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# A Multi-Phase Approach to Drying of Food Products Using Innovative Methodology

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A B S T R A C T

Food drying is a method of food preservation in which food is dried (dehydrated or desiccated). Drying inhibits the growth of bacteria, yeasts, and mold through the removal of water. Dehydration has been used widely for this purpose since ancient times; the earliest known practice is 12,000 B.C. by inhabitants of the modern Middle East and Asia regions. Water is traditionally removed through evaporation by using methods such as air drying, sun drying, smoking or wind drying, although today electric food dehydrators or freeze-drying can be used to speed the drying process and ensure more consistent results. There are many Mathematical models available for analysis the Drying Kinetics of Food products which depend on the studies undertaken by different groups of people and developed these mathematical models. The development of a mathematical model requires a lot of work and cannot be done without a well formed experimental setup. Hence forth in this project we will be developing a Multi-phase model which will serve for all purposes of Food Drying without a need of Experimental setup.

Keywords:CAD ,CAM ,FEM ,CFD , Prandlt no, Reynold No., Heat transfer.

## 1. Main text

Food dehydration is one of the oldest unit operations used by the food processing industry. Food dehydration is a process of reducing moisture of food to low levels for improved shelf life by adding one or more forms of energy to the food. However, it does not include removal of moisture from food by mechanical pressing or concentration of liquid foods. Most commonly, heat is added to the food by hot air, which also carries the moisture away from the food. The process of food dehydration involves simultaneous transfer of mass and heat within the food and the medium used to transfer energy to the food. In food dehydration methods that supply energy to the food using media other than hot air, air or some other gas may be required to move moisture away from the food. Drying is one of the most ancient methods of food preservation known to mankind. Preservation of meat, fish, and food plants by drying in the sun or in the naturally dry air of the deserts and mountains has been practiced since prehistoric times and is still a vital operation in the life of many rural communities.Drying or dehydration is, by definition, the removal of water by evaporation, from a solid or liquid food, with the purpose of obtaining a solid product sufficiently low in water content.

Nomenclature

A = area of heat transfer (m2)

H= heat transfer coefficient (Wm−2 K−1)

K = thermal conductivity (Wm−1 K−1)

Nu= Nusselt number

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Pr = Prandtl number

Q= heat transferred (W)

Re= Reynolds number

V= velocity (ms−1)

Δ = temperature difference (K)

μ= viscosity (kgm−1 s−1)

ρ = density (kgm−3)

ν=kinematic viscosity of the fluid, (m2/ s)

σ=Stefan – Boltzmann constant (W/ m2k4)

α= Coefficient of thermal expansion (E-06/0C)

E= Young's Modulus (Pa)

μ= Poisson's ratio

Cp= Specific Heat (J/kgK)

RIT=Rotor Inlet Temperature

CAD=Computer Aided Design & Drafting

FEM=Finite Element Method

CAE =Computer Aided Engineering

CAM=Computer Aided Manufacturing

I.e. that is

Etc. et cetera

E.g. for example

## 1.1.The main technological objectives of food dehydration are:

- Preservation as a result of depression of water activity.
- Reduction in weight and volume
- Transformation of a food to a form more convenient to store, package, transport, and use; for example, transformation of liquids such as milk, eggs, fruit and vegetable juices, or coffee extract, to a dry powder that can be reconstituted to the original form by addition of water (instant products).
- Imparting to a food product, a particular desirable feature such as a different flavor, crispiness, chewiness, etc., that is, creating a new food (e.g., transformation of grapes to raisins).

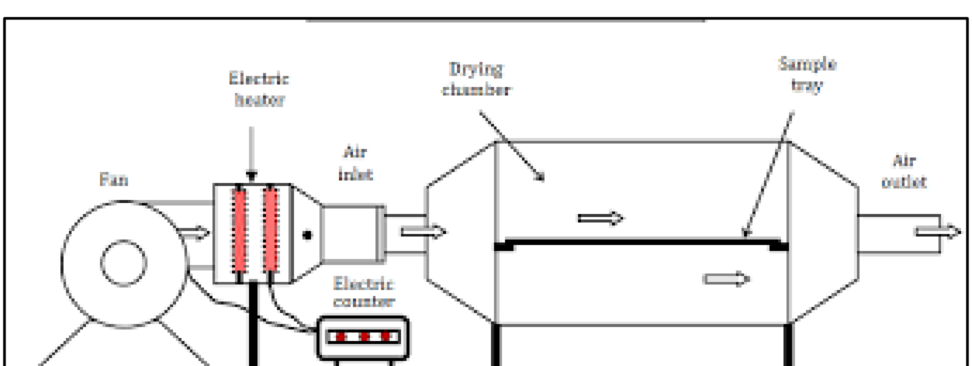


Fig. 1.1: A diagram of a Conventional Food Drying Setup

It can be seen from the figure 1.1 the main components of a Conventional Food Drying Setup namely heater or heating element, blower or fan and a drying chamber:-

- Heater is an appliance whose purpose is to generate heat for heating the Air for drying purpose.
- Blower for producing a current of air or for blowing air into a drying chamber, from a heater or heating element.
- Drying chamber for removing water from the food.

### 1.2. 1 NEED OF STUDY

- Despite the importance of drying as an industrial operation and recent progress in drying research, the physical principles of the complex phenomena that occur in the course of dehydration and rehydration are not entirely understood. Modeling of drying is discouragingly difficult in the case of food materials. A completely satisfactory model of drying kinetics, applicable to foods, is not available at the moment. Yet, in the following discussion of drying, extensive use will be made of models. It should be remembered that these theoretical models are only approximations. Their use as an exclusive tool for process development or design of equipment is not recommended. “Food drying engineering” still largely relies on experience and experimentation.

- Food drying is a method of food preservation in which food is dried (dehydrated or desiccated). Drying inhibits the growth of bacteria, yeasts, and mold through the removal of water. Dehydration has been used widely for this purpose since ancient times; the earliest known practice is 12,000 B.C. by inhabitants of the modern Middle East and Asia regions. Water is traditionally removed through evaporation by using methods such as air drying, sun drying, smoking or wind drying, although today electric food dehydrators or freeze-drying can be used to speed the drying process and ensure more consistent results. There are many Mathematical models available for analysis the Drying Kinetics of Food products which depend on the studies undertaken by different groups of people and developed these mathematical models. The development of a mathematical model requires a lot of work and cannot be done without a well formed experimental setup.

- The most important engineering and technological issues in food dehydration are the following:

- The kinetics of drying: With some notable exceptions such as spray drying, drying is a relatively slow process. Knowledge of the factors that affect the rate of drying is essential for the optimal design and operation of drying systems.

- Product quality: Removal of water is not the only consequence of most drying operations. Other important quality-related changes in taste, flavor, appearance, texture, structure, and nutritive value may occur in the course of drying. The extent of such changes depends on the process conditions.

- Energy consumption: Most common drying processes use extensive quantities of energy at relatively low efficiency. Energy-wise, drying is a wasteful water removal process, compared to other water removal operations such as evaporation or membrane separation.

- The mechanism of water removal by drying involves two simultaneous processes, namely, transfer of heat for the evaporation of water to the food and transport of the water vapors formed away from the food. Drying is, therefore, an operation based on simultaneous heat and mass transfer. As explained in the next sections, the rate-limiting mechanism may be superficial evaporation or internal transport of water, depending on the conditions.

- Depending on the mode of heat and mass transfer, industrial drying processes can be grouped into two categories: convective drying and conductive (boiling) drying.

- Convective drying: Hot and dry gas (usually air) is used both to supply the heat necessary for evaporation and to remove the water vapor from the surface of the food. Both heat and mass exchanges between the gas and the particle are essentially convective transfers, although conduction and radiation may also be involved to some extent. This widespread mode of drying is also known as air drying. Air drying is an inherently slow process. It is said that 2/3 of the drying time is used to remove 1/3 of the moisture.

- Conductive (boiling) drying: The moist food is brought to contact with a hot surface (or, in a particular application, with superheated steam). The water in the food is “boiled-off.” In essence, boiling drying is tantamount to evaporation to dryness. Vacuum drying, drum drying, and drying in superheated steam are cases of this mode of drying.

