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Heat Transfer Parameterization towards Enhancing Shelf Life of Vegetables in Low Cost Cold Chain with FACCC

Vardan Parashar, Shailesh Kumar Trivedi, Abid Haleem

Abstract:India is the second-largest vegetable producing country after China. It is observed that there is a huge loss of vegetables due to the lack of low-cost cold chain for its storage & transportation after harvesting from agriculture land to vegetable market. The shelf life of these vegetables is less due to poor temperature control during transportation and storage. If vegetables are not maintained at their prudent temperature, then they will lose their potency, which will lead to enormous economic loss. Therefore, it is observed that temperature control of vegetables and their heat transfer characteristics are a major factor to maintain potency and increase their shelf life. This paper proposed a low-cost design of FACCC for temperature control of vegetables during transportation and storage with the help of Chillers.

Further, the effect of air velocity on heat transfer rate and Nusselt number of various vegetables was evaluated to predict the performance of FACCC for enhancing the shelf life of vegetables.Thermophysical characteristics of these vegetables have been calculated at different air flow rate with the help of Reynolds analogy as a function of Stanton Number, Reynold's Number and Prandtl Number.The airflow rate was maintained between 0.2065 m/s - 0.413 m/s inside FACCC. Experimental study reveals that the average Nusselt Number of these vegetables lies in the range of 57.9 - 115.74 and the range of Surface heat transfer coefficient is 54.48-108.96 W/m^{2}K. Validation of FACCC performance has been done by comparing the heat transfer rate and Nusselt number from published literature. These results are obtained by temperature control of vegetables by varying air flow rate through four fans fitted inside FACCC. It results in higher shelf life due to favourable maintenance of thermodynamic parameters such as surface heat transfer coefficient, Nusselt number, Reynold number and preferable temperature for specific commodities.Thus, the proposed FACCC model can be an effective tool for enhancement of low-cost cold chain for vegetables in future.

Keywords: Cold Chain; Convective Heat Transfer Coefficient; Free Air Cooling Conditioning Chamber; FACCC; Nusselt Number; Reynolds Number; Stanton Number; Vegetables

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I. INTRODUCTION

Post-harvest life and quality of agricultural products depend on storing temperature of the commodity and found them asone of the most important governing parameters for the shelf life of agriculture products [1-2]. Every year more than 40% of fruits and vegetables are wasted because of poor maintenance of preferable temperature after harvesting from agriculture land to vegetable market [3].This leads to wastage of fruits &vegetables, resulting shortage of supply of vegetables; therefore, consumers have to purchase vegetables at a 35% high rate. Farmers deliver their vegetable crops at very nominal rates, but due to lack of cold supply chain for maintaining a preferable temperature of these vegetables for transportation and storage, the cost of end products increases. Storage conditions of agriculture products are an important aspect for the maintenance of the shelf life with improved quality. It is essential to maintain food, fruits & vegetables at prescribed temperature during storage, and further, the desired temperature should also be maintained during transportation. This requirement of the society has led to a research gap for evolving new concept of low-cost free air cooling conditioning chamber (FACCC) for maintenance of the desired temperature of vegetables during transportation and storage.

It is also noticed that there is a lack of linkage between governments, industry, and institution to take care of the interest of small farmers for transportation and storage of raw vegetables. Although high-cost options & advanced techniques for processing, storing & transportation of food items are available in the market, because of economic constraints of marginal farmers, such options are not viable to them. Freezing and cooling at low temperature is a common technique used for maintaining the shelf life of agriculture products for a long time [4]. Surface heat and mass transfer coefficients are local phenomena dependent primarily upon the temperature and velocity of the surrounding fluids [5]. An empirical relation to establishing correlation for Nusselt number, Reynolds number, Prandtl number apart from the temperature control [6].

Investigated the factors for cooling of fruits and vegetables and concluded that forced cooling could be achieved by flowing of air over agricultural products for temperature control [7]. Further determined that heat transfer for vegetables are dependent upon surface heat transfer coefficient, Nusselt Number, moisture content & internal heat generation of the commodity.

These are the significant parameter for affecting the shelf life of vegetables.

Thermal conductivity varies for different fruits as per the commodity shape, size and its surface friction coefficient [8]. Krokida et al, presented an analogy for heat transfer factors and Reynolds number for food processing [9]. Bhaskar et al, presented a modelling of various factors of post-harvesting losses in fruits and vegetable supply and concluded that lack of linkage between farmers and processing unit of vegetables in the cold chain of food is a most significant factor [10].Yang et al, studied on the status of domestic fruits and vegetables cold chain logistics in China [11]. They proposed some strategies for speeding up infrastructures construction and techniques upgrading, which are key factors to boost up vegetables cold chain logistics. A correlation between air velocity and heat transfer coefficient has been established for a specific food [12].

