APPLICATION OF HEAT TRANSFER FLUID IN SUB-ZERO TEMPERATURES

Abstract

The reliability and efficiency of industrial operations in cold conditions depend on the use of heat transfer fluids in subzero temperatures. Traditional water-based fluids might freeze and cause problems in the entire system. These difficulties are addressed by specialized heat transfer fluids that have low freezing points, great thermal stability, resistance to corrosion, and low viscosity at low temperatures. They are essential for maintaining efficient heat exchange, avoiding freezing, and preserving system parts from damages. These fluids are useful for applications in the oil and gas, refrigeration, solar thermal and automotive industries because they provide accurate temperature control and long-term operation in below-freezing conditions. The capabilities of heat transfer fluids are still being developed via ongoing research and innovation, which boosts the dependability and effectiveness of systems that operate in cold environments. The choice of HTFs significantly affects the system's performance as well as the heat transfer process's dependability, cost, and efficiency

Keywords: heat transfer fluids in subzero temperatures

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I. INTRODUCTION

Heat transfer is one of the most crucial industrial processes. Heat transfer fluids (HTFs)play a very important role in food processing where maintaining temperature control and food safety is critical. These fluids are frequently used to store and transfer heat in systems from one place to another place as per the requirement (Melinder, 2007). Throughout the production process, these specialized fluids are used in a variety of applications, enabling effective heat transmission, maintaining ideal processing conditions, and preserving the quality and purity of food items. The selection of HTFs has considerable impact on the performance of the system, cost, efficiency and reliability of heat transfer process (Yadav and Singh, 2011; Sain *et al.,* 2019a).

HTF also known as the secondary working fluid or secondary refrigerant; have typically used in many indirect refrigeration systems. Water is most commonly used as a HTF in various cooling application because of its high specific heat and thermal conductivity but it freezes at 0 °C which presents a challenge in subzero temperate cooling and freezing process (Sole *et al.*, 2014). HTFsusually consist of food-grade oils or glycols;effectively transfer heat from food through heat exchangers (Rasta and Suamir, 2019). These fluids ensure the necessary heating or chilling of the food by accurately managing the temperature, which leads to proper processing and preservation (Jaglan *et al.,* 2018).

In sub-zero temperatures, HTF play an especially important role. They enable efficient heat transmission in situations where maintaining a specific temperature is essential to protect equipment, preserve system functionality, or ensure safety (Vergara *et al.*, 2001). This fluid allows the quick cooling of food products, preventing the ice crystals formation and preserving food quality. However, heat transfer in sub-zero temperatures creates a unique set of difficulties (Mjalli *et al.*, 2014). The HTF must maintain its fluidity and thermal conductivity at subzero temperatures. In order to prevent system failure, it shouldn't freeze or get too thick or viscous (Alomar *et al*., 2016). Additionally, it is essential that the fluid should not corrode or harm the machinery, it is utilized in(Sain, 2019).

The objective of this chapter is to review and evaluate existing HTF and recent advances in this area. To address these challenges, HTF for use in sub-zero temperatures typically contain antifreeze chemical, such as propylene glycol (PG) or ethylene glycol (EG) (Hagg, 2005). Salt-based antifreeze formulations can also be employed since they effectively lower the fluid's freezing point and enhance its low-temperature heat transfer capabilities (Jiang *et al*., 2016). Therefore, it's crucial to choose the appropriate HTF for a given application, taking in to account factors like the lowest operating temperature, the material compatibility, and the fluid's environmental effect.

II. WATER AS A HEAT TRANSFER FLUID (HTF)

Water is one of the most often used HTF due to its distinctive thermal and physical properties.Due to its high specific heat capacity, water can absorb or release huge amounts of heat without significantly changing its temperature (Mohapatra and Loikits, 2005).Water is thus ideally suited to maintaining temperatures in heating and cooling systems. Compared to other liquids, water has a higher thermal conductivity, making it effective at transferring heat (Seiler *et al*., 2017). Water can absorb a high heat as it transforms from a liquid to a gas due to its high heat of vaporization. Water is therefore ideal for processes like power generation were steam powers turbines. Water is an economical HTF since it is widely available and reasonably priced. Water is a safe and ecofriendly HTF since It does not contribute to pollution and not harmful to living organisms (Ibrahim *et al*., 2019).

