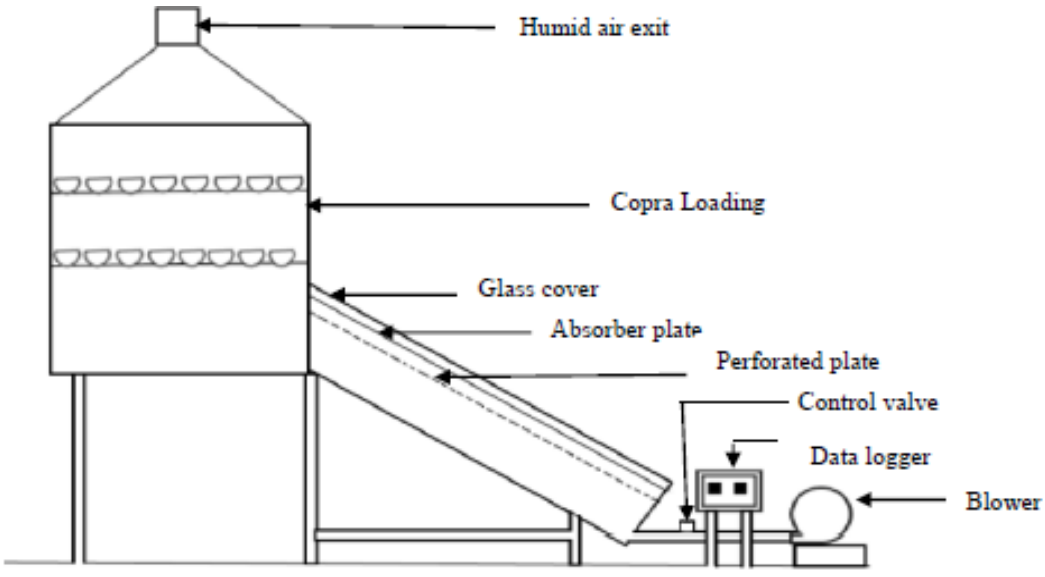
### 2.1. Solar Dryer and Site

Experiment study as been performed during January 2020 at the SJS oil mill Salem. A jet impinging type dryer as been fabricated and placed at SJS oil mill, Salem (India). Longitude 77.1460E: Latitude: 11.6643N. Salem has moderate climatic condition. Solar radiations spotted over the every year average on the horizontal surfaces in Salem is found to be 756W/$m^2$ and it is max range of (1250W/$m^2$) in summer and avg solar radiations as been spotted 870W/$m^2$. The total solar radiation on a 21.663 tilt surfaces towards the south direction is observed to be 630 W/$m^2$.

### 2.2. Experimental Procedure

The drying chamber shown in figure 1 is made from GI of 5mm thick and trays are made from aluminium mesh and placed inside the chamber. The collector was tilted by 21.6643$^o$ where overall length, width, and height of collector dimensions is 1.2 m x 0.5m x 0.15m. The 0.005m thickness transparent glass cover was used and 0.001m thick of copper corrugated plate used as absorber plate. The drying chamber was made from GI of 5mm thick and trays are made from aluminium mesh and placed inside the chamber. The perforated plate consists of 6mm holes section to test the flow of the dryer. The collector was made from GI of 5mm thickness. The 0.05m of polyurethane and with thermal conductivity 0.0288 W/$m^2$ K used for prevent the collector.

Figure 1 - Schematic View of Solar Dryer



Testing as been done in the month of January, the dryer was fixed under the sun with facing south directions to get better performances. Here we used pt-100 sensor which indicate the maximum accurate range of temperature. Here we using DHT22 Sensor for measuring the humidity of air at higher accuracy. In this experiment we used TES 1333 Solar power meter for measuring the solar intensity with better accuracy. Temperature reading as been recorded on hourly ranges starting from 9AM – 4PM.

### 2.3. Instrumentation and Experimental Process

Experiments as been conducted to study the properties and process of copra. Copra is the one of the highest production in India and having good nutritive values used for various applications. During these experiments the climatic conditions are moderately sunny. The experimental process were conducted from February to march 2020 at SJS mill, Salem. The moisture ranges as been determined regularly by weighing copra for every hour. The experimental setup is shown in figure 2 and perforated plate is shown in figure 3.

Figure 2 - Overall Position of Jet Impinging Dryer

Figure 3 - Perforated Plate

The new fresh copra are used for drying, 6-8mm thickness of copra was selected. The copra are placed uniformly on the two trays. The mass of 2.5kg of copra are used for drying in the chamber. While performing this experiment completely closed the door to prevent from thermal leakages. During this process the solar dryer as been tested under by solar radiation, humidity, moisture level of copra for every one hour interval of time.