Temperature control and its monitoring is a significant factor in the cold chain for agricultural food items. Optimal atmospheric conditions vary according to ripeness stage, duration of exposure and temperature control. Post-harvest management of agricultural products is very important for a sustained supply chain to improve the shelf life during storage and transportation with minimum loss of quality and nutrition [13]. An experimental analysis conducted for improved cold chain chamber for the agro commodity during transportation of fruits in India. They developed a low-cost model for handling agricultural commodities and achieved desirable temperature reduction, which helped maintain the potency level of fruits to enhance the shelf life [14].

A model on cold supply chain evaluated that fruits temperature can be maintained below atmospheric temperature by varying cool air flow rate over fruits inside improved cold chain chamber. Temperature control with the help of cooling techniques such as air conditioners etc. for agriculture products is quite costly and beyond the economic reach of small and marginal farmers [15]. Therefore, this research paper proposes a low-cost cold chain to maintain agriculture crops, especially vegetables, at a temperature lower than the atmosphere in a hot and humid country. This paper briefly states the performance of FACCC system & variation of cooling effect obtained due to varying air flow over vegetables for improved cold chain in hot countries as lower temperature prevailing in FACCC leads to slow growth of pathogenic fungi etc. which causes spoilage of vegetables. Thus the use of FACCC will undoubtedly reduce the wastage & deterioration in vegetables during transportation and storage.

II. METHODS AND MATERIALS

Transportation of vegetables from agriculture land to market place without maintaining thermo-physical properties leads to loss of a large amount of vegetables as they lose their potency or they shrivel or droop their freshness. Thus, the need for a device or arrangement for maintaining desired ambient conditions to retain freshness and shelf life of vegetables was always felt. In this paper, an experimental setup has been designed with an idea of maintaining the desired thermo-physical property of vegetables for low-cost cold chain. It will help resolve the issues toward the storage and transportation (logistics) of the Vegetables at a temperature lower than the ambient temperature. A low cost-free air cooling conditioning chamber (FACCC) is designed to address this problem. Inside FACCC, a pump is used to circulate coolant that is solid ice (or cold water) taken from a cold supply. The chillier water flows to the unit of FACCC with the help of a pump in an open flow chamber, and this circulating water acts as a heat sink. A copper coil is having the cluster of small-diameter tubes working as a heat exchanger. A pump is used to circulate cold water in the copper tubes and used fans to waft the air through the unit of FACCC. So temperature is maintained lower than the ambient temperature and has the cooling effect that is appropriate for increasing the shelf existence of commodities.

Observed that the use of FACCC reduces the temperature from 38^{0}C to 28^{0}C through the flow of cool air at a different velocity. Dimensions of chamber are 100 cm x 50 cm x 50 cm [Fig-1]

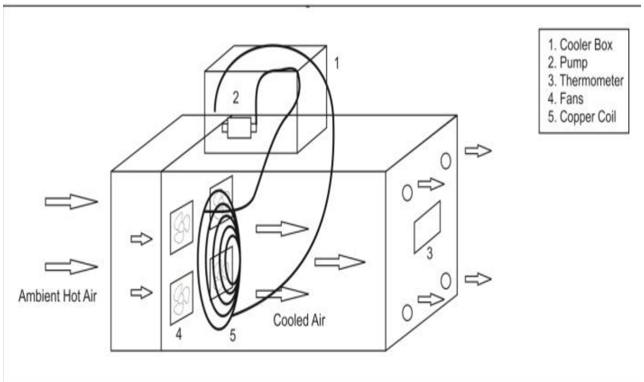

Fig 1: Free Air Cooling Conditioning Chamber (FACCC)

The layout of FACCC chamber is shown above in which cooled air is flowing via four distinct fans. The capacity of every fan is 35 CFM, and they are operated as per need and temperature control is obtained by varying flow rate of air. Examined different vegetable commodities for calculating heat transfer coefficient and Nusselt number. Effectiveness and smooth operation of FACCC may be justified by calculating its ability to transfer heat, resulting in a reduction in the temperature of vegetables placed inside FACCC to enhance their shelf life.

In this way, FACCC increases the shelf existence of vegetables during storage and transportation by way of the temperature control environment in the hot ambient conditions. It is developed for cooling the vegetables using forced convection.

In order to calculate the heat transfer parameters of vegetables, the required input data such as vapour pressure, transpiration rate and skin transfer coefficient are obtained from the ASHRAE Handbook, as shown in Table-1. These are valuable factors for calculating the Nusselt number and surface transfer coefficient for vegetables.

Table 1: Commodity skin friction coefficient

Commodity	Skin friction Coefficient C_f			Standard Deviation
	Low	Mean	High	
Tomato	0.217	1.10	2.43	0.67
Onions	-	0.8877	-	-
Potato	-	0.6349	-	-
Cabbage	2.5	6.72	13	2.84
Carrot	31.8	156	361	75.9
Lima beans	3.27	4.37	5.72	-
Green pepper	0.545	2.159	4.36	0.71
Sugar beets	9.09	33.6	87.3	20.1
Snap beans	3.46	5.64	10.0	1.77
Rutabagas	-	116.6	-	-

Source: Research, A. (2018). ASHRAE Handbook

Observed through thermodynamics literature that Prandtl number and Stanton number are the dependent factors for calculating the surface mass transfer coefficient.It is to be calculated by applying the Reynolds analogy [16]. Stanton number is calculated with the help of different Reynolds number at varying air flow rate inside FACCC. Nusselt Number and Surface heat transfer coefficient were determined by Stanton Number for each vegetable taken into consideration.