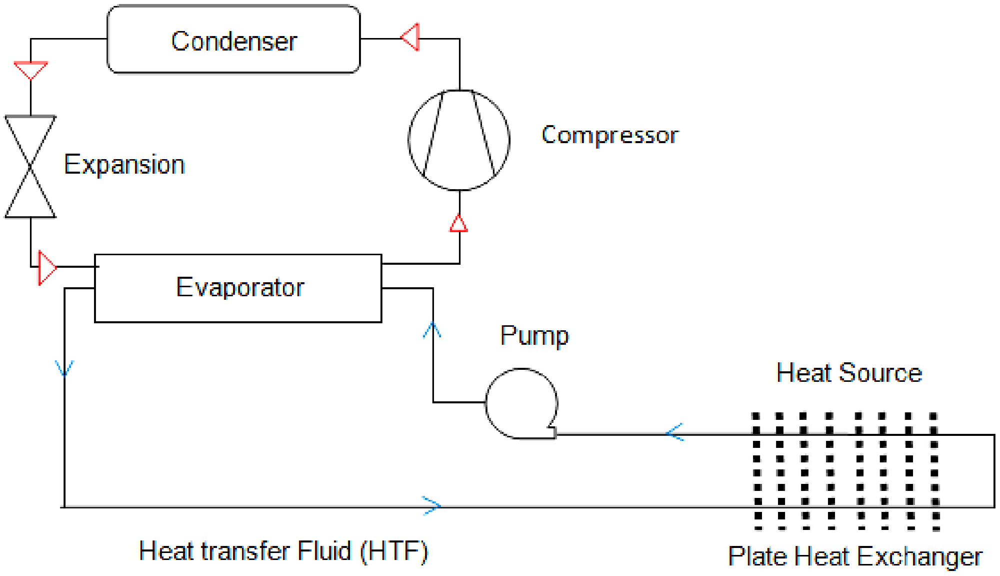

Figure 1: Schematic diagram of indirect refrigeration system

However, water also has several restrictions when used as a HTF i.e., Water boils at 100°C at atmospheric pressure, which limits its use in high-temperature applications. Water freezes at 0 °C, which can be problematic for systems in cold climates. It doesn't defend against freezing in low temperature applications since it solidifies at 32° F. If that were not enough, this transition to a solid is accompanied by expansion about 9% of original volumewith enormous potential force, which causes damage in the cooling system (Tijani and Sudirman., 2018).

Water can cause certain metals to corrode and can also result in the accumulation of scale in heat exchangers, both of which can lower system efficiency. Bacteria and other organisms can develop in water, which can result in biofouling and decrease system effectiveness. Additives are often used to mitigate these issues. Historically, these issues have been addressed by the addition of a hydrocarbon solvent along with various corrosion inhibiting additives (Gupta and Ramachandran, 2018). So that, water is completely or partially substituted and resulting mixture with water will be recognized as ordinary automotive antifreeze.

III. ANTIFREEZE CHEMICALS USED IN HEAT TRANSFER APPLICATION

The freezing point (FP) of solution will be drop down when antifreeze chemical is added to a water-based solvent as an additive. Antifreezes are used in HTFs to prevent the freezing below the FP of solution. Antifreeze solutions are not solidifying to several degrees below their freezing point (Capuano *et al.,* 2007). If antifreeze chemical is exposed 10° C below its freezing point, ice crystals is formed in the solution and becomes slush instead of solid material. At very low temperature, more ice crystals will generate and the antifreeze material will become a stiff mush but never crystalline solid. The solid phase is only formed from the pure water. This decreased the water portion and so the concentration of remaining antifreeze is increased and the freezing point depression (FPD) is increased further. The freezing point is referred as the temperature when the first ice crystal is appeared but the solution will become solid completely at the eutectic temperature. Therefore, antifreeze solutions have a freezing range rather than freezing point (Liu *et al.*, 2017).

