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Applications of vacuum technology in food processing

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Abstract
Vacuum is absence of matter. Importance of vacuum is to remove trapped and dissolved gases in the food packaging which prevents the reaction with food constituents, to provide working force in conveying of food grains, to decrease thermal transfer for maintaining coolness/hotness of liquids, to increase the mean free path to a useful dimension which is used in coating of equipment. Vacuum is used in many food processing applications such as packaging, filtration, conveying, cooling, freeze drying, frying, roasting, mixing, distillation, drying and evaporation.

Keywords: vacuum technology, food processing

1. Introduction
Vacuum is space devoid of matter. The word stems from the Latin adjective *vacuus* for "vacant" or "void". Vacuum is a region with a gaseous pressure much less than atmospheric pressure. Democritus (460 to 375 BC) is considered as father of vacuum. Evangelista Torricelli produced the first laboratory vacuum in 1643 and the experiment uses a simple barometer filled with mercury, then inverted on the dish full of mercury which causes the mercury in the tube to fall down until the difference between mercury on the surface and in the tube is about 760 mm. Vacuum pump was invented in 1650 by Otto Von Guericke. In the 17th century, Denis Papin carried out new research into preserving food using vacuum packaging. During 1920 in the United States, the first pieces of vacuum packed meat became available (Jousten, 2016) [9].

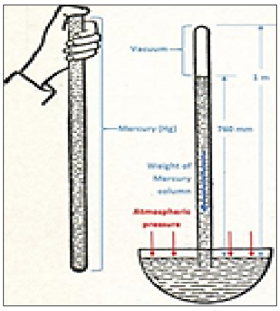

Fig 1: Torricelli laboratory Vacuum experiment

Fig 2: Vacuum pump

Table 1: Pressure ranges of each quality of vacuum in different units

Vacuum quality	Torr	Pa	Atmosphere
Atmospheric pressure	760	1.013×10^{5}	1
Low vacuum	760 to 25	1×10^{5} to 3×10^{3}	9.87×10^{-1} to 3×10^{-2}
Medium vacuum	25 to 1×10^{-3}	3×10^{3} to 1×10^{-1}	3×10^{-2} to 9.87×10^{-7}
High vacuum	1×10^{-3} to 1×10^{-9}	1×10^{-1} to 1×10^{-7}	9.87×10^{-7} to 9.87×10^{-13}
Ultra high vacuum	1×10^{-9} to 1×10^{-12}	1×10^{-7} to 1×10^{-10}	9.87×10^{-13} to 9.87×10^{-16}
Extremely high vacuum	$< 1\times10^{-12}$	$< 1\times10^{-10}$	$< 9.87\times10^{-16}$
Outer space	1×10^{-6} to $< 1\times10^{-17}$	1×10^{-4} to $< 3\times10^{-15}$	9.87×10^{-10} to $< 2.96\times10^{-20}$
Perfect vacuum	0	0	0

2. Importance of vacuum

2.1 To remove trapped and dissolved gases

Vacuum is used remove both trapped and dissolved gases. In the food packaging vacuum removes trapped gases which prevent the reaction with food constituents. Dissolved gases can be removed from water with boiling at low pressures.

2.1 To provide working force

Vacuum is used to provide working force in conveying of food grains, powders and liquids. Here the pressure difference in the conveyor is used as working force.

2.2 To decrease thermal transfer

Vacuum is used to decrease thermal transfer from inside of container to outside environment by convection process. Vacuum is created in the dewar flask to store cryogenic liquids such as LN2 which is having boiling point of -196 °C.

2.3 To increase the mean free path to a useful dimension

The mean free path increases in vacuum because under vacuum conditions each molecule moves longer distance to collide with another molecule. It is used in the inside coating of food equipment such as distillation systems (www.vacaero.com).