- Freeze-drying (lyophilization) is another method of water removal based on the sublimation of water from a frozen material under high vacuum.

### 1.2.2 Methods of Food Drying

There are many different methods for drying, each with their own advantages for particular applications. Depending on the nature of the products to be treated, either foodstuff or industrial material, these methods prove to be more or less adapted. These include:

- Convective Drying or Hot air drying: - Hot and dry gas (usually air) is used both to supply the heat necessary for evaporation and to remove the water vapor from the surface of the food. Hot air drying is the most common drying method as of today. It is simple and effective for sturdy industrial and food products and an inexpensive solution.

  However, this process can completely dehydrate the product surface, leading to cracks or heterogeneous result. It can also be a slow process depending on the product and the permissible drying temperature.

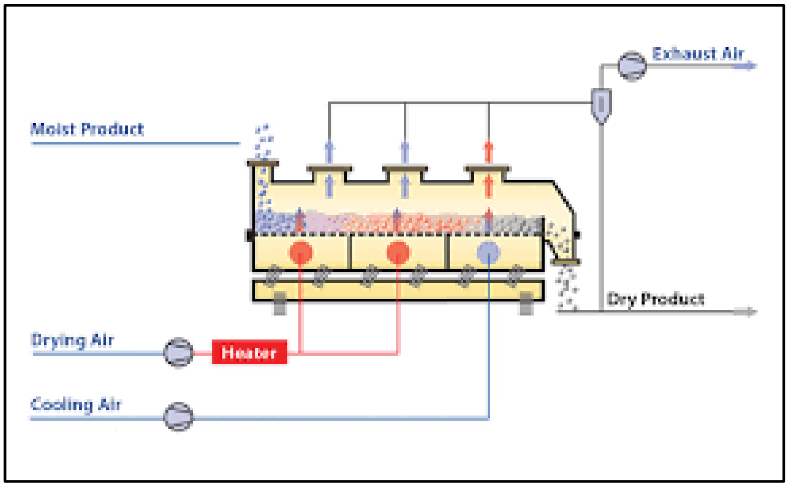


Fig. 1.2: Convective Drying or Hot air drying

- Sun drying: - Drying by exposure to the sun is the oldest and most economical solution. It is well adapted for traditional fruits and vegetables drying in remote areas, like apricots and tomatoes, although it doesn't preserve all the product properties and vitamins.

  But this method requires a lot of space and time, and offer few process control.

Fig. 1.3: Sun Drying

- Contact drying: - This drying method consists in drying a product by putting it in contact with heated walls. Most of the time the drying happens in rotating drums for a better homogeneity. This technology is mostly used in heavy industry drying processes.

However the direct contact of the product with the hot walls can lead to the denaturation of the dried product, and the process homogeneity is not guaranteed.

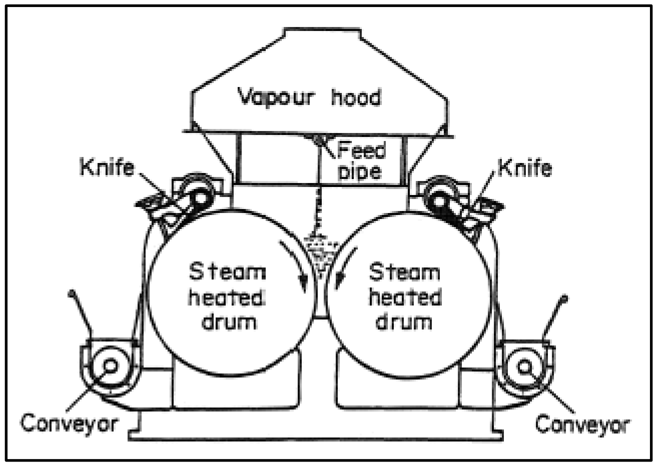


Fig. 1.4: Contact Drying

- Infrared drying: - Infrared drying evaporate water or solvent at high temperature. It can also be coupled with hot air and is used when the drying effect must be concentrated on the surface of the treated product to also obtain a roasting effect.

This solution is far from ideal for products that should not be exposed to high temperatures.

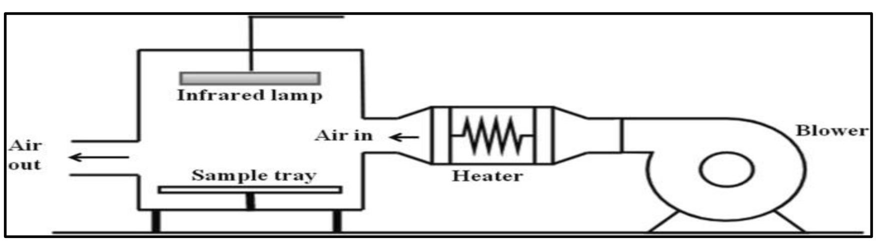


Fig. 1.5: Infrared Drying

- Freeze-drying: - Freeze-drying process is based on the water sublimation effect in a low temperature and low pressure environment. It is often recommended for the drying of temperature sensitive food products, as it preserve most of the organoleptic properties.
  On the other hand, freeze-drying is relatively slow and expensive technology, and is mainly a batch process as it works at low pressure.

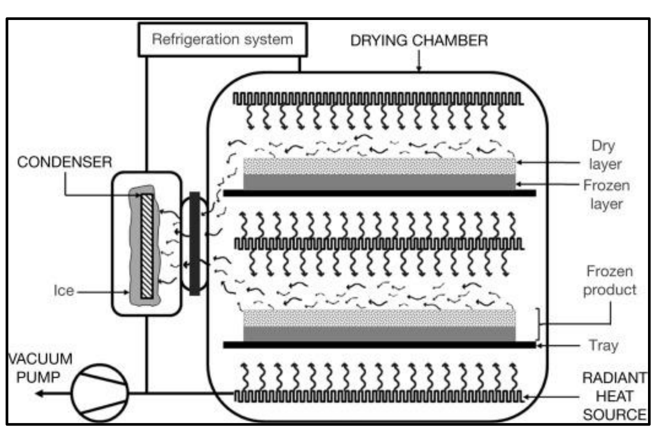


Fig. 1.6: Freeze Drying

- Fluidized bed drying: - This technology consists of mixing air and solid particles so that the whole behaves like a fluid. It is mainly used to dry seeds or grainy materials. This drying method is most of the time really quick.
  On the other hand, the treated product is subjected to a high temperature which can denature it.

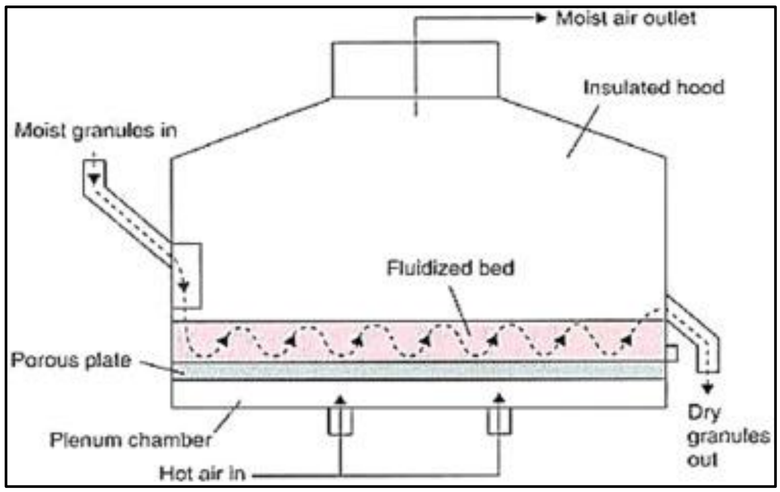


Fig. 1.7: Fluidized Bed Drying

- Dielectric drying: - Last but not least, the drying by microwave and radio frequency is based on the dielectric drying technology. By heating the entire volume of the product simultaneously, it is particularly recommended in applications where homogeneous and gentle drying is required.This solution is the most adapted for drying heat-sensitive products in the food, industrial and medical field, to preserve all of their properties.