### 2.4. Mathematical Modelling of Drying

The percentage of moisture content presented in the copra has been determined by following equation.

Moisture range content (%) = (At Initial stage of weight – At final Stage of weight)/(At the Initial stage of weight)×100 (1)

Insolation on the solar collector surfaces

The Total amount of the solar radiations $H_A$ available at the selected place is 550 W/$m^2$ and total insolation solar as ($I_C$) determined by following equation

$$I_C = H_A \times R \quad (2)$$

Where,

$H_A$ = 550 W/$m^2$

$$R = (1\text{-}D/G)\, r_b + D/G[(1+\cos\beta)/2] + [\rho(1-\cos\beta)]\,/2 \quad (3)$$

The $m_a$ is the Mass flow rate of the air calculated by

$$m_a = v'_a\, \rho_a \quad (4)$$

$$v'_a = v_a \times h \times w \quad (5)$$

Where the $V_a$ is velocity of air($m^3$/s), h is the height (metre, m) of the collectors, W is width of collectors. Air density (ρa) is taken as 1.225 (kg/$m^3$) $v'_a$ is Volumetric flow rate ($m^3$/s) and Optimum temperature for Copra is (55 to 65)$^o$C,

ΔT is the temperature difference, $\Delta T = (T_o - T_a)^oC = (70\text{-}30)^oC = 40^oC$

Calculation of Heat losses from the collector

$$I_C\, A_C\, \tau\, \alpha = Q_U + Q_L + Q_S \quad (6)$$

The amount of heat removal factors heat removal factor $F_R$ can be calculated by

$$F_R = Q_U / A_C\, [\, I_C \times \tau \times \alpha - U_L \times (T_0 - T_a)\, ] \quad (7)$$

The thermal efficiency of a solar collector is the ratio of useful heat gained to the solar radiation incident on the plane of the collector. This thermal efficiency is expressed as

$$\eta_C = m_a\, c_p\, \Delta T / A_c\, I_c \quad (8)$$

Where the $Q_U$ is how much useful energy where gained by the collectors (W), $A_C$ is how much area obtained in the collectors($m^2$) and $U_L$ is the how much overall heat transfer coefficient of the absorbers7

($Wm^{-2}K^{-1}$). Where m is overall air mass flow rate, $c_p$ is the specific heat of air (1004J/kg K for air), $T_o$ and $T_i$ is the exit and inlet collector temperature (°C), Ic is how much solar radiation in the collector area($w/m^2$).

## 3. CFD Analysis

The governing equations for the analysis are mentioned below

Continuity Equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0, \tag{9}$$

Momentum Equation

$$\frac{\partial (\rho u_i)}{\partial t} + \frac{\partial (\rho u_i u_j)}{\partial x_j} = \frac{\partial (\sigma_{ii})}{\partial x_i} + \rho g_i, \tag{10}$$