3. Applications of vacuum technology

3.1 Vacuum packaging

Vacuum packing is a method of packaging that removes air from the package prior to sealing. This method involves (manually or automatically) placing items in a plastic film package, removing air from inside, and sealing the package. The aim of vacuum packaging is to extend the shelf-life of foods with flexible package forms to reduce the volume of the contents and package. This gets rid of oxygen which affects food in various ways including odour, colour, taste & texture and allows for longer storage. Frozen food that is vacuum sealed lasts an average of 2-3 years, while it will last 6-12 months on average stored in other ways. Most vacuum sealed foods will last in the refrigerator for 1-2 weeks, which is much longer than the typical 1-3 days food will last when stored conventionally in a refrigerator (Meena *et al.*, 2017) [11]. The shelf life of papaya fruits increased under vacuum packing with room and refrigeration temperatures for one and four weeks, respectively (Padmanaban *et al.*, 2011) [15]. Vacuum packaging was a supplement to ice storage or refrigeration to delay spoilage, extend the shelf life, a high quality, assure the safety and reduce the economic loss of fish and fishery products. It offers an excellent protection against rancidity and also decreases the growth of aerobic spoilage microorganisms (Patil *et al.*, 2020) [16].

3.2 Vacuum filtration

Vacuum filtration is a procedure in which a pressure differential is maintained across the filter medium by evacuating the air below the filter paper. Vacuum filtration provides a force on the solution in addition to that of gravity and increases the rate of filtration. The liquid to be filtered is sent to the tub below the drum. The drum rotates through the liquid and the vacuum sucks liquid and solids onto the drum pre-coat surface, the liquid portion is "sucked" by the vacuum through the filter media to the internal portion of the drum, and the filtrate pumped away. The solids adhere to the outside of the drum, which then passes a knife, cutting off the solids. It provides filtration at the rate of 2000 liters/h with vacuum pressure of 70 kPa. The cycle time for the drum is 60 s and cake formation time is 15 s. It removes cake solids (dry basis) per volume of filtrate is 10 g/liter with slurry viscosity of 2.0 Cp (Sivakumar *et al.*, 2011) [18].

3.3 Vacuum conveying

Vacuum conveying is the process of moving bulk dry materials, such as powders, from one place to another place using suction. The material is transferred in a network of tubing from the pickup point or source to the required place. Most vacuum conveying systems transfer the product based on a timed interval to the vacuum receiver. At the end of timed sequence, the discharge valve will open and the material conveyed can discharge in to the process. A typical low-pressure conveying system using a rotary air lock feeder will use a high pick-up velocity of around 2, 500 fpm at the beginning of the system, and about 6, 000 fpm at the end. The conveying line pressure is under 15 psig at the beginning and near atmospheric pressure at the end.

3.4 Vacuum cooling

Vacuum cooling system consists of an airtight chamber which is maintained by removing air from the inside of the chamber using a vacuum pump. The products to be cooled are kept in that airtight chamber. As the pressure is reduced the boiling point of water reduces and water starts to evaporate, taking the heat from the product. This rapid evaporation of moisture from the surface and within the products due to the low surrounding pressure, absorbs the necessary latent heat for phase change from the product itself. This latent heat required for evaporation is obtained mostly from the sensible heat of the product and as a consequence of this evaporation the temperature of the product falls and the product can be cooled down to its desired storage temperature. The vacuum cooling is an excellent way to cool products such as leafy vegetables and mushrooms. Vacuum Pump creates Vacuum Pressure of about 0.01 bar inside the water container. In vacuum cooling systems temperature reduced up to 4 °C. Vacuum cooling ensures rapid cooling down of produce normally within 15-30 minutes (Sun and Zheng, 2005) [19]. The beneficial effect of vacuum cooling and packaging in prolonging shelf life and reducing weight loss of lettuce has been extensively reported (Donald and Sun, 2000) [6]. Use of a modulated vacuum cooler (MVC) allows rapid cooling of bakery products without adverse effects on volume and texture (Bradshaw, 1976) [4]. The major disadvantage of vacuum cooling is the loss of weight due to moisture removal. Weight loss is an inevitable consequence of the vacuum cooling related to temperature reduction (Barger, 1961) [3].

3.5 Vacuum freeze drying

Vacuum freeze drying is a process by which a solvent (usually water) is removed from a frozen foodstuff or a frozen solution by sublimation of the solvent and by desorption of the sorbed solvent (non-frozen solvent) generally under reduced pressure i.e., at temperature of 0 °C and 4.7 mm of Hg pressure.