In the experimental setup of FACCC, the desired temperature inside the chamber was achieved through various air velocity & discharge, controlled by four fans so that a high heat transfer rate can be accomplished through convection mode. In order to calculate Nusselt number, Stanton number, Reynolds number & surface heat transfer coefficient, the following governing equations are used [17].

$$N_u = \frac{hd}{k} \qquad (1)$$

The relative thickness of the thermal boundary layer and speed of the fluid is signified via the dimensionless parameter Prandtl Number (Pr). It is near to one for gases.

$$P_r = \frac{\mu Cp}{k} \qquad (2)$$

One of the important dimensionless parameters is Reynolds Number (Re), which depends on the floor roughness, geometry, fluid speed, kind of fluid etc.

$$R_e = \frac{Vd}{\upsilon} \qquad (3)$$

In Fig 2, the experimentally calculated values of Reynolds Numbers are shown at three specific air velocities obtained via fourfansfitted inside the cooling chamber of the experimental setup.

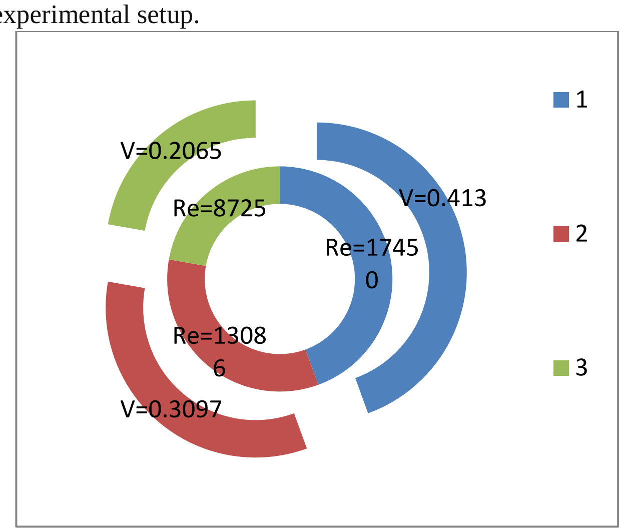

Fig 2: Reynolds Number at different air velocities

Calculated Stanton number with the help of skin friction coefficient and Prandtl number. Further, decided the value of the convective heat transfer coefficient by making use of Reynolds analogy for momentum and heat transfer in turbulent flow,by using the following equation.In this experiment, the turbulent flow analogy is used as a flow pattern of air over vegetables was found turbulent, which was also calculated and established by Reynold number.

$$\frac{Cf}{8} = S \qquad (4)$$

$$Sn = h/(\rho CpV) \qquad (5)$$

III. RESULTS

The shelf life of vegetables depends upon the specific temperature for a particular commodity. At the start of the experiment, vegetables were kept in the FACCC chamber at atmospheric temperature, i.e. 38^0C. The heat transfer rate inside the FACCC was controlled with the help of four fans by varying air velocity within the chamber. Reynolds number and Stanton numberwere calculated by varying air discharge inside the chamber. Finally, calculated the rate of convective heat transfer and Nusselt number, and evaluated the effectiveness of FACCC by comparing the various thermophysical properties at different illustrations for each vegetable kept inside the FACCC.

Three illustrations are presented here for evaluating the performance of FACCC. Values of surface heat transfer coefficient & Nusselt number for specific vegetables kept within the FACCC chamber were calculated. Following values of circulating air are referred from the published air table at 38^0 C [17].

- Dynamic viscosity (μ) = 1.604 * $10^{\wedge-5}$N-s/m^2,
- Specific heat (C_p) = 1006.5 J/kgK,
- Thermal conductivity (k)= 0.0263 W/mK,
- Density = 1.184 kg/m^3

A. ILLUSTRATION 1: (When all four fans are operating)

Data tested for different commodity is shown in Table-2. In first illustration, all four fans were running. Flow velocity of cooling air and Reynolds number (Re) and Prandtl Number (Pr) inside the FACCC chamber was calculated:

- Flow velocity in FACCC: V= 35 CFM*4*.000472/(0.4*0.4) = 0.413 m/s
- Reynolds number = Vd/υ =0.413*.66/.00001562 = 17450
- Prandtl Number (Pr) = μC_p/k = 0.6127

Table-2: Calculation for Nusselt Number and Convective heat transfer coefficient under four fan running conditions (V = 0.413 m/s)