Governing equations are solved using Ansys Fluent software

Figure 4 - Mesh Generation in CFD

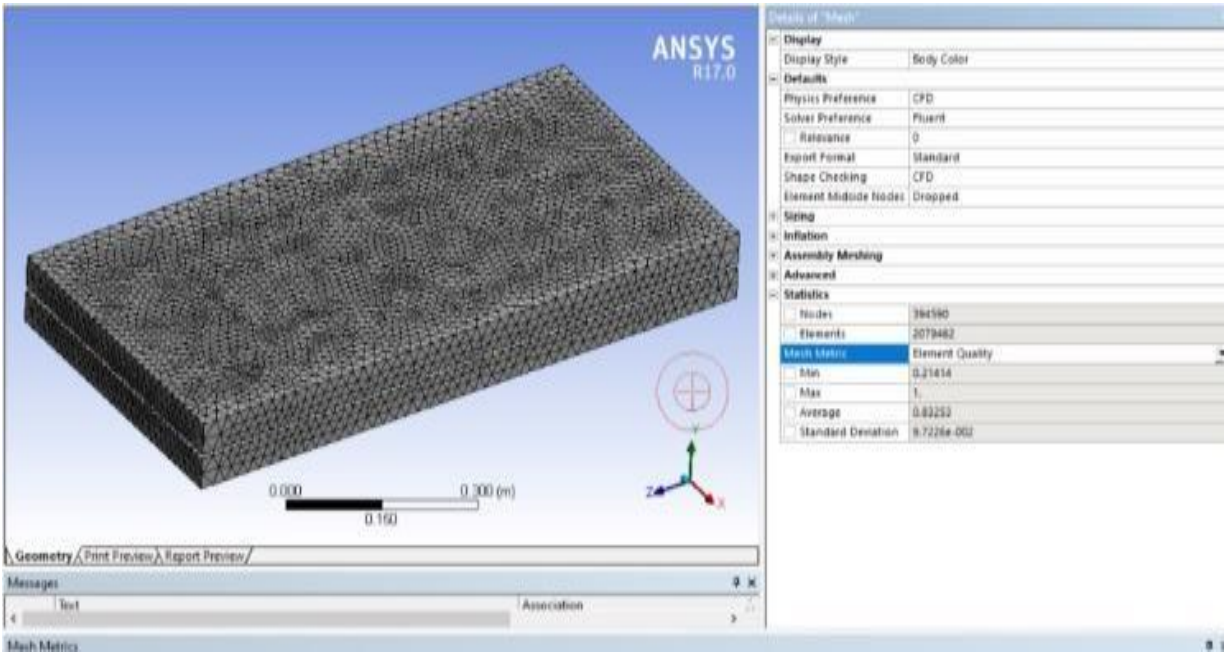


Figure 5 - Temperature Contour

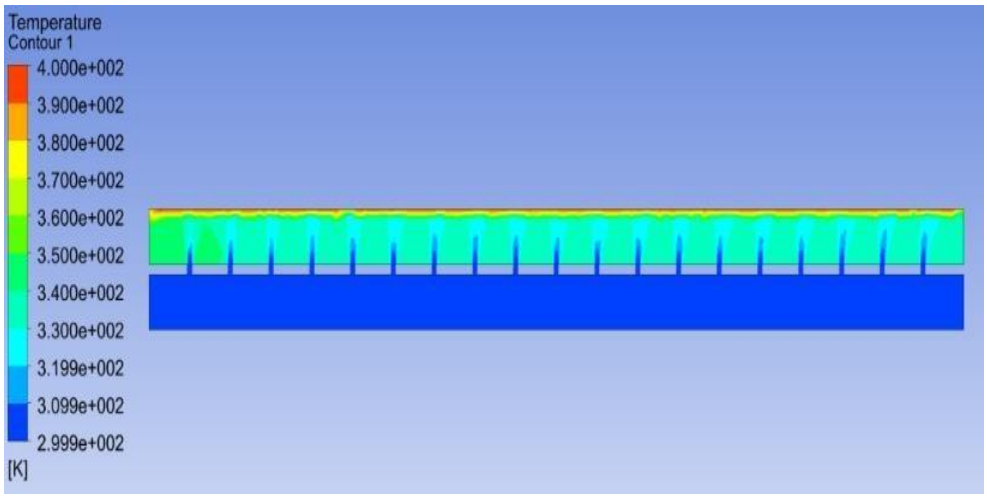



Figure 6 – Pressure Contour

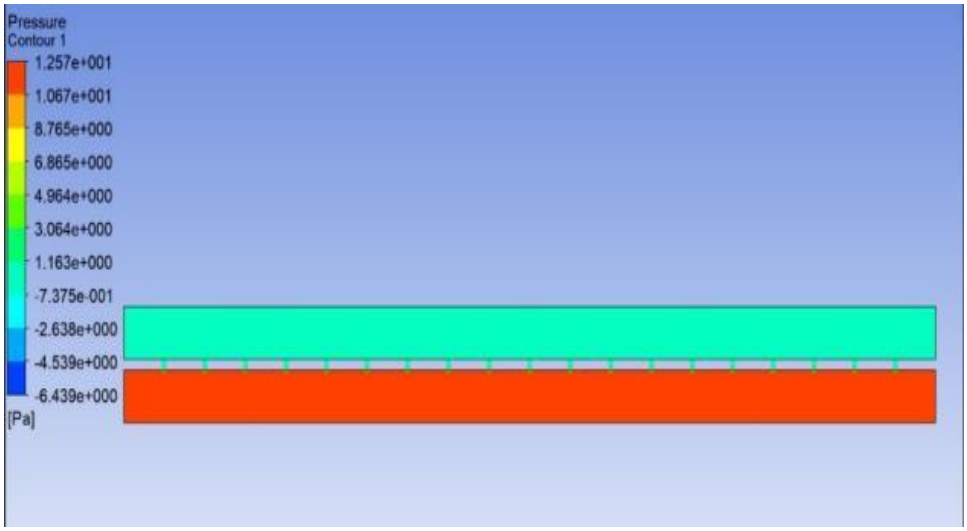
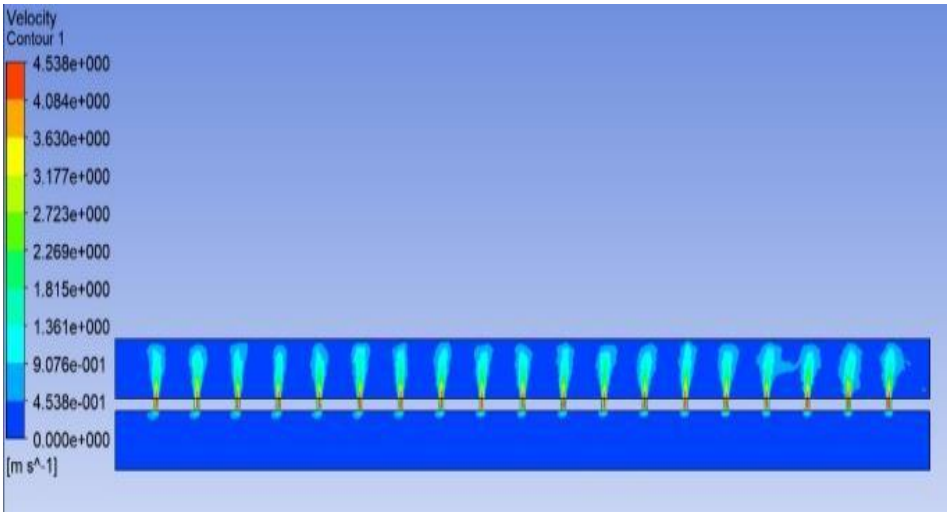



Figure 7 - Velocity Contour



The 3D model has been designed by using Solid Works software. Then it is imported in ANSYS. After importing of the model the meshing has been created by ANSYS ICEM software and therefore meshing created elements consist of around 28 millions elements. The created mesh is imported in ANSYS FLUENT software and the values taken from experimentation are used while simulating collector.

After setting of all boundary condition in fluent software, to solve numerical equations the starting initialization by inlet be done. To get the end results the numbers of iterations are to be set around to min of 10000. The result for these simulations as been converged at around 7218 iterations. As per number of elements is more to get the converged results and the time taken for these simulations will be higher with single or mono processor. After getting the results in the final stage of the flow distributions of air and the heat transfer of collector will be plotted in the contour plots. From