1. **Function of Antifreeze Chemicals:** Antifreeze helps in transferring heat away from the products. It circulates through the plate heat exchanger, absorbing the excess heat from the product and maintained the set temperature according to the application. Protecting the equipment and cooling system from freezing in cold weather is one of antifreeze's key purposes. Without antifreeze, the cooling system could freeze, potentially damaging the component of the system as frozen coolant expands. Antifreeze also raises the coolant's boiling point and point helps to prevent the engine from overheating and boiling the coolant at high operating temperatures (Cheralathan *et al.*, 2007). Metal parts of the cooling system, including the heat exchanger and water pump remain protected from rust and corrosion by chemicals found in antifreeze. Corrosion can lead to damage oh the cooling system and in result reduced efficiency. Antifreeze contains lubricating agents that help in reducing wear and friction between moving compartment in the cooling system, such as the water pump.

   Antifreeze keeps the cooling system's pH level steady, preventing it from becoming too acidic or alkaline, which could harm the cooling system's components. Antifreeze's lubricating characteristics are useful in protecting the water pump, which is essential for moving cooling medium throughout the heat transfer process (Khan and Spitler, 2004). The creation of foam within the cooling system, which can obstruct the efficient passage of heat, is prevented by antifreeze chemicals. It is significant to remember that in order to achieve the intended heat transfer characteristics and protection from corrosion, antifreeze must be diluted with water in the precise proportion recommended by the manufacturer. The longevity and optimum efficiency of the cooling system are dependent on regular maintenance and the correct application of antifreeze

2. **Classification of Antifreeze Chemicals:** Antifreeze compounds fall into a variety of categories; following are some typical categories for antifreeze chemicals depending on their composition and intended purpose,

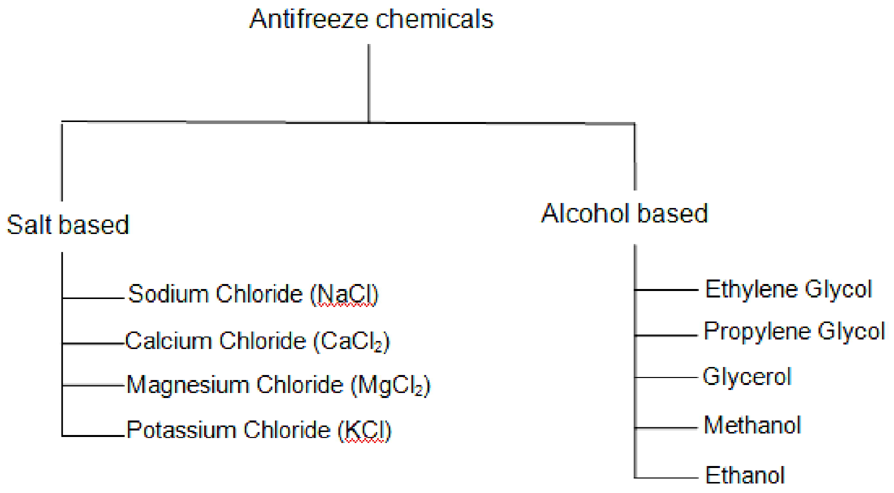

Figure 2 : Classification of antifreeze chemicals

3. **Characteristics of Antifreeze Chemicals:** Water's freezing point drops when a solute is added to it. The term "freezing point depression (FPD)" describes the difference between the FP of pure water and that of a solution. At the same molality (i.e., moles of solute per kilogram of solvent), an electrolyte causes a higher freezing point depression than a non-electrolyte (Jaguemont *et al.*, 2018). This is because electrolytes disintegrate into ions when they are mixed in water, producing more particles in solution. If ideal behavior is taken into account, the FPD is proportional to the number of ions created when dissolved to water.

   - **Salt-Based Antifreeze Chemicals:** A salt-based antifreeze composition typically includes water, a salt that lowers the freezing point, and additional potential additives that improve functionality or lessen corrosion brought on by the salt. It is also known as brine or saltwater solutions, and it is frequently used for de-icing and anti-icing purposes (Purohit and Sistla, 2017). These substances aid in lowering water's freezing point and preventing the buildup of ice on surfaces. The different types of salt-based antifreeze compounds are as follows:

     - **Sodium Chloride (NaCl):** The most popular and widely accessible salt-based antifreeze chemical is sodium chloride (NaCl). It is frequently used as rock salt to de-ice highways and roads throughout the winter. Because sodium chloride decreases the freezing point of water, ice does not form and snow melts more quickly. Despite being effective, it may corrode component and cooling system (Purohit and Sistla, 2021).Although less efficient than calcium chloride, regular table salt can be used as an antifreeze chemical. The FP of water can be lowered to around -21 °C (-6 °F) by a saturated solution of NaCl (about 26% at ambient temperature). Metals, notably iron and steel, can be corroded by sodium chloride.

