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TITLE

SLURRY ICE BASED FOOD CHILLING APPLICATIONS

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Synopsis

Environmental concerns over the ozone depletion potential of some CFCs used today have prompted a search for alternative cooling technologies. A number of Dynamic and Static ice production methods have been developed for various applications.

Slurry ice technology is the latest addition to other existing ice production techniques and it has the potential to achieve considerable environmental as well as economic benefits for both central cooling systems and direct ice production for ever expanding ice applications. Any conventional primary refrigerants can be used for slurry ice production.

The cooling capacity of slurry ice can be four to six times higher than that of conventional chilled water, depending on the ice fraction. The nature of the Binary (Crystal) ice formation allows end users to pump the ice and there are many slurry ice-based cooling systems operating around the world. Most air conditioning installations are based on ice storage, where the warm return water is used to melt the ice when required. Slurry ice is also circulated in close loop distribution systems directly for process and product chilling applications.

This paper investigates the advantages and disadvantages of using slurry ice food chilling applications. The most important physical properties and characteristics for Food Grade pumpable ice solution are presented in a form that will help food engineers and consultants to develop effective and efficient Slurry-Ice based Food Chilling system designs.

Keywords;

CFC - Chloro Fluoro Carbon, (TES) Thermal Energy Storage, Slurry-ICE, Binary-ICE, Liquid-ICE, FoodICE

1.0 - INTRODUCTION

Society's reliance on food cooling technology ranges from domestic refrigerators, to full production of all types of fresh and frozen food production. As a result, modern refrigeration technologies together with a wide range in food processing and preservation infrastructures have evolved around wide spread usage of refrigeration.

Direct or indirect ice usage has also expanded over the years to reduce operational costs and improve food quality and therefore many type of Dynamic and Static ice production methods have been developed for various food chilling applications.

It is vital to establish a balance between ***"energy consumption"*** and ***"environment protection***" and therefore any change in refrigeration technology by means of introducing new refrigerants or by adopting new techniques must be carefully balanced to reduce the overall environmental impact.

Environmental concerns over the ozone depletion potential of some CFCs used today have prompted a search for alternative cooling technologies. Slurry ice technology is the latest addition to other existing ice production techniques and it has the potential to achieve considerable environmental as well as economic benefits for direct ice production forever expanding ice applications.

Any conventional primary including natural refrigerants can be used for slurry ice production. The cooling capacity of slurry ice can be four to six times higher than that of conventional chilled water, depending on the ice fraction.

There are many slurry ice-based cooling systems operating around the world and most air conditioning installations are based on ice storage, where the warm return water is used to melt the ice. Slurry ice is also circulated in close loop distribution systems directly for process, district and product cooling applications.

2.0 CURRENT ICE PRODUCTION TECHNOLOGIES

Ice production techniques can be divided into two main groups [(1)] namely ***Dynamic*** and ***Static*** systems, Table 2.1, and the produced ice can be used either ***directly*** to chill the product such as fish, vegetables, meat, poultry etc. or indirectly as secondary coolant for the latent heat cooling effect such as ice storage TES systems for air conditioning and process cooling as a secondary cooling medium.

STATIC ICE PRODUCTION	DYNAMIC ICE PRODUCTION
1 - Ice Builders **2 - Ice Banks** **3 - Encapsulated Ice Modules** **a) Balls** **b) Flat Containers**	**1 - Plate Harvester** **2 - Tube Harvester** **3 - Flake Ice Machines** **4 - Binary Ice Machines**

Table 2. 1 - Current Ice Production Technology

3 - SLURRY ICE TECHNOLOGY

Slurry-ICE is a suspension of a crystallised water-based ice solution and the icy slurry can be pumped, hence, it is also called ***"Binary-ICE", " Liquid-ICE"*** or ***"Pumpable-ICE"*** [(2)]**.** The handling characteristics, as well as the cooling capacities can be matched to suit any application by means of simply adjusting the percentage of ice concentration.

Slurry-Ice comprises microscopic ice crystals giving a total surface area for heat exchanging that is very large in comparison with the conventional ice chilling concept and therefore ice instantly melts to meet the varying product cooling load. This ensures steady and accurate product final temperature control [(3)].