the result, it is evident that the temperature reached to maximum extent of 348K and average temperature at outlet is 334.61K. The temperature difference between Initial stage and Final stage varies from 35$^{o}$c and to 45$^{o}$c shown in figure 5. The figure 6 shows the pressure varied (drop) of the collector. Average pressure difference is 15pa (loss). The figure 7 shows the average air flow passage through the plate of 0.439m/s. Thus the evident from the results the average heat transfer at outlet is 334.61K is sufficient by using the Jet impinging process for drying the copra.

Table 1 - CFD Results of Jet Impinging Dryer

| Time (hr) | Solar Intensity(W/m$^2$) | Tamb ($^{o}$c) | Tout1 ($^{o}$c) | Tout2 ($^{o}$c) |
|---|---|---|---|---|
| 9AM | 346 | 28.3 | 47.2 | 48.219 |
| 10AM | 418 | 29.9 | 53.9 | 56.815 |
| 11AM | 497 | 31.4 | 59.1 | 61.977 |
| 12NOON | 587 | 32.9 | 65.4 | 67.583 |
| 1PM | 693 | 33.6 | 71 | 75.987 |
| 2PM | 712 | 34.4 | 72.8 | 77.432 |
| 3PM | 643 | 34 | 70.3 | 74.916 |
| 4PM | 502 | 33.4 | 69 | 71.123 |
| 5PM | 451 | 31 | 62 | 65.483 |

The table 2 shows the CFD Results of jet impinging solar dryer for copra. This analysis were taken from the Day-2 The max solar intensity obtained is 712 W/m$^2$ and maximum temperature of ambient and exit temperature of the dryer is 34.4$^{o}$C and 77.43$^{o}$C.