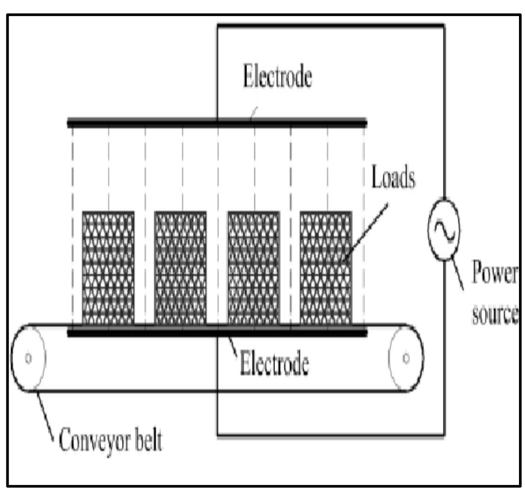


Fig. 1.8: Dielectric Drying

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## 1.3 OBJECTIVES

Many research papers and documents are available to understand the Drying Kinetics of Various Food material employing different Food drying methods. After reviewing various research papers published in different journals, conferences, research note is identified. The present study will be carried out for the following objectives,

I. Studying and analyzing the methods used for prediction of Food Drying mechanism.

II. Developing a Multi-phase approach for Drying of Food Products.

III. To analyze the Multi-phase model using Computational Fluid Dynamics.

IV. To develop a model as such that the Drying can be predicated without the use of Experimental setup.

Table 1Following Table show the modelling data taken for Validation Study,

| **Component** | **Specification** |
|---|---|
| Box or Enclosure | 1.22m by 8.60m made of 25 mm plywood with an inclination of about $17.5^0$ |
| Glass Cover | 4 mm thick clear glass with a total surface area of 1.22 m by 0.90 m. |
| Vents | 250x100mm at the low end of the front of the cabinet and at the upper end of the back of the cabinet. |
| Drying tray | 1180x820x20mm constructed with wire mesh. |
| Access door | 560x250mm for loading of the drying tray with food items. |

## 3. MODELLING FOR PROJECT STUDY

A Convective Dryer is used for the Project Study which is as shown in fig below. The only change in the Drying Process employing the Solar Food Drying and Convective Food Drying is that the later uses a fan to push hot air over the Food Products and an Electric heater to Heat the Air.

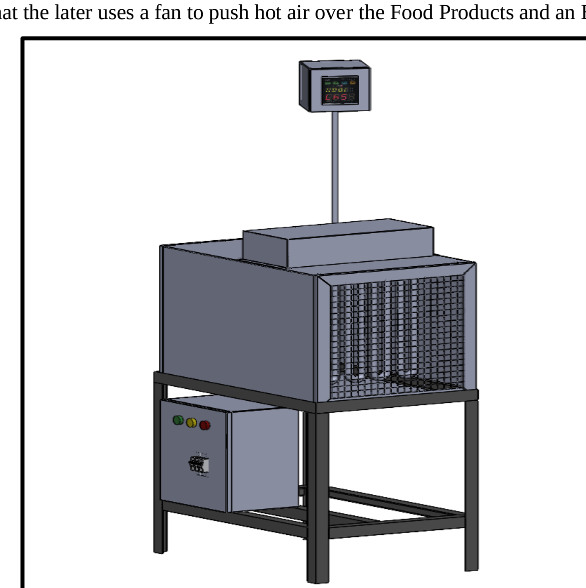

Fig. 3.1: Convective Solar Dryer Experimental Setup for Project Study

## 4.1 RESULTS OBTAINED FOR VALIDATION CASE

Table 4.1 shows the Drying time (hour) to reduce the moisture content to 60% and Drying Constant ($hr^{-1}$) data for Banana, Papaya and pineapple along with the validated results and the percentage difference between the literature results and validated results.

Table 4.1: Results obtained for Validation Case

| **Parameters** | **Results from literature paper** | | | **Validated results** | | | **Percentage Difference** | | |
|---|---|---|---|---|---|---|---|---|---|
| | Banana | Papaya | Pineapple | Banana | Papaya | Pineapple | Banana | Papaya | Pineapple |
| Drying time (hour) | 31 | 48 | 74 | 32.1 | 46.9 | 72 | 3.54 | 2.29 | 2.70 |
| Drying Constant (hr-1) *10-1 | 1.53 | 1.83 | 1.40 | 1.58 | 1.76 | 1.36 | 3.26 | 3.82 | 2.85 |

The validated results are shown in Table 4.1, in which the Drying time (hour) to reduce the moisture content to 60% and Drying Constant (hr-1) data for Banana, Papaya and pineapple is shown with its respective results below.

<table>
<tr><th>Results from literature paper</th><th>Validated results</th></tr>
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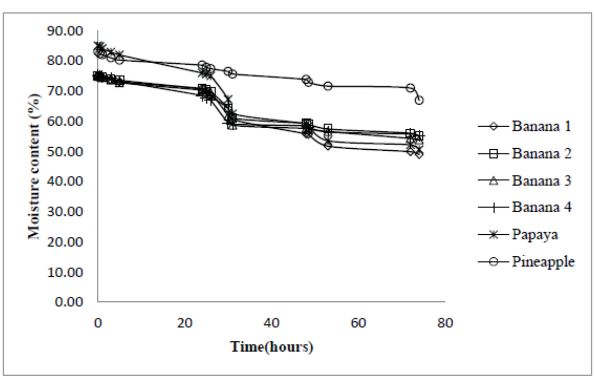

Moisture content versus time for solar drying
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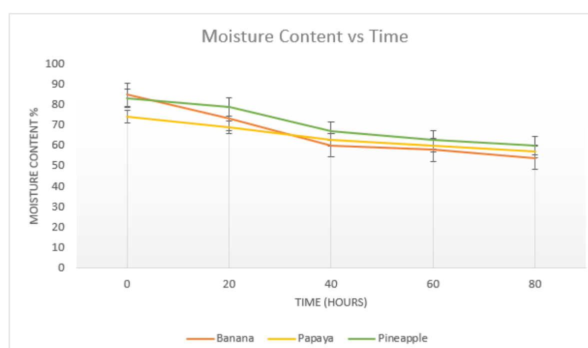

Moisture content versus time for solar drying
</td></tr>
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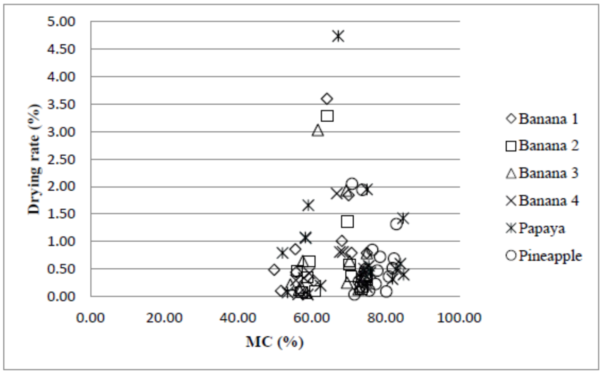
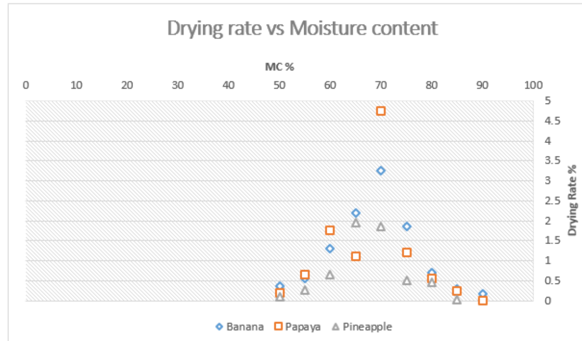



