International Journal of Science, Environment and Technology, Vol. 6, No 5, 2017, 2876 – 2884
ISSN 2278-3687 (O)
2277-663X (P)

EFFECT OF AIR VELOCITY AND MASS ON COOLING AND FREEZING TIME OF SELECTED VEGETABLES

Sanoj Kumar*, Ashok Kumar and Satish Kumar
Department of Agricultural Engineering
Bihar Agriultural college, Sabour, Bhagalpur – 813 210
E-mail: sanojk.cryo@gmail.com (**Corresponding Author*)
BAU Communication No. 304/2017

Abstract: Fast freezing arrests the deterioration of quality of food very effectively. The metabolic changes that are due to microbial, enzymatic and chemical reactions, are retarded and even eliminated if fast cooling rate is maintained and the required temperature is brought down with particular time period. This can be achieved by a high temperature gradient across the sample. Such environment results into the formation of small ice crystals in cell minimizing damage to the rupture of cell structure, migration of salt and ingredient in cellular fluid, thus improving the taste, colour, odour texture and freshness. This also lengthens the safe-storage-period of food products. The mathematical modelling of food freezing processes poses special challenges. Thermophysical properties such as specific heat and thermal conductivity change suddenly around the freezing point, leading to highly non-linear partial differential equations that are difficult to solve. In complex-shaped objects, the progress of the freezing front can be highly unpredictable. In this paper, simple regression equations have been developed for calculation of cooling and freezing time of various vegetables under home-freezer conditions. This study has been conducted on different mass sizes of suggarbeet, tomato, brinjal, potato and green peas under different air velocity conditions to develop correlations to predict the cooling and freezing time required with respects to their mass and air velocity.
Keywords: Freezing Time, Cooling Time, vegetables, air velocity, mass.

Introduction

Fruits and vegetables are perishable foods with extremely rapid deterioration; this means that their stability after harvesting and during sub-sequent storage is critical (Canet, 1989). Preservation of foods usually involves technologies that prevent microbial growth as well as retard quality degradation reactions. Among such processes, freezing is a proven and efficient method. For vegetables, freezing is widely recognized as the most satisfactory method for long-term preservation, and it is an important segment of the frozen food market.

Fresh vegetables when harvested continue to undergo chemical changes, which cause spoilage and deterioration of the product. Consumer acceptance has been poor because of loss in the quality attributes with time.

*Received Aug 20, 2017 * Published Oct 2, 2017 * www.ijset.net*

Presently there are several types of foods that are frozen by cryogenic methods, if the product is high-priced, then a little high processing cost of the food will not add appreciably to the final price of the product. Secondly, if the product has extremely high water content, the quality of the cryo-frozen product often will be superior to the conventional method because dehydration losses will be minimum. For examples, tomatoes, oranges have such a high water content that conventional freezing damages their cell structure significantly. If the food is highly perishable, then it must be frozen as quickly as possible to retain its freshness.

The freezing process involves several stages. The first stage – pre-freezing stage (a) – corresponds to the removal of heat from the food during the cooling period, when the temperature is reduced to the freezing point. This initial freezing temperature varies with product, depending on the moisture content. During this initial period sensible heat is removed from the product. The second stage – super-cooling (b) – when the temperature falls below the freezing point, is essentially transitory and not always observed. The third stage – freezing stage (c) – is the period of transformation of water into ice, throughout the whole mass of food. During this stage, the temperature remains constant in an ideal system, but in real situations falls slowly and continually while latent heat is extracted.

The transformation of water into ice is an example of crystallization. Crystallization is the formation of a systematically organized phase from a solution. The crystallization process consists of nucleation and crystal growth. Nucleation is the association of molecules into a tiny ordered particle of a size sufficient to survive and serves as a site for crystal growth.

Crystal growth is simply the enlargement of the nucleus by the orderly addition of molecules (Fennema, 1975). The last stage – sub-freezing stage (d) – is the period where the product temperature is lowered to the end temperature, which should be the intended storage temperature. In this part of the process, mostly sensible heat is removed.

Methods that have been applied to model the freezing processes can be classified into analytical, empirical and numerical techniques. The choice of technique depends on the objectives of the modellers and the technical means at their disposal. Analytical techniques produce exact results provided their underlying assumptions are fulfilled, which is rarely the case. Their main usefulness is in providing benchmark results for the verification of other methods. Empirical formulas are derived with the objective of providing quick answers, using no more than a hand calculator or spreadsheet, with accuracy (usually 10%) enough for most industrial users. They can be used only in situations similar to those used to derive and validate the formulas. Numerical methods can in principle provide exact or near-exact predictions for almost any situation, although in practice their accuracy is limited by inadequate knowledge of the problem's parameters (product properties, geometry, flow characteristics).