Figure 8 - Before Sun Dried Copra

Figure 9 - After Sun Dried Copra

Figure 10 - Before Jet Impingement Dried

Figure 11- After Jet Impingement Dried

As per standard the quality of oil must be within the specific ranges for the best results. From the standards the quality of copra consist of impurities, mouldy cups, black cups, wrinled cups, moisture content, peroxide value, FFA, specific gravity, Iodine value are 0.5, 4 ,5, 5, 6, 0.5, 0.4, 70, 8 respectively. From the results of sun dried copra the values are much less and not similar to the standards. Such as the quality of copra for the sun dried copra consist of impurities, mouldy cups, black cups, wrinled cups, moisture content, peroxide value, FFA, specific gravity, Iodine value are 9, 25, 2, 2, 7.08, 1, 0.8, 0.93, 8.7

Table 2 - Quality of Oil For Sun Dried Copra and Jet Impinging Dried Copra

| Characteristics | Content(%) | Characteristics | Content(%) |
|---|---|---|---|
| Impurities | 9 | Impurities | 6 |
| Mouldy cups | 25 | Mouldy cups | 11 |
| Black cups | 2 | Black cups | 3 |
| Wrinkled cups | 2 | Wrinkled cups | 2 |
| Moisture content | 7.08 | Moisture content | 6.5 |
| Peroxide value | 1 | Peroxide value | 0.5 |
| FFA | 0.8 | FFA | 2 |
| Specific gravity | 0.93 | Specific gravity | 0.9 |
| Iodine value | 8.7 | Iodine value | 8 |

The quality of oil by using the jet impinging method of dryed copra consists of impurities, mouldy cups, black cups, wrinkled cups, moisture content, peroxide value, FFA, specific gravity, Iodine value are 6, 11, 3, 2 ,6.5, 0.5, 2, 0.9, 8. From the analysis jet impinging method of drying copra provide higher quality ranges compared to sun dried copra. The jet impinging are also helps the quality of copra as well as increase the grading. From the analysis the jet impinging dryed copra are

having similar quality content to as per standards. By increasing the quality of copra the higher rate of oil extraction as been taken and microbiological attacks, fungus, bacteria, etc. are reduced.

## 4. Result and Discussion

Case 1: Sun drying method-variation of solar intensity with temperature and time

Figure 12 - Variation of Solar Intensity with Time

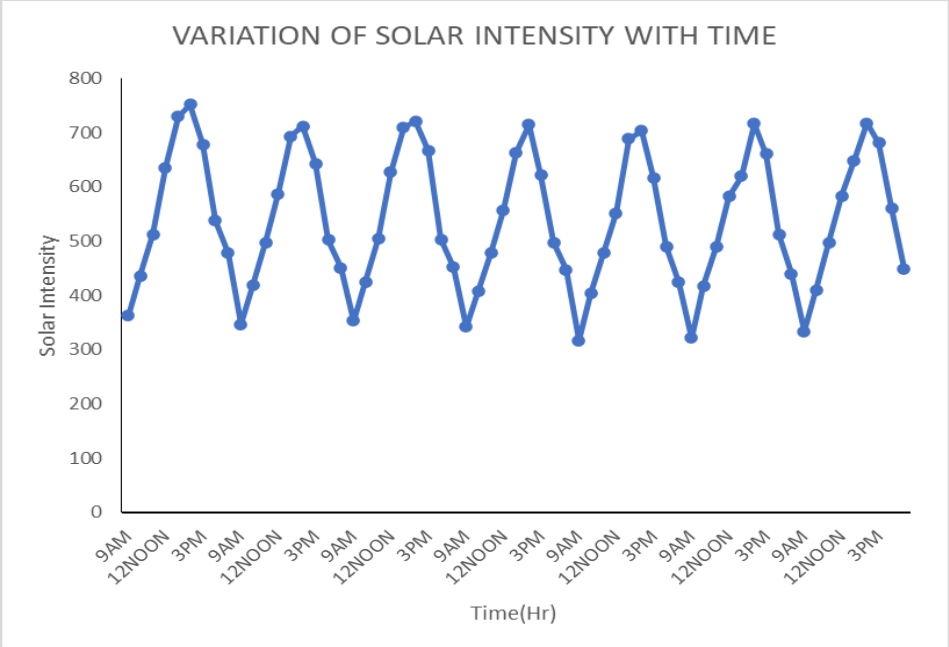
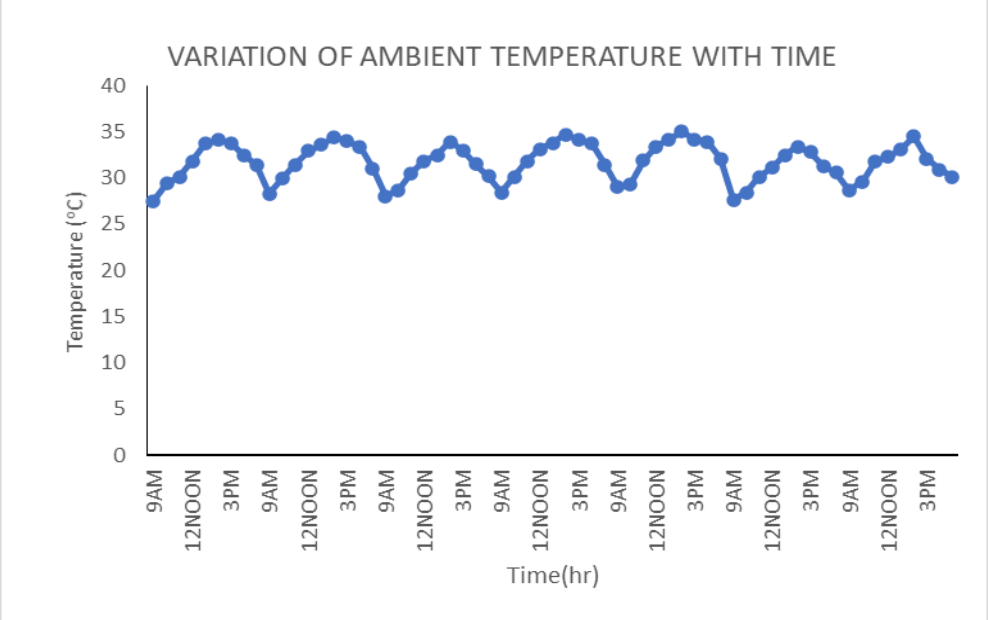