3.2 SLURRY ICE APPLICATIONS FOR FOOD PROCESSING

The important benefit of slurry ice is the " ***rapid cooling capacity"*** compared with air blast and conventional ice / chilled water cooling systems. Hence, it offers significantly reduced cooling times [(4)]. Slurry-ICE systems not only offer superior cooling performance and a significant installation cost reduction but the food chilling operating costs can also be reduced due to increased production rates for a given food processing application.

Sea water or alternatively brine solutions are the most commonly used SlurryICE production techniques within the sea food industry [(5)] but they can not be applied for other food chilling applications due to undesirable taste and visual impacts. Hence, the majority of Binary ice applications remain in sea food application with the exception of the poultry and meat industry which is utilised by means of relatively expensive harvester tank arrangements to reduce the salt concentration.

The main criteria for a pumpable food ice application are taste and visual impact of the final product. Hence, the solution MUST not affect taste or appearance. Even a low salt concentration may spoil the food product and when the product is dried some salt based solution leave an undesirable white residue.

Further to extensive research of the commonly used food additives, author has identified a number of potential freeze depressants for pumpable ice production which can be used on food products and a general list of these additives can be found in Table 1. However, further research had to be carried out to establish ideal combinations of these chemicals to form a physically and thermodynamically acceptable SlurryICE solution from the available ice slurry production machinery and their officially acceptable limits as a food additive for the food production point of views.

The main criteria for NO TASTE and NO VISUAL IMPACT remained the main target for this search and following various combination of these fluids, author managed to test and produce satisfactory freeze depressant combination out of the enclosed list to satisfy all the criteria mentioned above.

NUMBER	CHEMICAL NAME	NUMBER	CHEMICAL NAME
E100	Curcumin	E367	Calcium fumarate
E101	Riboflavin (vitamin B2)	E370	1,4-Heptonolactone
E102	Tartrazine	E375	Niacin
E104	Quinoline Yellow	E380	Tri-ammonium citrate
E107	Yellow 2G	E381	Ammonium ferric citrates
		E385	Calcium disodium EDTA
E110	Sunset yellow FCF	E400	Alginic acid
E120	Cochineal, carminic acid	E401	Sodium alginate
E122	Carmoisine	E402	Potassium alginate
E123	Amaranth	E403	Ammonium alginate
E124	Brilliant scarlet 4R	E404	Calcium alginate
E127	Erythrosine	E405	Propylene glycol alginate
		E406	Agar
E128	Red 2G	E407	Carrageenan
E129	Allura red AC	E410	Locust bean gum
E131	Patent blue	E412	Guar gum
E132	Indigo carmine	E413	Tragacanth
E133	Brilliant blue FCF	E414	Acacia
E140	Chlorophyll	E415	Xanthan gum
E141	Copper complexes of chlorophyll and chlorophyllins	E416	Karaya gum
E142	Green S	E420	Sorbitol
E150	Caramel	E421	Mannitol
		E422	Glycerin
E151	Brilliant black BN	E432	Polysorbate 20
E153	Vegetable carbon	E433	Polysorbate 80
E154	Brown FK	E434	Polysorbate 40
E155	Chocolate brown HT	E435	Polysorbate 60
E160 (a)	Carotene - ?, ?, ?	E436	Polysorbate 65
E160 (b)	Annatto (bixin, norbixin)	E440 (a)	Pectin
E160 (c)	Capsanthin	E440 (b)	Amidated pectin
E160 (d)	Lycopene	E441	Gelatine
E160 (e)	Beta-apo-8'-carotenal	E442	Ammonium phosphatides
E160 (f)	Ethyl ester of beta-apo-8'-carotenic acid	E450	Sodium and potassium polyphosphates
E161	Xanthophylls	E460	Powdered cellulose
E161 (g)	Canthaxanthin	E461	Methylcellulose
E162	Beet red, betanin	E463	Hydroxypropyl-cellulose
E163	Anthocyanins	E464	Hydroxypropyl-methylcellulose
E170	Calcium carbonate	E465	Methylethylcellulose
E171	Titanium dioxide	E466	Sodium carboxymethyl-cellulose
E172	Iron oxides	E469	Sodium caseinate
E173	Aluminium	E470	salts of fatty acids
E174	Silver	E471	Mono- and diglycerides of fatty acids
E175	Gold	E472	fatty acid esters of glycerol
E180	Pigment rubine	E473	Sucrose esters of fatty acids
E181	Tannic acid, tannins	E474	Sucroglycerides
E200	Sorbic acid	E475	Polyglycerol esters of fatty acids
E201	Sodium sorbate	E476	Polyglycerol polyricinoleate
E202	Potassium sorbate	E477	Propylene glycol esters of fatty acids
E203	Calcium sorbate	E480	Dioctyl sodium sulphosuccinate
E210	Benzoic acid	E481	Sodium stearoyl-2-lactylate
E211	Sodium benzoate	E482	Calcium stearoyl-2-lactylate
E212	Potassium benzoate	E483	Stearyl tartrate
		E491	Sorbitan monostearate
E213	Calcium benzoate	E492	Sorbitan tristearate
E214	Ethyl 4-hydroxybenzoate	E493	Sorbitan monolaurate
E215	Ethyl4-hydroxybenzoate sodium salt	E494	Sorbitan mono-oleate
E216	Propyl paraben	E495	Sorbitan monopalmitate
E217	Propyl 4-hydroxybenzoate	E500	Sodium carbonates
E218	Methyl paraben	E501	Potassium carbonates
E219	Methyl 4-hydroxybenzoate	E503	Ammonium carbonates
E220	Sulphur dioxides	E504	Magnesium carbonate
E221	Sodium sulphite	E507	Hydrochloric acid
E222	Sodium bisulphite	E508	Potassium chloride
E223	Sodium metabisulphite	E509	Calcium chloride
E224	Potassium metabisulphite	E510	Ammonium chloride
E225	Potassium sulphite	E511	Magnesium chloride
E226	Calcium sulphite	E513	Sulphuric acid
E227	Calcium hydrogen sulphite	E514	Sodium sulphate
E228	Potassium bisulphite	E515	Potassium sulphate
E230	Biphenyl	E516	Calcium sulphate
E231	2-hydroxy biphenyl	E518	Magnesium sulphate