     - **Calcium Chloride ($CaCl_2$):** $CaCl_2$ is more efficient at melting ice and preventing its formation because it has a lower freezing point than sodium chloride. Antifreeze with a calcium chloride base works well to stop ice from forming and decrease the FP of water. The FP of water can be lowered to -55 °C (-67 °F) in a solution of calcium chloride at a concentration of 30% (Oro *et al.*, 2012). A calcium chloride solution, like the majority of salt-based antifreezes, can corrode various metals over time. To preserve metal components, the composition may contain anti-corrosion additives.

- **Magnesium Chloride ($MgCl_2$):** In de-icing solutions, magnesium chloride is frequently used instead of calcium chloride, especially in places where calcium chloride's corrosive properties are a concern. It is efficient at melting ice and preventing ice formation because it has a lower freezing point than sodium chloride. Magnesium chloride can still corrode metals even if it is less corrosive than sodium chloride. It may be necessary to add a chemical like sodium hydroxide (NaOH) or hydrochloric acid (HCl) as needed to control the pH of the solution and prevent any pH-related issues. Water's freezing point can be lowered to around -33°C (-27°F) with a solution of 25% $MgCl_2$.

- **Potassium Chloride (KCl):** Compared to sodium chloride and calcium chloride, Potassium chloride (KCl) has less of an influence on the environment because it is less corrosive and less damaging to flora. KCl is frequently used in conjunction with other salts or as a less aggressive alternative in some circumstances; however, it is less successful than other salts at melting ice and preventing its development (Liu *et al.*, 2023). When selecting the right salt-based antifreeze chemical for a particular application, it's essential to take into account aspects like the impact or effect on the environment, the risk for corrosion, and the effectiveness.

The FP of water is lowered by salt-based antifreeze. The addition of salt prevents the water from freezing at normal temperatures by interfering with the water molecules' capacity to form crystalline structures. Antifreezes made with salt can corrode metal. When coupled with water, they can cause rust and other types of corrosion on metal surfaces. Many formulations have corrosion-preventive or -slowing additives as a way of reducing this. The formulation might include a corrosion inhibitor such sodium nitrite ($NaNO_2$) or sodium molybdate (Na_2MoO_4). Depending on the inhibitor type, the precise amount will vary, but normally it will fall between 0.5 and 3% of the overall solution.

Salt-based antifreeze is inflammable-in contrast to glycol-based antifreeze and it is now safer to use in many applications as a result. Antifreezes made of salt have an adverse effect on the environment (Zhu *et al.*, 2022). Salt can taint water sources and harm vegetation. The price of salt-based antifreeze is often lower than that of other varieties. There may be a problem with foaming in some situations. Small quantities, typically less than 0.1% of the total solution, of an antifoam agent, such as a silicone-based defoamer, may be used.

Table 1: Freezing Point depression of eutectic salt-water solutions

Solutions	Subcooling [ºC]	Freezing temperature [ºC]	Melting temperature [ºC]	(Freezing point depression)
5% NaCl	3.87	-3.87/-4.27	-4.8/-3.18	3.04
10% NaCl	6.28	-7.60/-7.70	-7.80/6.10	6.56
15% NaCl	5.30	-15.19/-15.29	-10.40/-9.20	10.88
20% NaCl	2.79	-18.22/-17.92	-18.92/-14.62	16.45
21% NaCl	2.20	-18.46/-18.26	-18.86/-14.62	17.77
22% NaCl	1.60	-21.95/-21.39	-20.15/-19.65	19.17
23% NaCl	0.20	-20.89/-21.85	-22.15/-19.65	20.66
24% NaCl	0.30	-20.19/-19.9	-3.28/-2.08	-
5% KCl	1.59	-3.38/-3.58	-11.79/-6.00	2.32
10% KCl	7.48	-6.60/-7.10	-11.40/-9.60	4.80
15% KCl	4.40	-12.80/-13.20	-10.23/-9.43	-
20% KCl	5.59	-12.93/-13.13	-10.15/-9.15	-
21% KCl	4.80	-10.35/-10.65	-10.15/-9.65	-
22% KCl	6.90	-10.45/-11.25	-10.95/-9.15	-
23% KCl	7.48	-12.12/-12.82	-12.32/-9.83	-
24% KCl	5.10	-10.80/-11.10	-11.10/-9.10	-