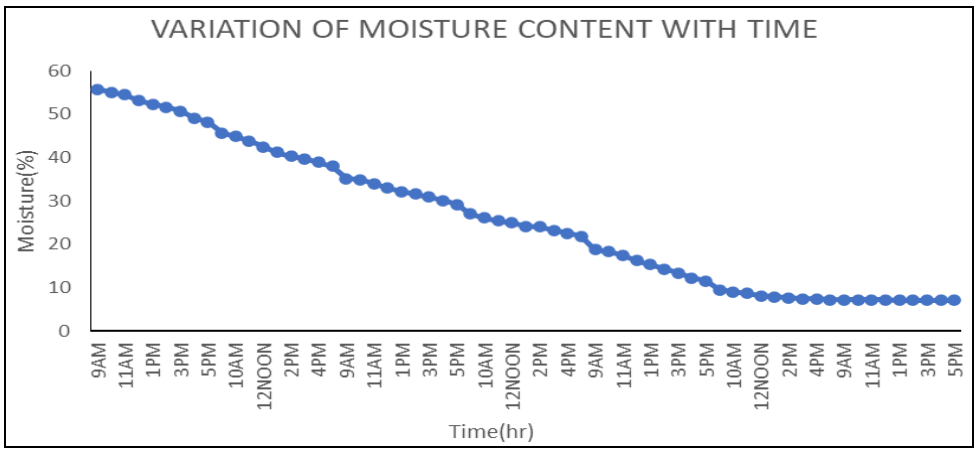

Figure 13 - Variation of Temperature with Time



The figure 12 shows that solar intensity is varied respect to time intensity get increase at time of maximum of 752 W/m$^2$ at time 2pm and gets reduced to 478 W/m$^2$ at 5pm. The solar intensity has been taken for the duration of seven days. During this experiments, the sky was clear and maximum solar radiation observed on first day, the average of 541W/m$^2$ solar intensity has been observed.

The figure 13 shows that variation of ambient temperature and time. The maximum temperature attained 35.1$^o$c at time 2pm and get reduced to 28$^o$C at 5pm.During this experiment of seven day duration the maximum temperature attained on fifth day of maximum temperature of 35$^o$C.

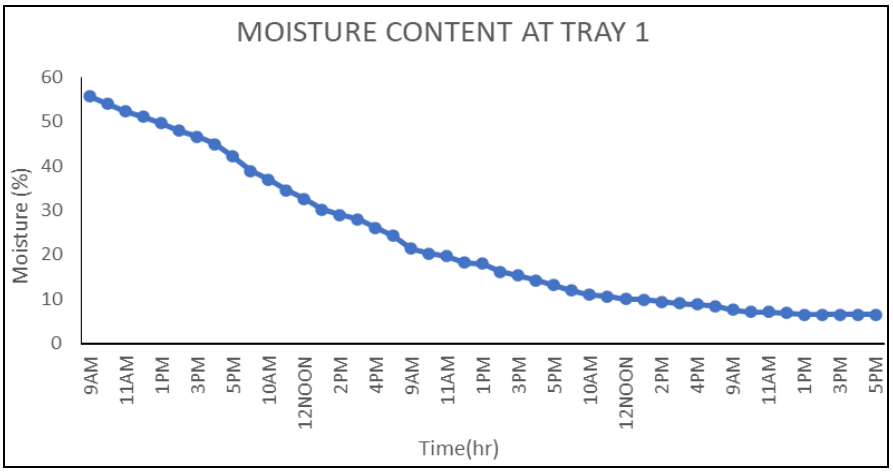
Figure 14 - Variation of Moisture with Time