Drying rate versus Moisture Content for solar drying




Drying rate versus Moisture Content for solar drying

Table 4.2 Comparison of Results for Validation Case

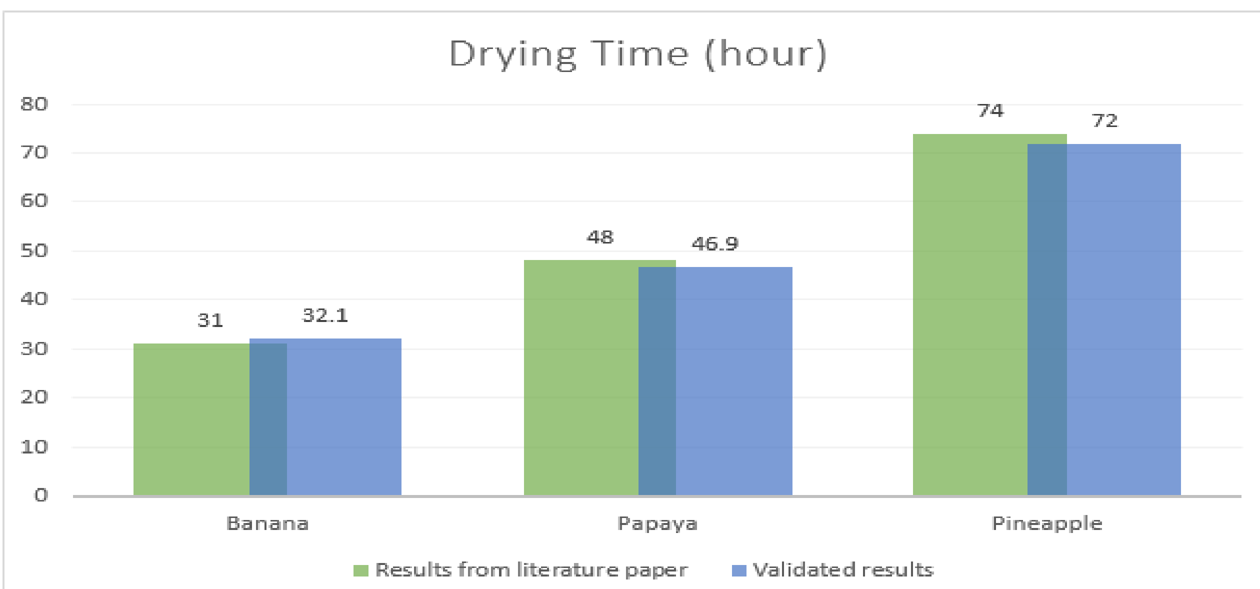



Fig 4.1: Comparison of Results for Validation Case for Drying Time

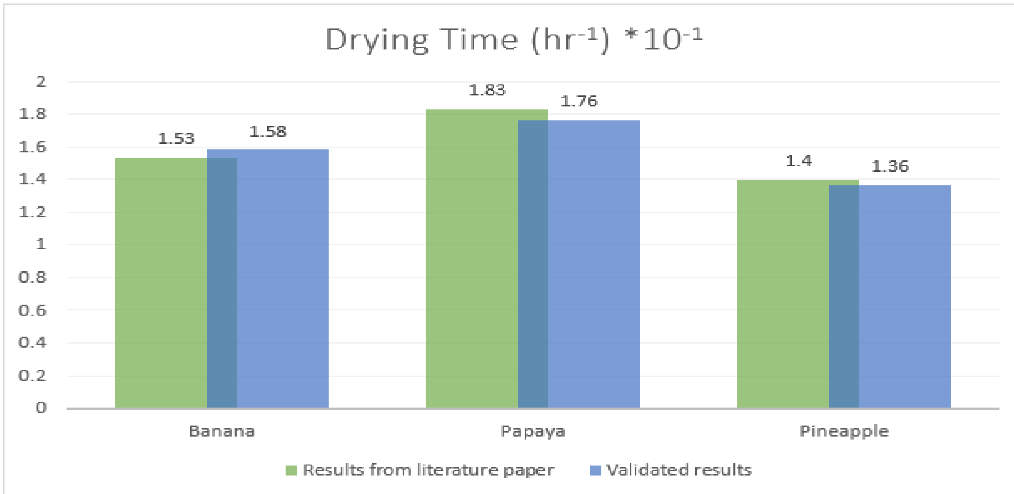



Fig 4.2: Comparison of Results for Validation Case for Drying Constant

## 4.2 RESULTS OBTAINED FROM PROJECT STUDY

By performing CFD analysis over a Specimen in Convective Dryer the Drying time (hour) to reduce the moisture content to 60% are obtained as shown in Table 4.3

Table 4.3: Results Obtained from CFD analysis

| **Type of Fruit** | Drying Time (hours) @ 1.5 m/s air velocity | | |
|---|---|---|---|
| | 65 $^0$C | 75 $^0$C | 85 $^0$C |
| Blueberries | 11.7 | 7.6 | 4.5 |
| Dates | 5.8 | 5.1 | 2.3 |
| Kiwi | 9.4 | 6.5 | 3.6 |

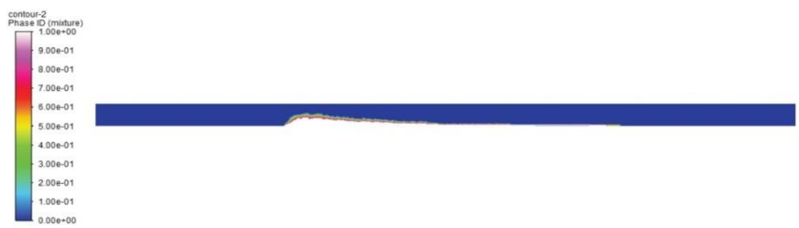
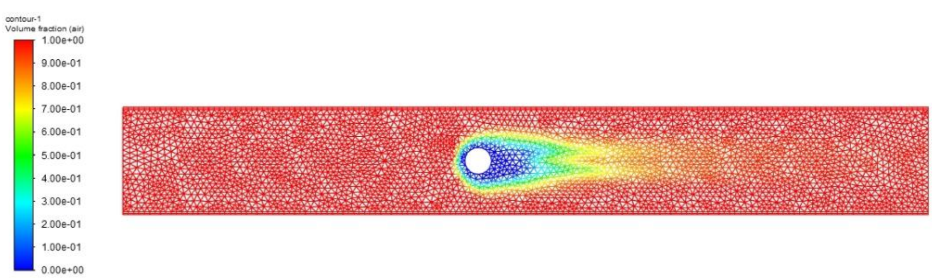
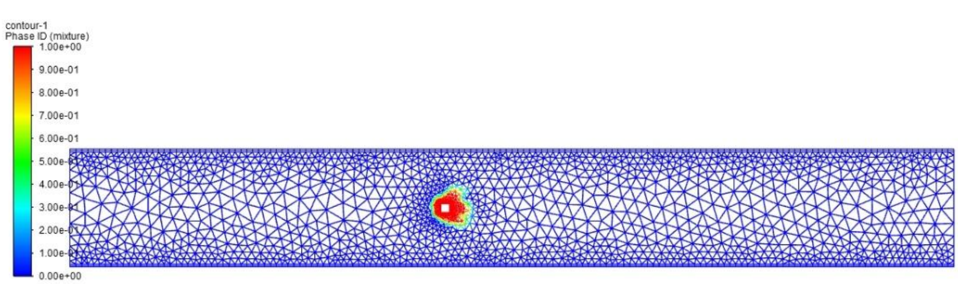
| | Water removal Process in CFD |
|---|---|
| Blueberries |  |
| Dates |  |
| Kiwi |  |