Commodity	Skin mass transfer Coefficient (Cf)	Reynolds Number (Re)	Stanton Number (Sn)	Convective heat transfer coefficient (h)	Diameter of Commodity d(m)	Nusselt Number (Nu)
Tomato	1.1000	17450	0.1375	67.6734	0.04	102.7652
Onions	0.8877	17450	0.1110	54.6125	0.02	41.4657
Potato	0.6349	17450	0.0794	39.0599	0.04	59.3142
Cabbage	2.5000	17450	0.3125	153.8033	0.05	291.9465
Lima beans	3.2700	17450	0.4088	201.1747	0.02	152.7464
Green pepper	0.5450	17450	0.0681	33.5291	0.032	40.7324
Snap beans	3.4600	17450	0.4325	212.8637	0.015	121.2162

As per the results obtained for each commodity, Nusselt number, heat transfer coefficient and cumulative variation ofthese parameters are shown through Fig. 3, Fig. 4 &Fig. 5. These results indicatethat a precise range of thermo-physical parameters can be identified for each vegetable keptinside the FACCC. Observed that temperature inside the chamber gets reduced by 10^{0}C helping in the improved shelf life of vegetables.

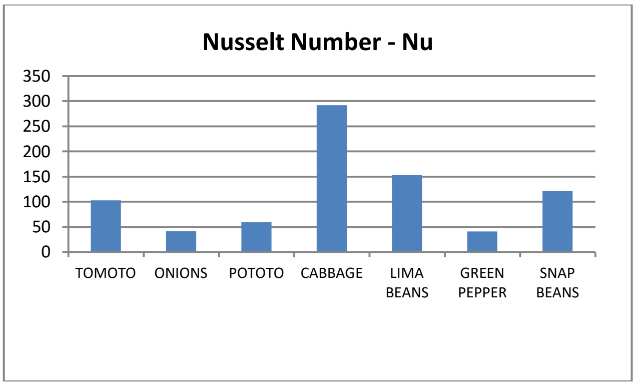

Fig 3: Nusselt Number for Different Vegetablesinside the FACCC

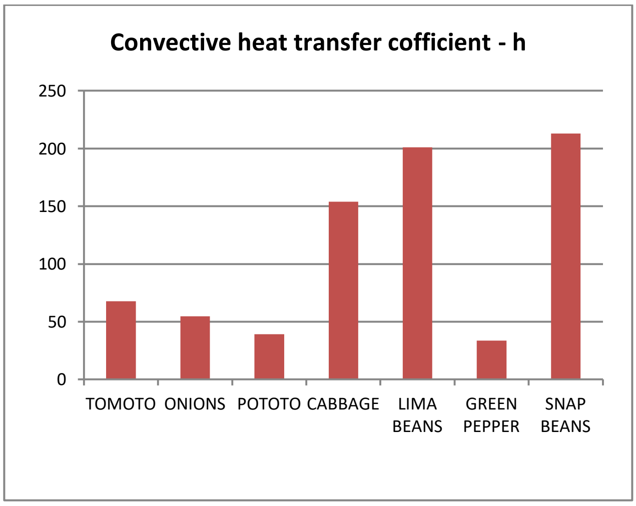

Fig 4: Convective heat transfer coefficient for Different Vegetablesinside the FACCC

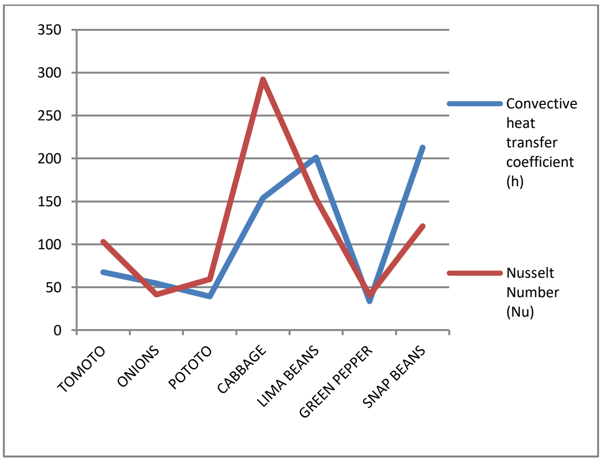

Fig 5: Cumulative variation of Convective heat transfer coefficient and Nusselt Number inside FACCC

Based on the above results, the average value of Nusselt Number was 115.74 and Surface heat transfer coefficient was 108.96 W/m^2K. These results were evaluated for airflow velocity at 0.413 m/s, and Reynolds Number was 17450 inside FACCC by operating all the four fans. Observed that vegetable quality was found fresh & acceptable even after 16-20 hour of operation.