Table 1 – Food Additives for SlurryICE Applications

However, freeze depressants can be considered as the first hurdle towards the conquest of a satisfactory pumpable ice solution for food application. Majority of these chemicals causes excessive corrosion problems and the low concentration levels for food application expose the solution to bacterial growth. Hence, it is vital to provide satisfactory Corrosion Inhibitor and Biocide combinations to pass strict food hygiene regulations. Some of the commonly used corrosion inhibitors and biocides are not acceptable for food production or they may cause operational problems for the ice production machine as well as the quality of the pumpable ice solution.

Following extensive tests, an acceptable combination of ***FREEZE DEPRESSENT***, ***CORROSION INHIBITOR*** and ***BIOCIDE*** mixture has been established to satisfy all the criteria set above. For simplicity, this solution is referred to as FoodICE solution as part of this paper and the thermodynamic and physical properties are included in Table 2.

Temp deg C	Density kg/m^3	Kinematic Viscosity mm^2/s	Dynamic Viscosity mPas	Specific Heat kJ/kg K	Thermal Conductivity W/m K
30	1031	0.84	0.87	3.977	0.612
25	1032	0.93	0.96	3.969	0.604
20	1033	1.05	1.08	3.960	0.595
15	1034	1.18	1.22	3.951	0.586
10	1035	1.36	1.40	3.942	0.577
5	1036	1.57	1.63	3.933	0.567
0	1037	1.81	1.88	3.924	0.559
-1.5	1037.3	1.91	1.98	3.921	0.556

Table 2 – FoodICE Physical Properties

Majority of the food chilling applications remains above –2 °C, which is considered to be the limit before frost damage. The above solution is used for food chilling testing for various types of food chilling applications and the relevant cooling curves can be seen in Figure 3.2.1, Figure 3.2.2 and Figure 3.2.3 for meat, vegetable and fruit cooling applications respectively.