Table 4.4: Water removal Process in CFD

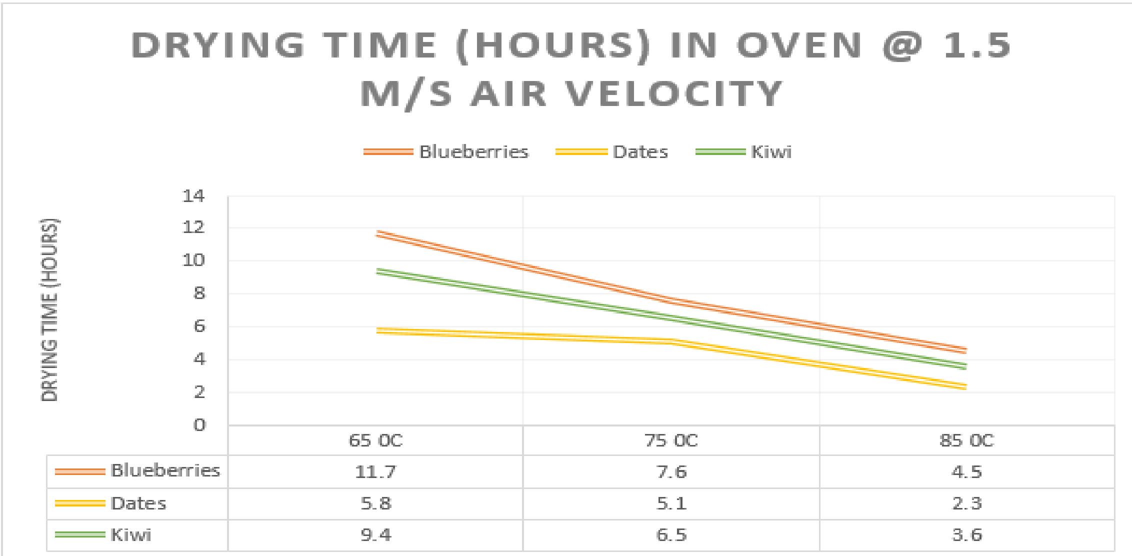



Fig 4.3: Results Obtained from CFD analysis.

**Results calculated by performing CFD analysis on Specimen in Convective Dryer are shown below**

Velocity Distribution along a Specimen in Convective Dryer.

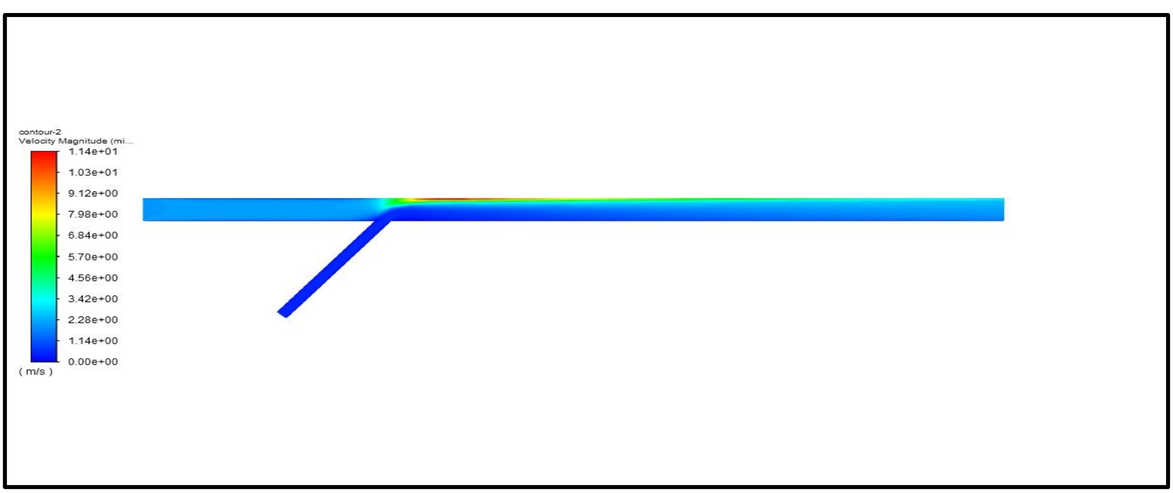



Fig 4.4: Velocity Counters on Blueberries in Convective Dryer.

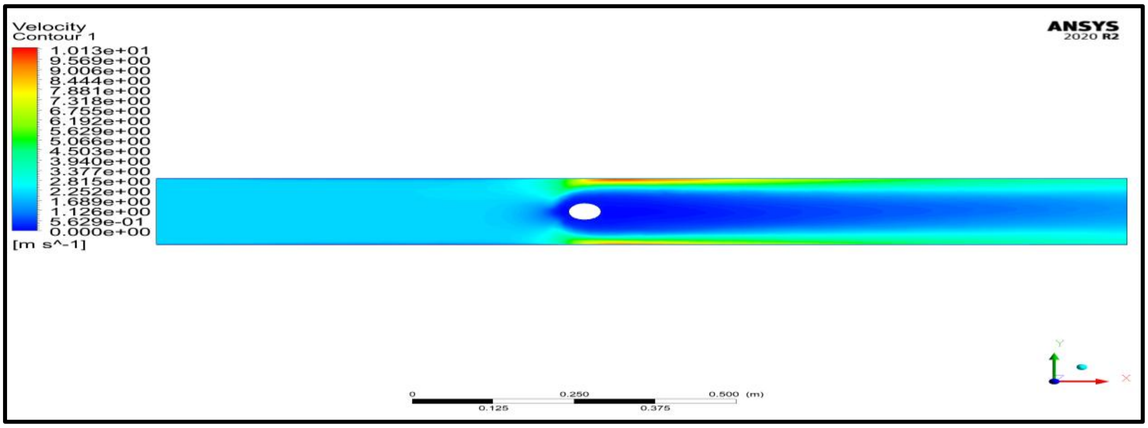



Fig 4.5: Velocity Counters on Dates in Convective Dryer.

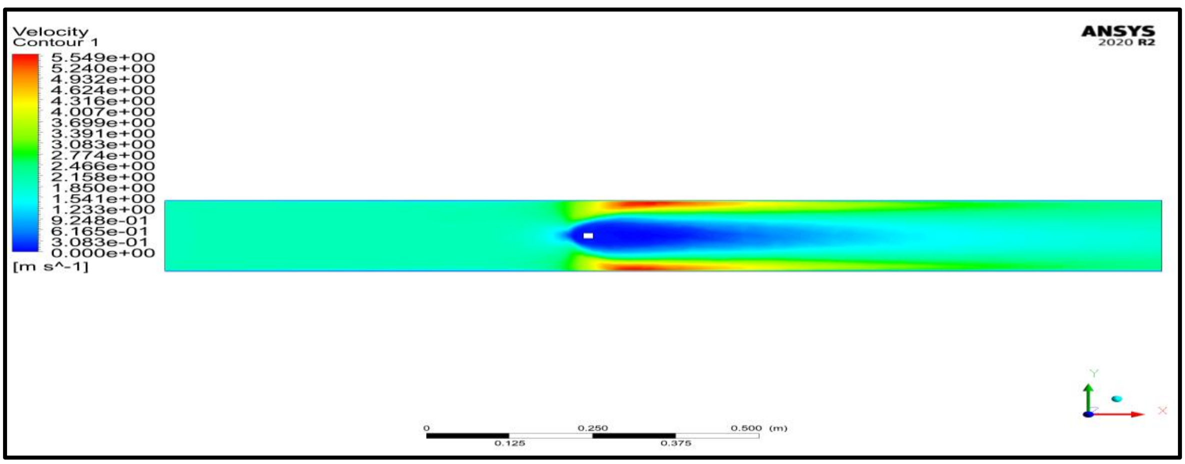



Fig 4.6: Velocity Counters on Kiwi in Convective Dryer.

Temperature Distribution along a Specimen in Convective Dryer.