B. ILLUSTRATION 2:

(when only three fans are operating)

Table 3 shows the data tested for different commodities. In the second illustration, three fans were running. Calculated the flow velocity of cooling air, Reynolds number (Re) and Prandtl Number (Pr) inside the FACCC chamber:

- Flow velocity in FACCC:
  V= 35 CFM*3*0.000472/(0.4*0.4) = 0.3097 m/s
- Reynolds number = Vd/υ = 0.3097*0.66/0.00001562 = 13087
- Prandtl Number (Pr) = $\mu C_p/k$ = 0.6127

Table-3: Calculation for Nusselt Number and Convective heat transfer coefficient under three fan running conditions (V = 0.3097 m/s)

Commodity	Skin mass transfer Coefficient (Cf)	Reynolds Number (Re)	Stanton Number (Sn)	Convective heat transfer coefficient (h)	Diameter of Commodity d(m)	Nusselt Number (Nu)
Tomato	1.1000	13086	0.1375	50.7469	0.04	77.0614
Onions	0.8877	13086	0.1110	40.9527	0.02	31.0943
Potato	0.6349	13086	0.0794	29.2902	0.04	44.4785
Cabbage	2.5000	13086	0.3125	115.3338	0.05	218.9245
Lima beans	3.2700	13086	0.4088	150.8566	0.02	114.5413
Green pepper	0.5450	13086	0.0681	25.1428	0.032	30.5444
Snap beans	3.4600	13086	0.4325	159.6220	0.015	90.8975

As per the results obtained for each commodity, Nusselt number, heat transfer coefficient and cumulative variation ofthese parameters are shown in Fig. 6, Fig. 7& Fig. 8. These results indicate that a clear range of thermo-physical parameters can be identified for each vegetable kept inside the FACCC.

It is observed that temperature inside the chamber gets reduced by 8-9^{0}C, leading to the increased shelf life of vegetables.

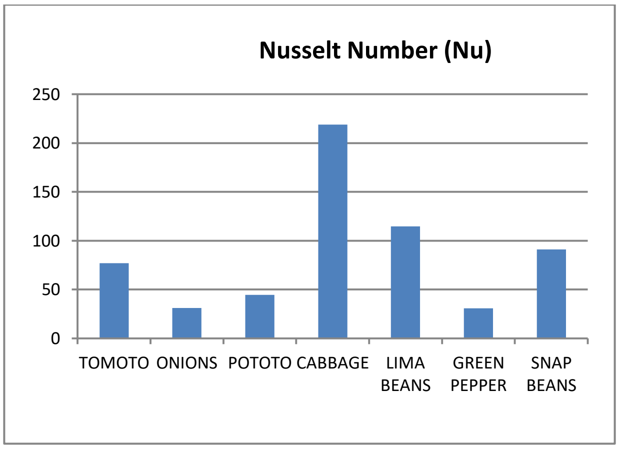

Fig 6: Nusselt Number for different vegetables inside the FACCC.

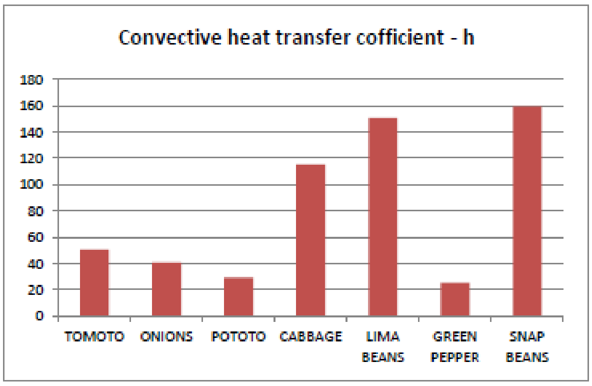

Fig 7: Convective heat transfer coefficient for Different Vegetablesinside the FACCC

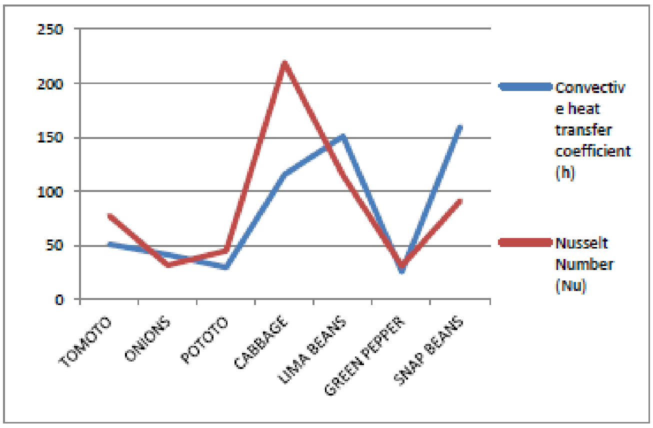

Fig 8: Cumulative variation of Convective heat transfer coefficient and Nusselt Number inside FACCC.

Based on the above results, the average value of Nusselt Number was 86.79 and Surface heat transfer coefficient was 81.71 W/m^{2}K. These results were evaluated for airflow velocity at 0.3097 m/s, and Reynolds Number was 13086 inside FACCC by operating three fans. Observed that vegetable quality was found acceptable & fresh even after 14-18 hour of operation.