The figure 14 shows that variation of moisture content of copra and time. The average moisture content of copra get reduced from 55.72% to 7.08% in 63 hrs.

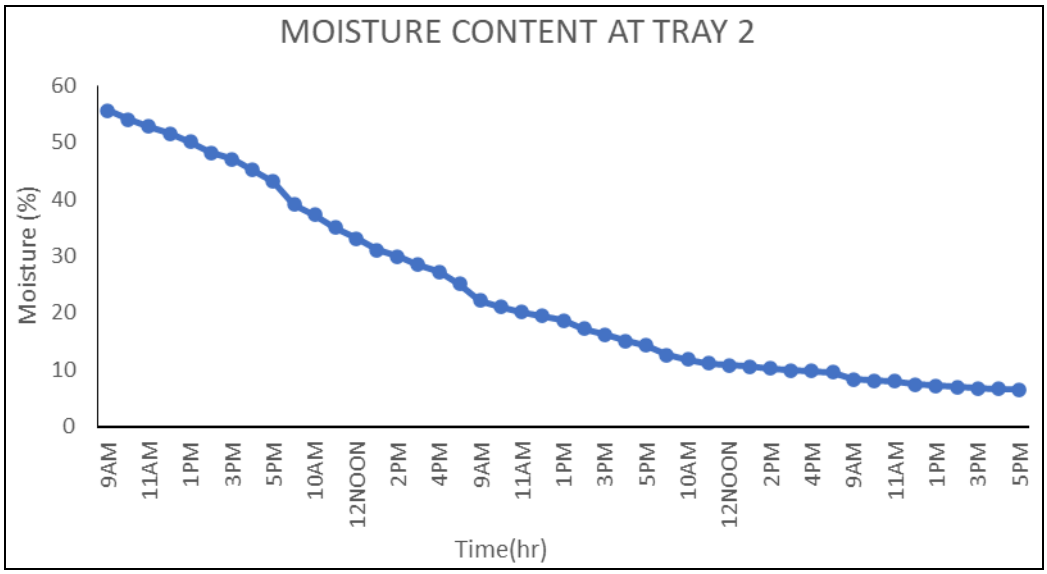
Case 2: Jet impingement method-Variation of solar intensity and moisture and time

Figure.15 Variation of moisture ranges and time at tray 1



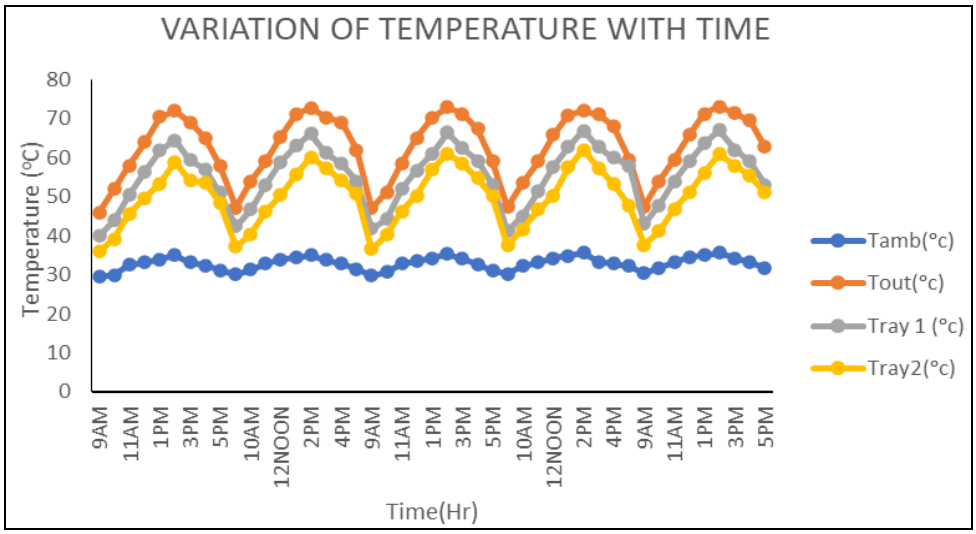
The figure 15 shows that variation of moisture ranges of copra and time. The average moisture content get reduced from the range of 55.64% to 6.5% at 45hours. The moisture reduced from 55.64% to 6.5% in tray 1 at 41hours and tray 2 at 45hours shown in the figure 16.