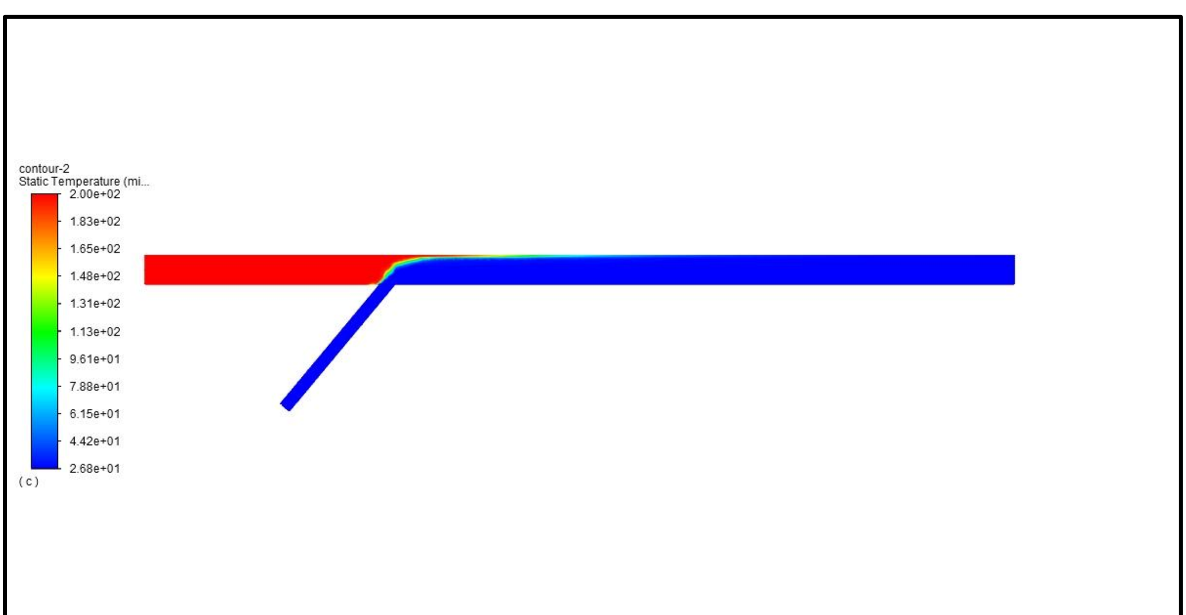


Fig.4.7: Temperature Counters on Blueberries in Convective Dryer.

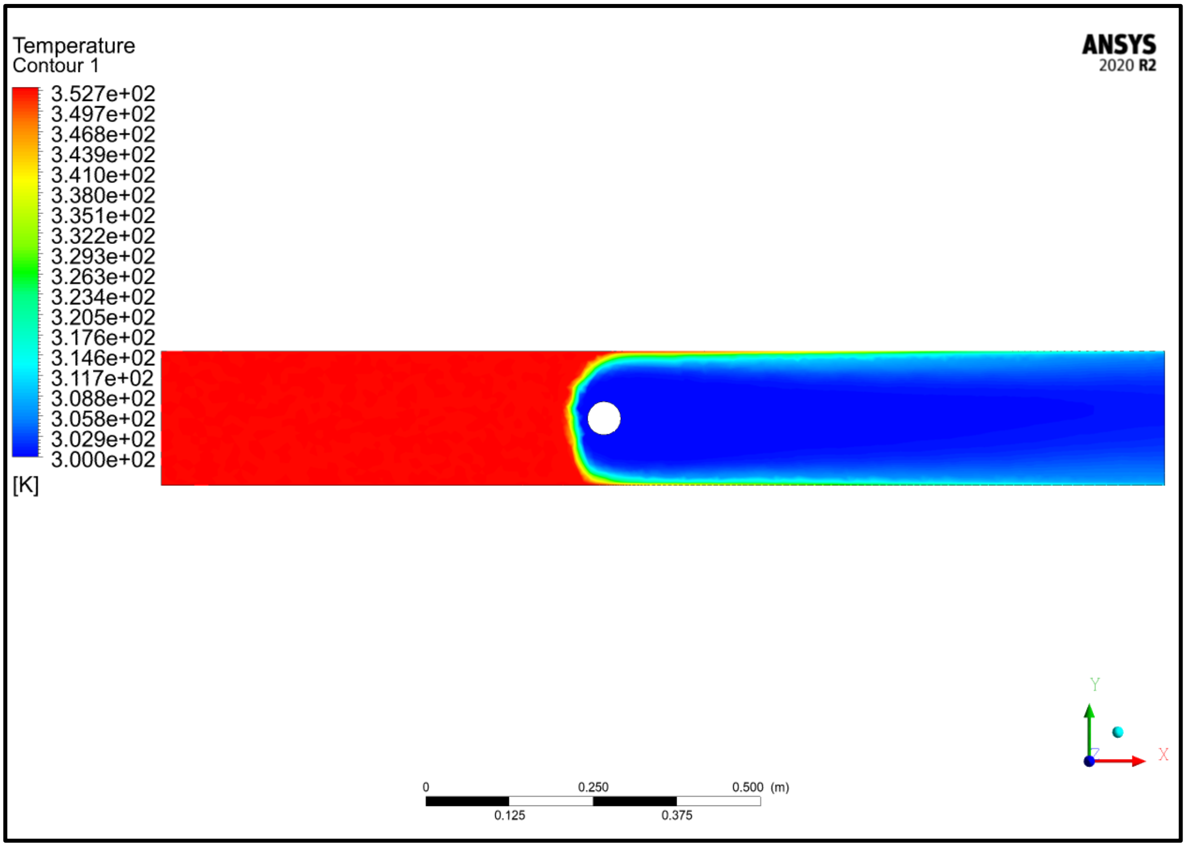



Fig.4.8: Temperature Counters on Dates in Convective Dryer.

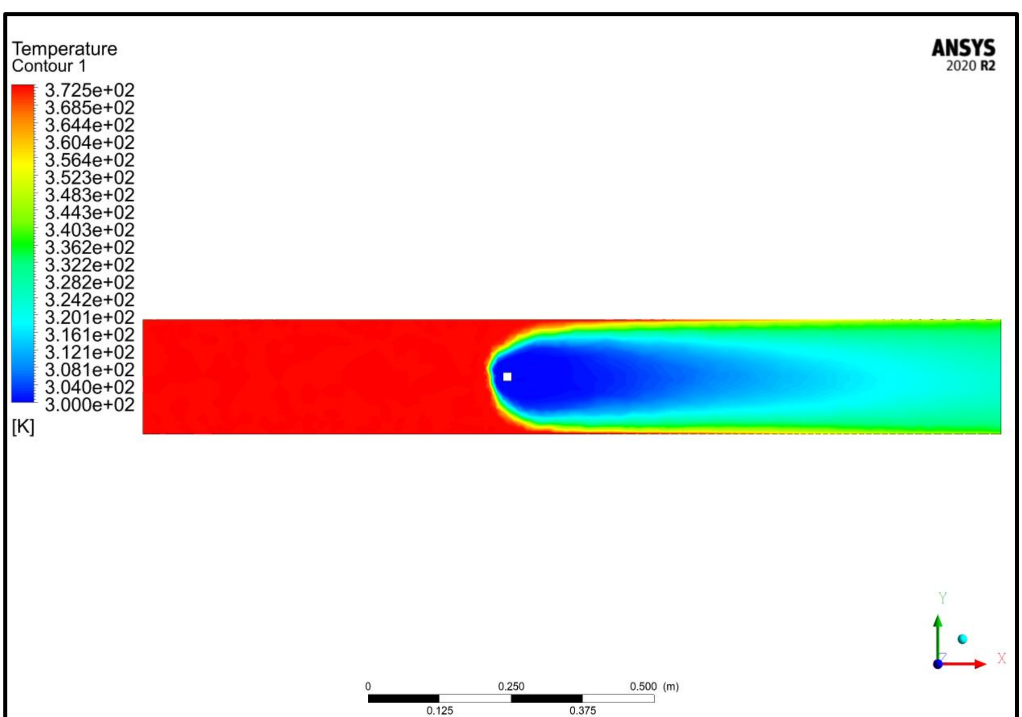



Fig.4.9: Temperature Counters on Kiwi in Convective Dryer

Pressure Distribution along a Specimen in Convective Dryer.

