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Investigation of the parameters governing the performance of jet impingement quick food freezing and cooling systems – a review

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Abstract

Jet Impingement Technology (JIT) is a heat transfer enhancement technique. Available literature soundly confirm its wide applications in the cooling of combustion chambers, critical parts of turbines, glass technology, electronic components, drying of paper and textile materials, drying of biomaterials and food preservation. The technology has interesting fluid dynamics and heat transfer properties. Its relative simplicity and low cost, abundance of air, generation of high heat transfer and faster freezing rates have made it a subject of extensive investigations. Several investigations on jet impingement quick food freezing and cooling systems which range from visualization, experimental, computational simulations and or numerical analysis, factorial and mathematical models have been studied. This paper reviews the governing parameters of the jet impingement quick food freezing and cooling systems.

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1. Introduction

The early 1990s earmarked the introduction and engineering of the impingement freezer technology to the marketplace by Frigoscandia Equipment for a wide variety of thin food products [1]. From the report, this came as a result of continued research by food processors to develop technologies that could freeze food products faster for a

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number of benefits. The benefits included keeping pace with newer high-speed formers and other high-speed production line equipment upgrades, providing better economic yields as a result of reduced freezing cost, and preserving the quality of the food products. Impingement freezing utilizes high velocity air jets that are directed perpendicular to the surface of the food [2]. High velocity air jets are reported to reduce thermal barriers surrounding the food product surface [3], increasing convective heat transfer coefficients and allowing for faster freezing of the food product sealing it in its freshness [4]. The time it takes to freeze food is a very important factor in the preservation of food [5, 6]. The main appeal of this technology is to increase the rate of heat transfer so as to reduce the freezing time of food as quickly as possible to maintain its safety and quality. Faster freezing is reported to result in smaller ice crystals which result in reduced cellular damage of the food products which will then be juicier, have better texture and exhibit less dehydration (drip loss) when thawed. The technology is widely used for preservation of sandwich egg patties, thin bakery products, chewing gums, sticky cookie dough, confectionery products, fish fillets, shrimp, potato products, meat patties, poultry parts and fillets. The system is said to be governed by many parameters which include, freezing air temperature and velocity [7], nozzle to food spacing or distance from the stagnation point, geometry of food slab, its dimensions, food product water content; specific heat for unfrozen and frozen food, thermal conductivity, food density and its initial and final target temperature, latent heat of fusion, conductivity of packing material, convective heat transfer coefficient [8, 9], Reynolds number [10, 11, 12], design of the injections, orientation of the impinging air to the target surface [13], type, size and shape of nozzles [14,15,16]. The current paper reviews these parameters and their effects on the performance of jet impingement quick food freezing systems.

Nomenclature

A	round jet area (m^2)
D	nozzle diameter or width (m)
h	convective heat transfer coefficient (W/m^2 K)
Nu	Nusselt number
H	nozzle-slab distance (m)
V	air jet velocity (m/s)
Re	Reynolds number
S	slot nozzle area (m^2)
R	radial distance (m)
L	nozzle length (m)
H/D	nozzle-plate distance to jet diameter ratio
L/D	nozzle length to jet diameter ratio

2. Jet impingement quick food freezing or cooling parameters

The impinging jet flow patterns can be categorised into three characteristic regions namely, the free jet region, impingement or stagnation flow region and wall jet region [7]. The free jet region was further classified into three sub-regions namely, the potential core region, developing flow region, and developed flow region. Maximum heat transfer between the flow and the surface was reported to be experienced in the stagnation region. The slowest cooling zones (SCZs) are found to lie off-centre in the wall jet region. Figure 1 shows the schematic diagram of a typical flow structure of an impinging jet on an object surface. Impingement process produces high but also spatially variable convective heat transfer coefficients due to the variations of flow patterns in the jet impingement regions [6]. Variation of heat transfer on the food surface is a point of interest when using air impingement freezing or cooling systems. This was reported to cause undesirable variations in certain quality attributes on the food product as a result of localized hot and cold spots on the food product surface. This has been a useful indication for the need to optimize impingement system heat transfer on the entire food surface, a subject that has brought extensive studies of the parameters that govern the performance of impingement quick food freezing or cooling systems. A review of some of the studies conducted on impingement food freezing or cooling parameters is presented in this section.