The freeze drying separation process involves the following three stages:

a. Freezing stage
b. Primary drying stage
c. Secondary drying stage

a. Freezing stage
The objective of the freezing stage is to freeze most of the water originally present in the product for its posterior sublimation. The freezing stage represents the first separation step in the freeze drying process, and the performance of the overall freeze drying process depends significantly on this stage.

b. Primary drying stage
In primary drying stage, the product is placed in the chamber where pressure is reduced to a value that would allow the sublimation of solvent (water). The water vapor produced by the sublimation of the frozen water in the frozen layer and by the desorption of sorbed (non frozen) water in the dried layer during the primary drying stage travels by diffusion and convective flow through the porous structure of the dried layer and enters the drying chamber of the freeze dryer. Most of the water removed during the primary drying stage is produced by sublimation of the frozen water in the frozen layer. The time at which there is no more frozen layer is taken to represent the end of the primary drying stage.

c. Secondary drying stage
The secondary drying stage involves the removal of water that did not freeze (sorbed or bound water). The bound water is removed by heating the product under vacuum, the heat is supplied to the product usually by conduction, convection, or radiation.
The following product temperatures are usually employed:
(a) Between 10 and 35 °C for heat sensitive products
(b) 50 °C or more for less-heat-sensitive products

The residual moisture content in the dried material at the end of the secondary drying stage, as well as the temperature at which the dried material is kept in storage, are critical factors in determining product stability during its storage life (www.ift.org).
Nindo *et al*., 2003 [14] reported that the drying of sliced asparagus using freeze drying and other drying methods including tray dryer, refractance window dryer, and spouted bed dryer. The highest amount of ascorbic acid was retained when samples were dehydrated by freeze drying and refractive window drying. Freeze drying preserved total phenolics in marionberries, strawberries, and corn better than air drying (Asami *et al*., 2003) [2]. Hawlader *et al*., 2006 [8] compared quality of guava obtained by heat pump dryers (RH = 10%, v = 0.7 m/s, T = 45 °C, 8 h), vacuum (vacuum pressure = 15, 000 Pa, T = 45 °C, 8 h), and freeze-dryers (freezing at −20 °C for 24 h, and less than 613.2 Pa vacuum pressure, 10 °C shelf temperature, 24 h for freeze-drying). Porosity, color, rehydration, and vitamin C retention of guava produced by freeze drying were better, resulting in freeze dried guava being the most desirable powder compared to that produced by vacuum and heat pump dryers. Freeze drying was able to retain 63% vitamin C, whereas heat pump dryer retained only 25%.

3.6 Vacuum frying
Vacuum frying is a frying process that is carried out at pressures well below atmospheric level. Vacuum frying offers an alternative way to improve the quality of fried fruit and vegetables other than by atmospheric frying. Vacuum frying system consists of three components, namely: a) Vacuum frying chamber, b) Refrigerated condenser and c) Vacuum pump. The vacuum frying chamber is an air tight vessel provided with an oil heater and a frying basket. The frying basket is raised and lowered into the heated oil by a lift rod. The lift rod is usually connected to a spinner motor that is used for centrifuging the product after frying to get rid of surface oil. The refrigerated condenser is provided to trap the evolved steam during frying by condensing it on a cold surface. The use of a refrigerated condenser is recommended for better efficiency compared with water-cooled condensers. The vacuum pump provides the required low pressures for the process and get rid of non-condensable gases.
The vacuum frying process required the heating of oil to the required temperature. Then the sample to be processed is placed in the basket inside the frying chamber but suspended above the hot oil. The pressure inside the vacuum frying chamber is reduced to the required pressure. The sample is then lowered into the hot oil for the required duration and then the basket is raised above the oil and then centrifuged within the chamber for the required speed and time. The fried product can also be taken out of the chamber and centrifuged using a separate machine or stood in the frying chamber to drain the surface oil. The product is then placed on absorbent paper, cooled and packed in an aluminium laminate bag with or without nitrogen flushing. The operating pressures should be lower than 7 kPa, which caused a great reduction in the boiling point of water, allowing frying to be carried out at temperatures even lower than 90 °C. The fried product can be centrifuged within the drying chamber at speeds up to 750 rpm (Diamante *et al*., 2015) [5].
Vacuum fried products contains lesser oil content, but this is not only the single health benefit of vacuum fried products. Lower operating temperature during vacuum frying, reduce 94% of acrylamide formation in potato chips. Acrylamide is recognised as a potential carcinogenic compound found in fried snacks, which is formed by the Maillard reaction (Granda, 2004; Shyu and Hwang, 2001; Moreira, 2014) [7, 12, 17].