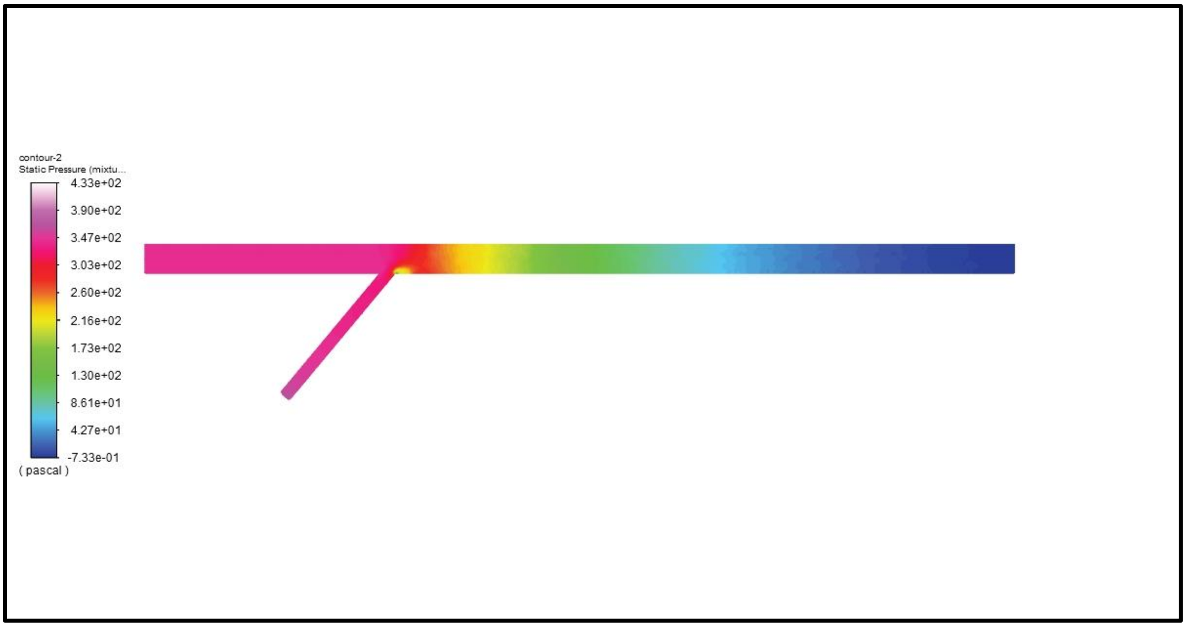



Fig 4.10: Pressure distribution on Blueberries in Convective Dryer

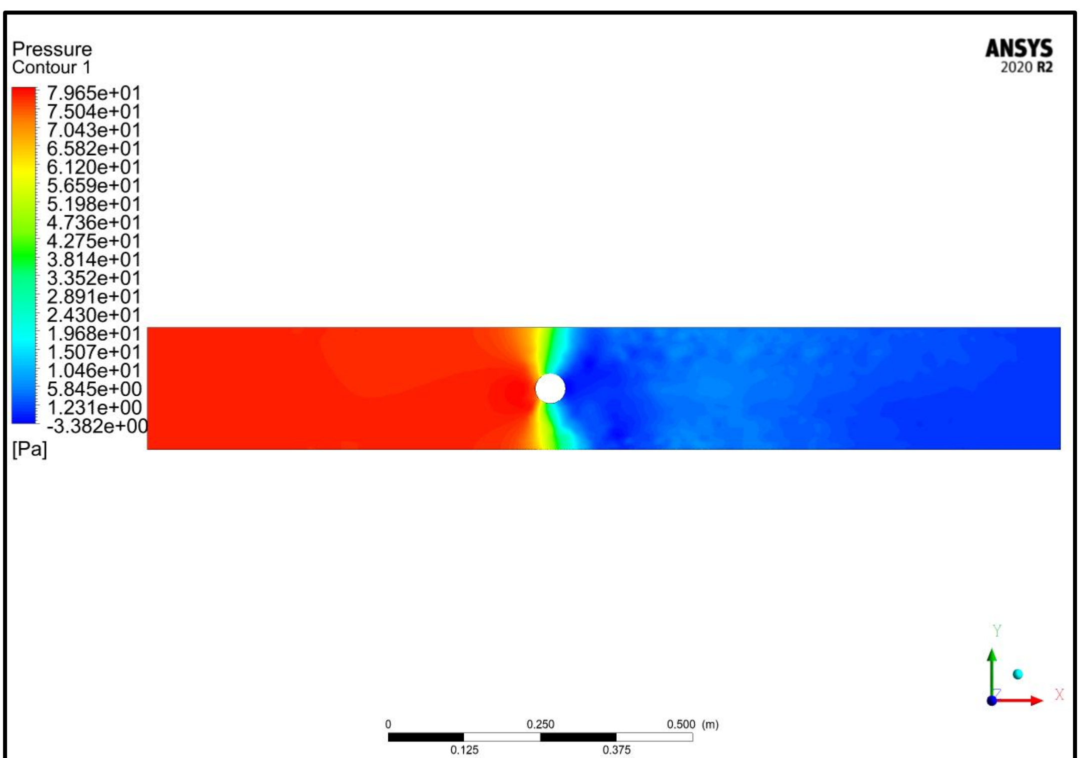



Fig 4.11: Pressure distribution on Dates in Convective Dryer

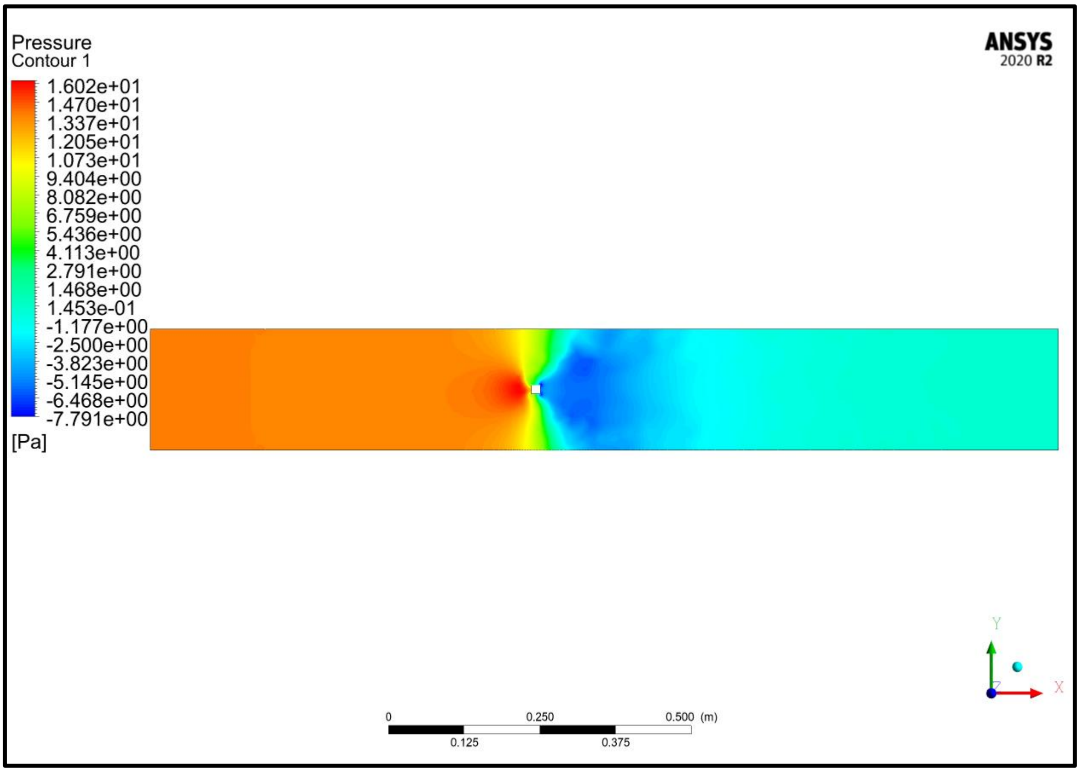



Fig 4.12: Pressure distribution on Kiwi in Convective Dryer

Above figures illustrates the nature of fluid flow, temperature distribution, Velocity vectors etc. By studying these results we can understand where how the water evaporation takes place in Food Drying as shown in Table 4.7

Table 4.5: Results obtained by performing CFD analysis on Blueberries in Convective Dryer

| Sr. No | Properties | Minimum Value | Maximum Value |
|---|---|---|---|
| 1 | Velocity | 0 m/s | 11.4 m/s |
| 2 | Temperature | 26.8 $^{0}$C | 100 $^{0}$C |
| 3 | Pressure | -0.73 Pa | 43.30 Pa |