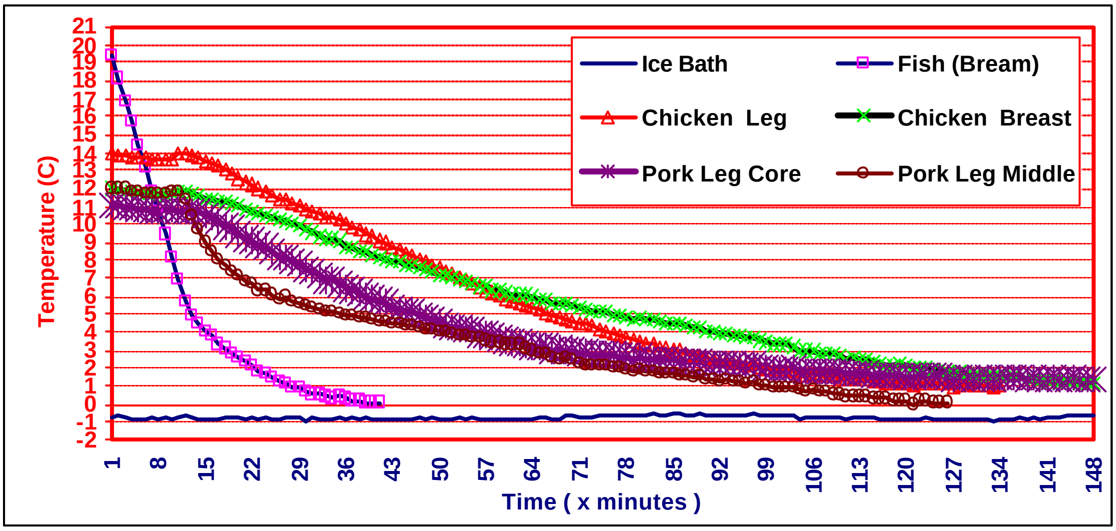

Figure 3.2.1 – Meat Cooling Test using FoodICE solution.

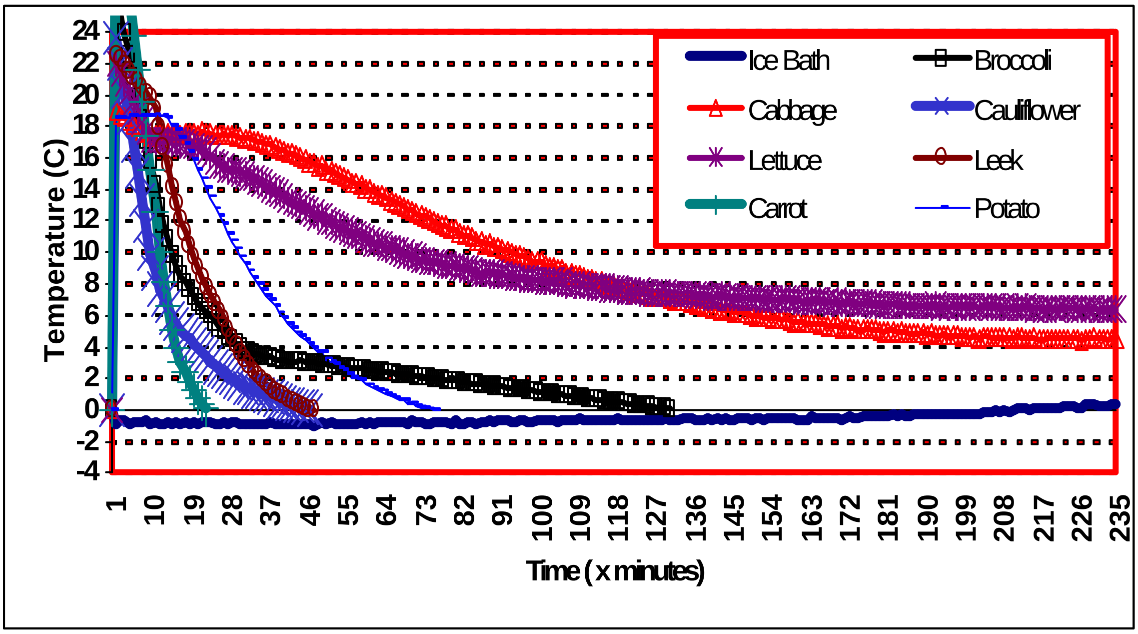

Figure 3.2.2 – Vegetable Cooling Test using FoodICE solution.