3.7 Vacuum drying
It is a drying method that places the object to be dried in an enclosed container to vent air and reduce the pressure with a vacuum pump in order to artificially increase the water vapour partial pressure difference. Vacuum drying is the mass transfer operation in which the moisture present in a substance, usually a wet solid, is removed by means of creating a vacuum. Vacuum drying is generally used for the drying of substances which are hygroscopic and heat sensitive, and is based on the principle of creating a vacuum to decrease the chamber pressure below the vapour pressure of the water, causing it to boil. With the help of vacuum pumps, the pressure is reduced around the substance to be dried. This decreases the boiling point of water inside that product and thereby increases the rate of evaporation significantly. The result is a significantly increased drying rate of the product.
The pressure maintained in vacuum drying is generally 0.03–0.06 atm and the boiling point of water is 25-30 °C. The vacuum drying method dries an object with a temperature of 25 °C three times faster comparing to drying with warm air of 30 °C and humidity of 50%. This method requires some type of heating in order to prevent the temperature drop of the drying object accompanying evaporation of moisture.
In order to prevent the temperature drop of drying object, the following conditions must takes place:

1. Raising the temperature prior to placing an object in a container.
2. Heating the entire container to warm the drying object with radiant heat.
3. Heating the drying object with conduction heat from a heater plate in the container.

The vacuum drying forces the pressure in the narrow gaps and in the tubes to decrease, which enables the moisture in the gaps to evaporate faster. In addition, moisture trapped in the narrow gaps by a bumping phenomenon could blow out, unless the temperature inside the drying object drops excessively, which further expedites drying. Therefore, using a pump with a volume sufficient for venting evaporated moisture for vacuum drying enables any porous or even powder like object to be dried thoroughly even from the inside uniformly (Maisnam *et al*., 2017) [10]. Microstructure of food materials dried by vacuum-drying is generally identified as having a higher porosity (compared to that of a material dried by hot air), resulting in less shrinkage and having higher rehydration and reconstitution capabilities (Ngamwonglumlert and Devahastin, 2018) [13].

3.8 Vacuum evaporation

Vacuum evaporation is the process of causing the pressure in a liquid-filled container to be reduced below the vapour pressure of the liquid, causing the liquid to evaporate at a lower temperature than normal. Although the process can be applied to any type of liquid at any vapour pressure. The vacuum evaporation treatment process consists of reducing the interior pressure of the evaporation chamber below atmospheric pressure. This reduces the boiling point of the liquid to be evaporated, thereby reducing the need for heat in the boiling process.

When the process is applied to food and the water is evaporated and removed, the food can be stored for long periods of time without spoiling. It is also used when boiling a substance at normal temperatures would chemically change the consistency of the product, such as egg whites coagulating when attempting to dehydrate the albumen into a powder. This process is used industrially to make such food products as evaporated milk for milk chocolate, and tomato paste for ketc.hup.

At 28.92 inches of Hg, water can boil at 26.67 °C. In the sugar industry vacuum evaporation is used in the crystallization of sucrose solutions. Traditionally, this process was performed in batch mode, but nowadays continuous vacuum pans are available (www.nzifst.org.nz).

3.9 Vacuum distillation

Vacuum distillation is a method of distillation performed under reduced pressure. As with distillation, this technique separates compounds based on differences in boiling points. This technique is used when the boiling point of the desired compound is difficult to achieve or will cause the compound to decompose. This distillation method works on the principle that boiling occurs when the vapor pressure of a liquid exceeds the ambient pressure. A reduced pressure decreases the boiling point of compounds then separation of compounds takes place at lower temperatures than usual.

Vacuum distillation is used with or without heating the solution.Vacuum distillation allows for purification technique to be used on compounds with high boiling points, or those which are air-sensitive. Temperature sensitive materials (such as beta carotene) require vacuum distillation to remove solvents from the mixture without damaging the product. Compounds with a boiling point lower than 150 ˚C can typically be distilled without reduced pressure. The apparatus for vacuum distillation can be filled with the inert atmosphere when the distillation is complete (www.omicsonline.org).

Vacuum distillation is sometimes referred to as low temperature distillation. This type of distillation is in use in the oil industry. The absolute pressure of 10 to 40 mmHg is maintained in the vacuum column is most often achieved by using multiple stages of steam jet ejectors, so as to limit the operating temperature to less than 370 to 380 °C.