Table 4.6: Results obtained by performing CFD analysis on Dates in Convective Dryer

| Sr. No | Properties | Minimum Value | Maximum Value |
|---|---|---|---|
| 1 | Velocity | 0 m/s | 10.13 m/s |
| 2 | Temperature | 300 K | 352.7 K |
| 3 | Pressure | -3.38 Pa | 79.65 Pa |

Table 4.7: Results obtained by performing CFD analysis on Dates in Convective Dryer

| Sr. No | Properties | Minimum Value | Maximum Value |
|---|---|---|---|
| 1 | Velocity | 0 m/s | 5.54 m/s |
| 2 | Temperature | 300 K | 372.5 K |
| 3 | Pressure | -7.79 Pa | 16.02 Pa |

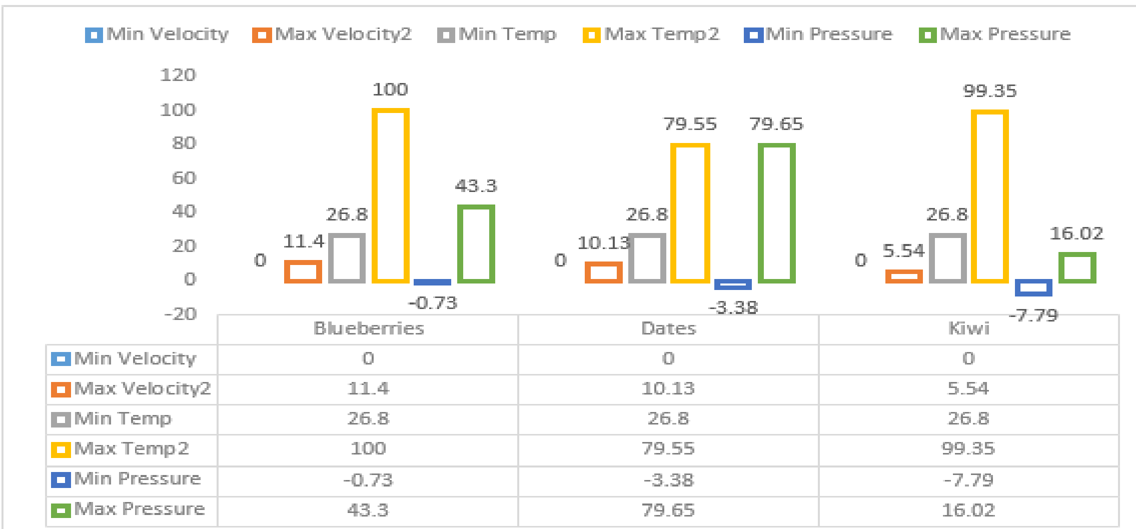



Fig 4.13: Comparison between Results obtained by performing CFD analysis in Convective Dryer

## 5. Conclusion:-

Based on CFD analysis it is to be state that, the higher the temperature the faster is the Drying of Food products. Results show the temperature counters, Phase Changes on the Specimen in Convective Dryer.

Conducting Multi-phase mapping using CFD tool provides extensive information about effects of different Drying Temperatures and air velocities of the Drying Rates of Food Products. It gives better approximate solutions with actual experimentation. It can be implemented where the direct contact Multi-phase mapping techniques cannot be applied. The following observations can also conclude accordingly.

- At high temperature the rate of drying is higher at a given velocity.
- There is a Pressure drop when the flowing air comes in contact with the Specimen to be dried.
- Turbulence is created where there is drop in pressure.
- Phase transformation can be easily visualized in the CFD domain.
- CFD tools are best for Multi-phase mapping of Specimen in Convective Dryer and are also reliable.

Based on the experimental results the following conclusions are made:-

**Conclusion of CFD analysis performed on Specimen in Convective Dryer**

Table 5.1: Results Obtained from CFD analysis.

| **Type of Fruit** | Drying Time (hours) @ 1.5 m/s air velocity | | |
|---|---|---|---|
| | 65 $^0$C | 75 $^0$C | 85 $^0$C |
| Blueberries | 11.7 | 7.6 | 4.5 |
| Dates | 5.8 | 5.1 | 2.3 |
| Kiwi | 9.4 | 6.5 | 3.6 |

- Based on CFD analysis it is to be state that, the higher the temperature the faster is the Drying of Food products. The least time required for drying is 2.3 hours for Dates at 85 $^0$C as the Dates has the least moisture content and the max drying time is for Blueberries which is 4.5 hours at 85 $^0$C.

- The Velocity counters as from CFD Analysis show that there is increase in Velocity as the flow proceeds over the Specimen and a pressure drop is also seen near the specimen.
- The Phase change results show the removal of water vapour from the specimen at different rates in different Food Products.
- The Phase change result in Blueberries show the removal of Water vapour from the upper side of the Specimen. In case of Dates it is to be seen that the water vapour is been removed from all the sides and for the Kiwi there is a small area where the vapour is being removed from the Kiwi and getting mixed with the Flow of air.
- The temperature profiles in all the results show that there is decrease in temperature once the air flows over the specimen as the temperature is used for evaporating the Water in the Specimen.

## 5.2 Future scope:-

Food drying is a method of food preservation in which food is dried (dehydrated or desiccated). Drying inhibits the growth of bacteria, yeasts, and mold through the removal of water.

There are many Mathematical models available for analysis of the Drying Kinetics of Food products which depend on the studies undertaken by different groups of people and developed these mathematical models. The development of a mathematical model requires a lot of work and cannot be done without a well formed experimental setup. A developed Multi-phase model will serve for all purposes of Food Drying without a need of Experimental setup.

Many of engineering problems can be solved by using this technique and can be extensively used in future. Multi –phase environments can be simulated by using this technique.

This technique can also be used for following engineering field in future.

- Food engineering.
- Medicine Technology.
- Supermarkets and Grocery Stores.

## References

1.Mitrevski, Vangelce, Cvetanka Mitrevska, Mirko Babić, Tale Geramitcioski, and Vladimir Mijakovski. “Mathematical Modelling of the Thin-Layer Drying Kinetics of Some Fruits.” Journal on Processing and Energy in Agriculture 22, no. 2 (n.d.): 1–4. doi:10.5937/JPEA1801001M.

2. Amer, B. M. A. “SIMULATION OF AIR CHARACTERISTICS FOR PV HYBRID DRYING SYSTEM AND DRYING KINETICS OF STRAWBERRY FRUITS.” Misr Journal of Agricultural Engineering, 36(2), 515–534. https://doi.org/10.21608/MJAE.2019.94662

3. Pavkov, I., Stamenković, Z., Radojčin, M., Krstan, K., Bikić, S., Lutovska, M., & Ponjičan, O. “Air drying of blueberry fruits: Drying kinetics, mathematical modeling and physical properties.” Journal on Processing and Energy in Agriculture, 23(4), 151–157. https://doi.org/10.5937/JPEA1904151P

4. N. Shahari, S. Hibberd, “Modelling of drying Tropical fruits using Multiphase model”, WSEAS transactions on mathematics, E-issn: 2224-2880, Volume 13, 2014

5. R., Baini, Lai J C H., Abdul Samat N.A., Rahman M.R., and Mohidi N.S.A. “Performance Evaluation of Solar and Oven Drying for Tropical Fruits.” International Journal of Advances in Scientific Research and Engineering 4, no. 12 (n.d.): 215–24. doi:10.31695/IJASRE.2018.33025.

6. Aravindh, M.A., Sreekumar, A., Solar Drying – A Sustainable Way of Food Processing, In: Energy Sustainability through Green Energy, Ed: Atul Sharma Kar and Sanjay Kumar, 27–46.

7. Inyang, Uwem Ekwere, Innocent Oseribho Oboh, and Benjamin Reuben Etuk. “Kinetic Models for Drying Techniques—Food Materials.” Advances in Chemical Engineering and Science 08.02 27–48. Web.