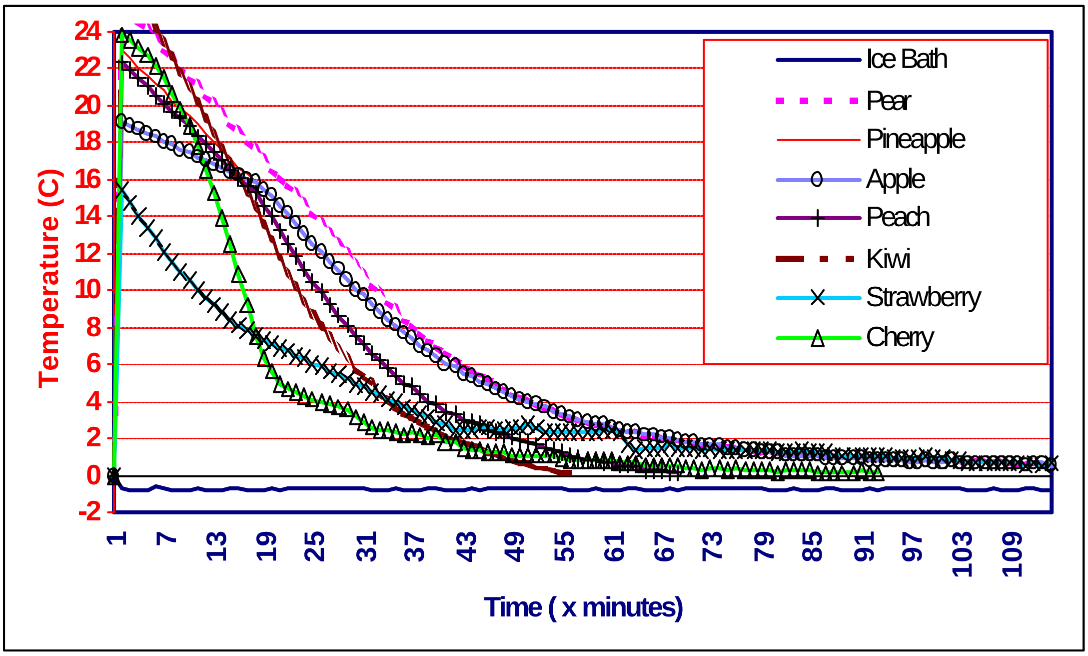

Figure 3.2.3 – Fruit Cooling Test using FoodICE solution.

Test results indicate significantly reduced cooling times and superior product quality in comparison with conventional techniques. The shelf life of these products is also significantly increased due to the rapid cooling effect.

4- **CONCLUSION**

There are many type of slurry ice production machinery operating around the world and a slurry ice rapid food cooling system can provide all the benefits offered by conventional ice /chilled water cooling technologies with additional benefits;

- **Hygienic Systems**
- **Quick Response**
- **Reduced Equipment Size**
- **Capital Cost Saving**
- **Energy Cost Saving**
- **Energy Saving**
- **Improved System Operation**
- **Flexibility for the Future Capacities**

Moreover, the pumpable characteristic over any other type of ice production system offers efficient compact equipment design, flexibility of location of storage tank(s) and the most economical capacity and duty balancing for any given food chilling application [(6)].

Storage tank(s) can be placed: under, beside, inside, or on top of a building and can be any shape or size to match building and architectural requirements.

FoodICE is a very versatile cooling medium. The handling characteristics, along with the cooling capacities can be matched to suit any application by means of simply adjusting the percentage of ice concentration.

As they are microscopic the ice crystals melt quickly to meet varying cooling loads instantly.

FoodICE not only offers higher efficiency and cost effective ice production but also its unique pumping and easy handling characteristics provide totally sealed "Hygienic Systems", increased production, flexibility of operating temperature and consistency of application, for optimum results.

Direct contact pumpable ice chills faster, providing instant protection, maintaining freshness and preserving colour. The tightly packed pumpable ice inhibits air entraintment, which is the main cause for causes premature ice melting as in the case of solid ice for transport and storage applications. Hence, **FoodICE** lasts longer in comparison with solid ice.

The challenge for designers and food manufacturers is to explore the possibility of every alternative design solutions, which can minimise the use of energy for the refrigeration system. A FoodICE based cooling systems may be the answer for many food chilling applications for an Environmentally Friendly and Economical alternative.

6.0- REFERENCES

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