C. ILLUSTRATION 3: (When only two fans are operating)

Data tested for a different commodity is shown in Table-4.Two fans were running for the third illustration. Calculated the flow velocity of cooling air and calculated Reynolds number (Re) and Prandtl Number (Pr) inside the FACCC chamber:

- Flow velocity in FACCC :
  V= 35 CFM*2*0.000472/(0.4*0.4) = 0.2065 m/s
- Reynolds number = Vd/υ = 0.2065*0.66/0.00001562 = 8725
- Prandtl Number (Pr) = μCp/k = 0.6127

Table-4: Calculation for Nusselt Number and Convective heat transfer coefficient under two fan running conditions (V = 0.2065 m/s)

Commodity	Skin mass transfer Coefficient (Cf)	Reynolds Number (Re)	Stanton Number (Sn)	Convective heat transfer coefficient (h)	Diameter of Commodity d(m)	Nusselt Number (Nu
Tomato	1.1000	8725	0.1375	33.8367	0.04	51.3826
Onions	0.8877	8725	0.1110	27.3062	0.02	20.7329
Potato	0.6349	8725	0.0794	19.5299	0.04	29.6571
Cabbage	2.5000	8725	0.3125	76.9016	0.05	145.9733
Lima beans	3.2700	8725	0.4088	100.5873	0.02	76.3732
Green pepper	0.5450	8725	0.0681	16.7646	0.032	20.3662
Snap beans	3.4600	8725	0.4325	106.4319	0.015	60.6081

As per the results obtained for each commodity, Nusselt number, heat transfer coefficient and cumulative variation ofthese parameters are shown in Fig. 9, Fig. 10& Fig. 11. These results indicate that a clear range of thermo-physical parameters can be identified for each vegetable kept inside the FACCC. It was also observed that temperature inside the chamber was reduced 70C, leading to the increased shelf life of vegetables.

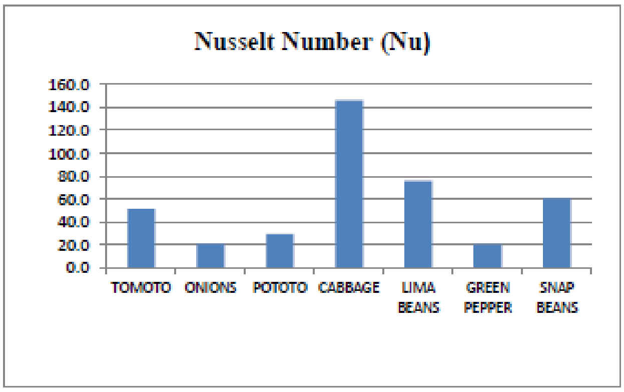

Fig 9: Nusselt Number for Different Vegetablesinside the FACCC.

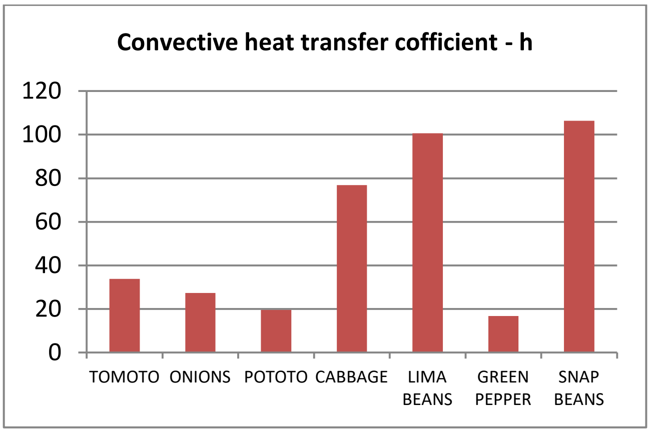

Fig 10: Convective heat transfer coefficient for different Vegetablesinside the FACCC

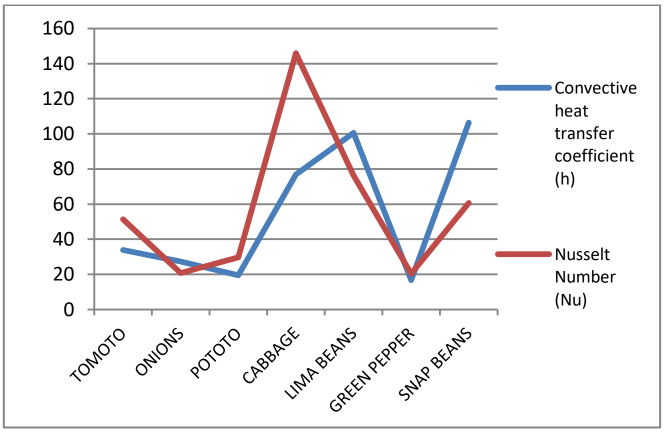

Fig 11: Cumulative variation of Convective heat transfer coefficient and Nusselt Number inside FACCC.

IV. ALIDATION OF RESULTS AND DISCUSSIONS

Based on above results,It is observed that highest temperature reduction is achieved in case of four fan operation wherethe average value of Nusselt Number was 115.74 and Surface heat transfer coefficient was 108.96 W/m^2K. These results were evaluated for airflow velocity at 0.413m/s, and Reynolds Number was 17450 inside FACCC by operating four fans. Observed that vegetables quality was found acceptable & fresh even after 16-20 hours of operation.