The freezing time is affected by the product size (particularly thickness) and shape, composition of the fruit or vegetable, and by the parameters of the heat transfer process and the temperature of the cooling medium. Many attempts have been made to mathematically model the freezing process, therefore the freezing time can be theoretically predicted from the system physical parameters (Cleland and Earle, 1984a, 1984b; Mannapperuma and Singh, 1988). From a physical point of view, foods may be considered as dilute aqueous solutions, with a freezing point below 0 ^{0}C. The freezing point depression is 1.86 ^{0}C mol$^-$1 L$^-$1, which means that the freezing point depends on the concentration of dissolved molecules in the water phase, and not only on the water content. In general, the temperature range which causes most irreversible changes is from about 1◦C to −5^{0}C. Therefore, during freezing, foods should pass this temperature range reasonably quickly (Boegh-Sorensen and Jul, 1985). Tressler and Evers (1957) suggested that the solidification, the zone of the maximum crystal formation between 0^{0}C and −3.9 ^{0}C, must be passed in less than 30 minutes.

The effective freezing time is defined as time required to lower the temperature of the product from its initial temperature to a given temperature at its thermal centre. In this study, the time necessary for the temperature to reach –12 ^{0}C at the thermal centre was taken as the "effective freezing time". While the cooling time is defined as the time required to lower the temperature of the product from its initial temperature to initial freezing point temperature at its thermal centre.

In this study, the freezing and cooling time of five vegetable samples viz sugarbeet, tomato, brinjal, potato and green peas of different mass are determined under different air flow conditions and the correlation is developed for prediction of cooling and freezing time under different air velocities and mass of vegetable products.

Materials and Methods

A lab scale experimental setup for freezing of food with provision of measuring the temperatures at thermal centre of a vegetable product and air velocity around the food was developed. The setup consists of a home-freezer with two numbers of top opening doors. The product is kept inside the freezing chamber in a tray. The pitot tube is kept in such a way that it can measure the approach velocity of air towards food product. The initial temperatures of the vegetables were varying in between 21-23.5 ^{0}C, hence for practical purpose it has been assumed constant in this paper. The setup consists of the following.

1. It has one freezing chamber
2. Air distribution system
3. Sample holder
4. Instrumentation

Air distribution system consists of 0.5 HP electric motor and fan/rotor assembly as shown in Fig. 1 and 2. The electric motor was set on the top of one of the doors of the freezer.

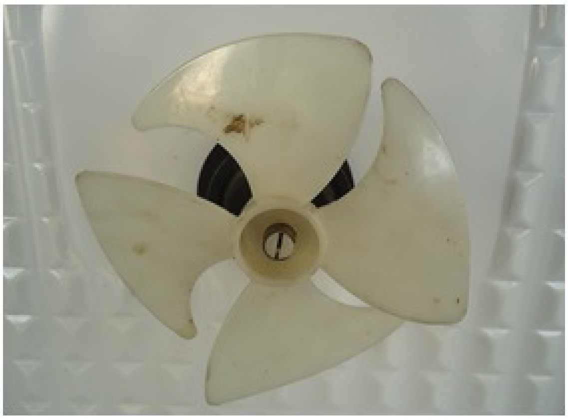

Figure1. Motor for fan assembly **Figure 2. Fan/rotor assembly**

The following sets of instrument were used for data monitoring and control of process parameters.

1. Air velocity meter
2. Temperature data logger using thermocouples as sensors
3. Mass measurement
4. Multi channel data logger for measurement of thermo-physical properties

Air velocity Measurement: To measure air velocity around the food product placed inside the chamber an anemometer using Pitot tube was used. It was calibrated using a hot wire anemometer for use in low temperature environment. The measurement ranges of this device are 1 to 40 m/s with resolution > 0.1m/s. The air velocity is shown in a digital meter, which is kept outside of freezer. The air velocity measurement unit is shown in Fig. 3.

Figure 3. Pitot tube arrangement for air velocity measurement.

Temperature measurement: Type-T thermocouple was used for the temperature measurement. The limit of errors for this thermocouple is $\pm 1^0$C in the temperature range from -200^0C to 350^0 C. The hot junctions of the thermocouple were joined by soldering and inserted inside the vegetables and placed at the thermal centre of the product. The other ends of the thermocouple was connected to the microprocessor based Temperature logger MODEL 1551C32K for monitoring temperatures at thermal center of the vegetables. The instrument is designed to accept thermocouple sensor as input. Instrument measures input signal, process it and display measured parameter on LCD display. Sixty four channels are provided to use with thermocouple sensor. The measured data of all the channels may be sent to PC for on line storage which may be captured by our DLOG-2 software or may be stored in externally connected memory module, through RS-232C link. Off line data from memory module can be downloaded to PC through our DLOG-2 software. The sensor output is processed throughout the range by lookup table to provide utmost accuracy. The unit is mains operated and portable. The unit is supplied with suitable accessories and software to display /download the data to PC through serial link. Suitable software is provided for generating Online & Logged Data, Alarm Reports. Report accessible from excel rtf or pdf format. Alarm setting and channel selection may be done from software. The temperature logger is shown in Fig. 4. The thermocouples were inserted inside the freezing chamber from a hole made at centre of the one of the top opening door as shown in Fig. 5, and the thermocouples are connected to 32-Channel temperature data logger.