Figure 16 - Variation of Moisture and Time



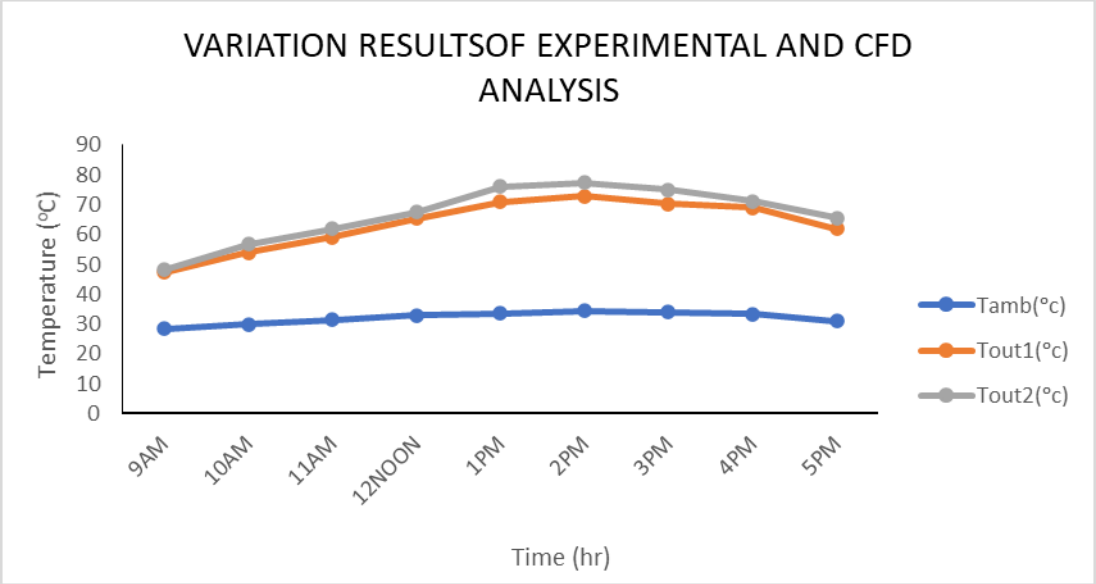

The moisture reduces shows that solar intensity is varied respect to time intensity get increase at time of maximum of 752 W/m$^2$ at time 2pm and gets reduced to 478 W/m$^2$ at 5pm. The solar intensity has been taken for the duration of five days. During these experiments, the sky was clear and maximum solar radiation observed on first day, the average of 541W/m$^2$ solar intensity has been observed.

Figure.17 Variation of Temperature with time for dryer and Ambient temperature



The figure 17 shows that variation of dryer temperature and ambient temperature with time(Hr). The maximum temperature of 72.9°C at Tout and 66.4°C at tray1 and 61°C at tray2.The average temperature at the dryer is 55.5°C as been obtained. During this experiment the maximum temperature of dryer is 72.8°C at the ambient temperature of 35.6°C.

Figure 18 - Variation of Temperature and Time for Experimental and Analytical Results




The figure 18 shows the variation of Analytical and Experimental results of Time(Hr) and Temperature. The analysis done from the DAY 2 data shows that the ambient temperature raised to maximum. The Analytical results are higher compared to the experimental results due to some losses in the actual results. The collector temperature varies directly by dependent on solar intensity. Due to some local available properties in the analysis the losses are occurred. This result shows there will be best result obtained during the sunny days.

## 5. Conclusion

The solar air heater cannot reach to maximum extent temperature as well as pressure drop along the side is also higher. For the better extent temperature and time considerations in this project, we have discussed with jet plate impingement to provide maximum heat supply and less time consideration.

The copra drying time period are also reduced from 63hrs to 48hrs and the moisture ranges of the copra varies from 54.72% to 7.08% in sun dried copra and 55.64% to 6.5% in jet impingement

method. The moisture content as reduced maximum less than 6.5% as per (IS 6620 1971) standard for oils. From this analysis we used 8mm hole section of perforated plate and checked with different conditions. Where by using the jet plate impingements techniques we have reached maximum heat supply. From the analysis the pressure drop is also less and it is concluded that sufficient for drying the copra for given conditions.

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