The better results obtained in this paper is due to phenomena of heat transfer between the vegetable surface and adjacent fluid motion, and it involves the combined effects of conduction, convection and fluid motion. It is found that the faster the fluid motion, the higher the convection heats transfer. The presence of bulk motion of the fluid enhances the heat transfer between vegetable and fluid. In this case, it can be inferred that heat is first transferred to the air layer adjacent to the vegetable surface by conduction & this heat is then carried away from the vegetable surface by convection. Therefore, the combined effects of heat transfer are due to random motion of air molecules and bulk motion of the air. This removes the hot air near the vegetable surface and replaces it by cooler air as we know that the heat transfer coefficient depends on various variables that influence convection such as surface geometry, nature of fluid, i.e. air, its properties, bulk fluid velocity and flow pattern near the vegetable surface. Therefore, when all the four fans cause the air to move, the value of heat transfer coefficient is greater, leading to higher heat transfer and subsequently desired to cool off around 10^0C.

Here three different scenarios have been studied for determination of effective cooling of FACCC and based on these illustrations; it is obvious that such systems can be designed for specific vegetables on preferred storing conditions. A cumulative result of the above three illustrations of Nusselt number and convective heat transfer coefficient at different velocities of air inside the FACCC has been shown in Fig- 12 & Fig-13.

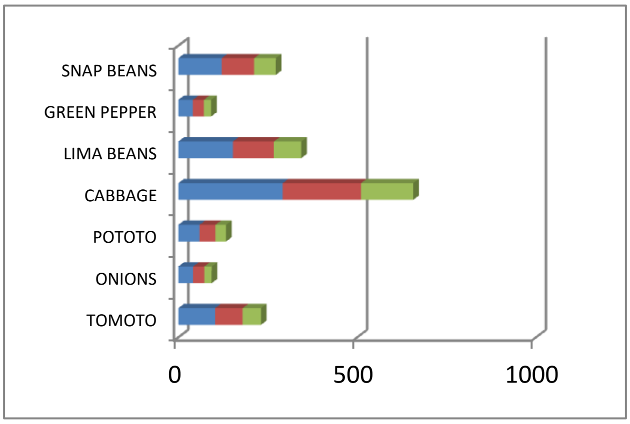

Fig -12: A cumulative result of the above three illustrations of Nusselt number at different velocities of air inside the FACCC

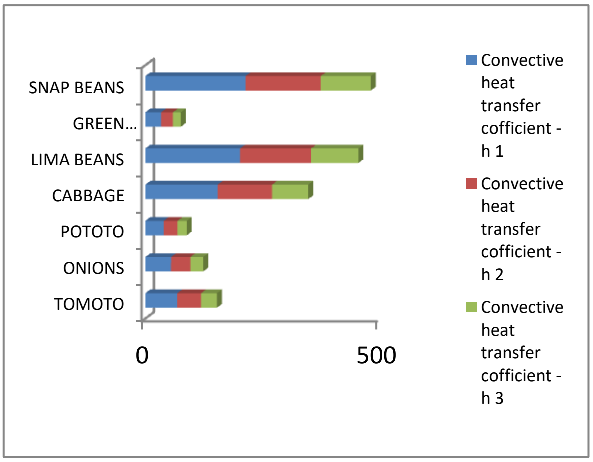

Fig -13: A cumulative result of the above three illustrations of the convective heat transfer coefficient at different velocities of air inside the FACCC

The estimated outcome of this experimental study was concluded in terms of Nusselt Number, and surface heat transfer coefficient and the same was found within prescribed limits as it shows the wayfor an extended shelf life of vegetables and reduction in temperature inside the FACCC. The information related to validation of result is collected from published literature. Ghiaus et al. [18]in their study for Mathematical modelling for fruits and vegetables suggested that the Nusselt Number varies between 40.87-50.70. Vagenas et al.

[19] analyzed in their study that Nusselt number varies between 82.94-123.19 at 60^0C and airflow rate of 2 m/s.

In the present study, Nusselt Number values vary from 57.9-115.74 and Reynolds number varies from 8725 to 17450 in FACCC with different inside air velocities, i.e. air velocity was 0.2065 m/s for two fan operation & 0.413 m/s for four fan operation at 38^0C ambient temperature.

Further, Ghiaus et al [18] suggested the surface heat transfer coefficient as 114.6 W/m^{2}K and Vagenas et al [19] suggested it as 100.9 W/m^{2}K. ASHRAE Handbook, [20] shows the range of surface heat transfer coefficient range as 10.2-66.4 W/m^{2}K for different agricultural commodity under variable air flow rate and temperature. Results of this study show that the average value of Surface heat transfer coefficient is in the range of 54.48-108.96 W/m^{2}K for the specific ambient condition in FACCC. The outcome of this paper will reduce the loss in storage, circulation & transportation of agricultural products in designing the cold chain logistics as desired by Daofang et al [21]. Extensive research work is needed to avoid huge loss of vegetables due to lack of low-cost cold chain for its storage & transportation. Therefore research on FACCC will be helpful in minimizing the circulation and operating cost of agricultural products.