Figure 4. 32-Channel data logger system for temperature measurement

Figure 5. Arrangement for inserting thermocouples and for tubes for air velocity measurement

Mass measurement: One table top series weighing scale (10 W, 230 V AC, 50 HZ) built in rear display, 12.5 mm bright red LED display, built in battery backup and protected internal calibration was used for weighing the vegetables prior to freezing/cooling, as shown in Figure 6.

All together four sets of each vegetable of different mass were cooled and frozen under four air velocity conditions inside the freezing chamber of freezer. The four air velocities selected were 0, 0.5, 1 and 2 m/s. The experimental condition is shown below in tabular form in Table 1.

Table 1. Experimental condition

Sr. No.	Vegetable	Air Velocity (m/s)	Mass (gm)
1,	sugarbeet	0	132.84
		0.5	132.80
		1	99.13
		2	133.07
2.	tomato	0	84.15
		0.5	79.82
		1	95.61
		2	85.93
3.	brinjal	0	190.20
		0.5	194.36
		1	195.37

		2	209.38
4.	potato	0	110.62
		0.5	113.96
		1	96.97
		2	131.65
5.	green peas	0	0.08
		0.5	0.10
		1	0.13
		2	0.17

Results and Discussion

The results obtained from experiments are shown in Table 2 for all the experimental conditions.

Mass (gm)	Air velocity (m/s)	Freezing Time (Min)	Cooling Time (Min)
Sugarbeet			
132.84	0	386	53
132.80	1	320	42
99.13	1.5	258	32
133.07	2	197	21
Tomato			
84.15	0	366	56
79.82	1	310	44
95.61	1.5	265	34
85.93	2	180	25
Brinjal			
190.20	0	466	58
194.36	1	401	46
195.37	1.5	347	35
209.38	2	240	24
Potato			
110.62	0	342	46
113.96	1	292	37
96.97	1.5	237	31
131.65	2	179	28
Green peas			
0.08	0	28	12
0.10	1	25	11
0.13	1.5	22	8
0.17	2	16	5

The regression equations for the prediction of freezing and cooling time (Min) were developed using MS-Excel and are shown in tabular form in Table 3.

Table 3. Regression equations developed for the prediction of freezing and cooling time (Min) for various vegetables.

Vegetable	Freezing time (Min)	Cooling Time (Min)
Sugarbeet	(0.784m-4.564)V+(0.952m-26.71)	(-0.052m-8.72)V+(0.121m+35.4)
Tomato	(-0.294m-68.62)V+(2.872m+115.7)	(-0.233m+2.87)V+(0.731m-7.218)
Brinjal	(-1.034m+77.21)V+(2.074m+67.72)	(-0.282m+36.41)V+(0.503m-40.76)
Potato	(-0.813m-3.821)V+(2.237m+96.83)	(-0.135m+4.298)V+(0.363m+4.075)
Green peas	(-21.54m-6.379)V+(110.7m+20)	$(-259.1m^2+51.52m-6.826)$ v + (52.39m + 8.467)

Where: m = mass of vegetables (gm) and V = air velocity (m/s)

Conclusion

The use of numerical methods by the food industry is still uncommon, development of accessible software for the industry is necessary. From the practical point of view simple formulae are still preferred. Any prediction method needs to be tested against experimental data, so objective testing of the accuracy of food freezing/cooling time prediction formulae requires experimental data to be of high quality. Hence, an attempt has been made to generate regression equations using experimental data to predict the cooling and freezing times of vegetables under varying air velocity condition and mass of different vegetables. From experimental results, it is quite evident that as the velocity is increased the cooling/freezing time reduces. At the same time, increasing mass of vegetable will require increased time for cooling and freezing.

References

[1] Boegh-Sorensen, L. and Jul, M. (1985). Effects of freezing/thawing on foods. In: R.K. Robinson, ed. *Microbiology of Frozen Foods.* London and New York: Elsevier Applied Science Publishers. 41–82.

[2] Canet, W. (1989). Quality and stability of frozen vegetables. In: S. Thorne, ed. *Developments in Food Preservation*,), Vol. 5. New York: Elsevier Science Publishing. 1–50.

[3] Cleland, A.C. and Earle, R.L.J. (1984a). Assessment of freezing time prediction methods. *Journal of Food Science* 49: 1034–1042.

[4] Cleland, A.C. and Earle, R.L.J. (1984b). Freezing time predictions for different final products *Journal of Food Science* 49: 1230–1232.

[5] Fennema, O. (1975). Effects of freeze-preservation on nutrients. In: Roberts S. Harris and Endel Karmas, eds. *Nutritional Evaluation of Food Processing*, 2nd edn. Westport, CT: AVI Publishing. 244–288.

[6] Mannapperuma, J.D. and Singh, R.P. (1988). Prediction of freezing and thawing times of foods using a numerical method based on enthalpy formulation. *Journal of Food Science* 53(2), 626–630.

[7] Tressler, D.K. and Evers, C.F. (1957). *The Freezing Preservation of Foods - Freezing of Fresh Foods*, Vol. I. The AVI Publishing Company, Inc. Westport, CT.