3.9 Vacuum roasting

It is the process of roasting under the vacuum. Vacuum roasting system consisting of an oven equipped with heated plates for optimal heat transfer under vacuum conditions, and connected to a vacuum pump. Roasting is carried out for increasing lengths of time at atmospheric pressure (hereafter called conventional roasting), for 10 min followed by vacuum treatment (i.e. 0.15 kPa; hereafter called vacuum roasting). In vacuum roaster temperature reaches about 200 °C (Anese *et al*., 2014) [1].

3.10 Vacuum mixing

It is the process of mixing under vacuum conditions. Mixers equipped with a vacuum pump able to lower the mixing pressure from 1, 013 to 50 mbar are an interesting way to improve the performance by lowering the air content.

4. References

1. Anese M, Nicoli MC, Verardo G, Munari M, Mirolo G, Bortolomeazzi R. Effect of vacuum roasting on acrylamide formation and reduction in coffee beans. Journal of Food Chemistry 2014;145(2):168-172.
2. Asami DK, Hong YJ, Barrett DM, Mitchell AE. Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry and corn grown using conventional, organic and sustainable agricultural practices. Journal of Agricultural and Food Chemistry 2003;51:1237–1241.
3. Barger WR. Factors affecting temperature reduction and weight-loss in vacuum cooled lettuce. Marketing Research Report No. 469, United States, Department of Agriculture 1961, 5-20.
4. Bradshaw W. Modulated vacuum cooling for bakery products. Bakers Digest 1976;50:26-31.
5. Diamante LM, Shi S, Hellmann A, Busch J. Vacuum frying foods: products, process and optimization. International Food Research Journal 2015;22(1):15-22.
6. Donald KM, Sun DW. Vacuum cooling technology for the food processing industry: a review. Journal of Food Engineering 2000;45:55-65.
7. Granda C. Reduction of acrylamide formation in potato chips by low-temperature vacuum frying". Journal of Food Science 2004;69:405-411.
8. Hawlader MNA, Perera CO, Tian M, Yeo KL. Drying of guava and papaya: Impact of different drying methods. Drying Technology 2006;24:77–87.
9. Jousten K. Handbook of Vacuum Technology. Wiley-VCH 2016, 22-38.
10. Maisnam D, Rasane P, Dey A, Kaur S, Sarma C. Recent advances in conventional drying of foods. Journal of Food Technology and Preservation 2017;1(1):22-23.

11. Meena MK, Chetti MB, Nawalagatti CM, Naik MC. Vacuum packaging technology: a novel approach for extending the storability and quality of agricultural produce. Journal of Advances in Plants & Agriculture Research 2017;7(1):221-225.
12. Moreira RG. Vacuum frying versus conventional frying-An overview. European Journal of Lipid Science and Technology 2014;116:723-734.
13. Ngamwonglumlert L, Devahastin S. Microstructure and its relationship with quality and storage stability of dried foods. Food Microstructure and Its Relationship with Quality and Stability 2018, 139-159. doi:10.1016/B978-0-08-100764-8.00008-3.
14. Nindo C, Sun T, Wang S, Tang J, Powers J. Evaluation of drying technologies for retention of physical quality and antioxidants in asparagus (*Asparagus officinalis*, L.). LWT 2003;36:507–516.
15. Padmanaban G, Singaravelu K, Annavi ST. Increasing the shelf-life of papaya through vacuum packing. Journal of Food Science and Technology 2011;51(1):163-167.
16. Patil AR, Chogale AD, Pagarkar AU, Koli JM, Bhosale BP, Sharangdhar ST *et al*. Journal of Experimental Zoology India 2020;23(1):807-810.
17. Shyu S, Hwang S. Effects of processing conditions on the quality of vacuum fried apple chips". Food Research International 2001;34:133-142.
18. Sivakumar T, Vijayaraghavan G, Vimal Kumar A. Enhancing the performance of rotary vacuum drum filter. International Journal of Advanced Engineering Technology 2011;2(4):41-47.
19. Sun DW, Zheng L. Vacuum cooling technology for the agri-food industry: Past, present and future. Journal of Food Engineering 2005;77(2):203-214.
20. www.ift.org
21. www.nzifst.org.nz
22. www.vacaero.com
23. www.omicsonline.org