The variation of the results can be justified since experimental outcomes estimated in this research work have been tested for definite geometry of FACCC with specific ambient conditions prevailing inside the FACCC. The validation of estimated results is not available in the published literature with identical ambient and process conditions. However, we can justify the outcome of our research on the basis of satisfactory end resultsobtained from the experimental setup leading to FACCC temperature drop which was observed up to 10^0C & freshness of vegetables was maintained up to 20 hours. Therefore, estimated results of FACCC can be considered acceptable as it facilitates in enhancing the shelf life of vegetables and fulfils its intended purpose of a low-cost cold chain of vegetables.

V. CONCLUSION

Free air cooling conditioning chamber (FACCC) is conceptualized in this paper for a low-cost cold chain of vegetables. The intended objective of FACCC was to maintain the freshness of vegetables for longer duration by lowering the inside temperature at a low cost. In FACCC, temperature drop was observed up to 10^0C & freshness of vegetables was maintained up to 20 hours. The thermo-physical properties of different vegetables have been studied at different Reynolds's number by varying the airflow rate inside the FACCC. It was designed for storage and transportation of vegetables at low temperature than ambient in hot countries or in hot weather. It is observed that temperature dropped up to 10^0C with the help of the airflow rate. Four fans were fitted in the FACCC, and air velocity was varied from 0.2065 m/s to 0.413 m/s. Thermo-physical parameters of Vegetables, i.e. Surface heat transfer coefficient and Nusselt number has been studied under these conditions.The flow pattern inside the FACCC was found to be turbulent. Experimental results show the average range of Nusselt number and surface heat transfer coefficient, which was evaluated as per application of Reynolds's analogy for turbulent flow:

- Nusselt number varies from 40.7-291.9, and Surface heat transfer coefficient varies from 33.5-212.8 W/m^{2}K at airflow 0.413 m/s, and Reynolds's Number is 17450 inside FACCC. This result was obtained by operating four fans inside FACCC, and it led to a temperature drop of 10^0C. Vegetable quality was found acceptable & fresh even after 16-20 hour of operation.
- Nusselt number varies from 30.5-218.9, and Surface heat transfer coefficient varies from 25.1-159.6 W/m^{2}K at airflow 0.3097 m/s, and Reynolds's Number is 13086 inside FACCC. This result was obtained by operating three fans inside FACCC, and it led to a temperature drop of 8-9^0C. Vegetable quality was found acceptable & fresh even after 14-18 hour of operation.
- Nusselt number varies from 20.3-145.9, and Surface heat transfer coefficient varies from 16.7-106.4 W/m^{2}K at airflow 0.2065 m/s, and Reynolds's Number is 8725 inside FACCC. This result was obtained by operating two fans inside FACCC, and it led to a temperature drop of 7^0C. Vegetable quality was found acceptable & fresh.
- The flow of air over vegetables inside FACCC results in a reduction of temperature and is helpful in the maintenance of a lower temperature of agro-products than atmospheric temperature & helps to improve the cold chain of vegetables.
- Surface transfer coefficient and Nusselt Number are influenced by varying airflow rate over vegetables.
- It was also observed that vegetable quality was found acceptable & fresh even after 20 hours of operation, which is a reasonable period for storage or transportation of vegetables from the agricultural field to the marketplace. It is observed that a higher rate of airflow inside FACCC resulted in a higher rate of surface heat transfer.

Based on results obtained for FACCC, the following objectives have been achieved in this paper:

- Design and development of a chamber for the cold chain of vegetables called FACCC to maintain the agro-commodities at a lower temperature than atmosphere by the use of Chillers. It may be used for storage and transportation of raw vegetables. It will be helpful to improve the cold chain of vegetablesfor maintaining its quality and freshness. The results so obtained were also validated from published literature.
- Estimation of the Surface heat transfer coefficient and Nusselt Number for vegetables at different airflow rates
- An enhanced low-cost cold chain is introduced for vegetables in hot weather conditions to reduce wastage of vegetables due to lack of proper cold chain.

FACCC seems economical for maintaining cold chain of raw agriculture commodities where wastage is high because of not maintaining the recommended temperature due to the high cost of traditional cooling methods, i.e. transportation in Air-conditioned vehicles etc. Therefore, the need for low-cost FACCC for maintaining the shelf life of vegetables was highly desirable.

It can improve the management ofvegetables storage and transportation ata lower cost after harvesting.

The experimental investigation has been performed for the use of FACCC designed for the improved cold chain of vegetables in hot countries. This study shows how FACCC can yield better result and reduces the temperature of vegetables which is one of the most important parameters as the lower temperature of vegetable leads to slow respiration rates and ripening, which prolongs the storage life of vegetables. Present analysis in this paper is limited to a particular configuration of FACCC for specific vegetables considered for the study. The variation of many other parameters such as humidity control etc. has not been included in this paper because of academic limitations of the work, though these may also influence the system performance. But to make the system cost-effective and economically feasible along with efficient use, detailed experimental work and analysis need to be carried out for FACCC. Further analysis may also include an extensive experimental trial for optimization of the FACCC performance for each type of vegetables.

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