The degree of sub cooling for NaCl solutions is lower compared to KCl. Thus, NaCl solutions are more efficient salt-based antifreeze chemical than KCl solutions for cooling applications (Yilmaz *et al.*, 2010).Brines are highly restrictive to heat transfer process because they are the most corrosive to metals and form scale deposition on surface.

- **Alcohol-Based Antifreeze Chemicals**: Alcohol has a wide range of uses and is frequently employed because of its low freezing point, efficient heat transfer, and low toxicity. The primary categories for alcohol-based antifreeze compounds are as follows:

  - **Ethanol (C_2H_5OH):**Alcohol-based antifreeze chemical ethanol is frequently employed in applications where non-toxicity is important. It is effective at preventing freezing in systems or environments because it has a lower freezing point than water. Applications include heating and cooling systems, solar thermal systems, and laboratory equipment all use ethanol-based antifreeze (Wu *et al.*, 2021). Ethanol should be handled and stored with the proper safety precautions because it can be flammable.

  - **Methanol (CH_3OH):** Methanol, commonly referred to as wood alcohol, is a different kind of antifreeze substance. It has a low freezing point and good heat transfer properties. In racing automobiles, snowmobiles, and other automotive applications where high-performance antifreeze is required, methanol-based antifreeze is typically employed. It should, however, be handled with the utmost caution because it is extremely hazardous.

The boiling point of ethanol and methanol are low however, they are occasionally used despite their drawbacks. During the summer month the significant quantity of alcohol can be evaporated and these lose cause a costly replacement of the additive. The problems of using alcohols are that they have low flash points. Moreover, methanol is very poisonous. Therefore, the use of alcohol in resent time has decreased almost completely.

- **Ethylene Glycol ($C2H6O2$):** Ethylene glycol (EG) is not as efficient in the depression of the freezing point (FP) as methanol glycol however it has a very low vapor pressure. Due to evaporation of water the evaporation loss in a coolant system is high. Mixtures of EG and water of 1:1 do not exhibit a flashpoint at all. EG based antifreeze may also contain fewer amounts of other glycols like as triethylene glycol or diethylene glycol. When toxicity is considered propylene glycol (PG) is used. In the heat transfer for depression of freezing point EG considered most effective.

  Pure water will expand approximately 9% by freezing. The amount of expansion will be reduced by the addition of EG as antifreeze and the system cannot be damage. The crystal formation is mainly due to the water at freezing temperature. Therefore, the amount of antifreeze in the solution will be raising and further depression of the freezing point of the remaining liquid is occurred (Hollis *et al.*, 2002). The solution never solidifies completely at higher glycol concentrations. The fluid becomes taffy and thick. The temperature at which the fluid will flow is known as the pour point. The temperature of pour point is significantly lower than the freezing point temperature. Although, the pumping energy will be increased and heat transfer rate is decreased when the system is used down to the pour point. Therefore,it is not used beyond the FP of mixture.The eutectic point of ethylene glycol (EG) with water at around −70 ˚C between 65% and 80% concentration. The solidification point of Pure EG is −14 ˚C.

- **Ethylene Glycol vs. Propylene Glycol:** In heat transfer performance EG will provide better heat transfer than PG because EG has less viscosity than propylene glycol across the entire temperature range. However, propylene glycol is preferred than ethylene glycol when toxicity is considered, such as with food applications because it has a lower acute oral toxicity as compared to EG (Rohit *et al.,* 2022).

Table 2: Physical properties of antifreeze compound

Property		**water**	**Ethylene glycol (EG)**	**Propylene glycol (PG)**
Molecular weight		18.016	62.07	76.09
Specific gravity, 20°C		1.00	1.1155	1.0381
Specific heat, J/gk		4.1742	2.40	2.51
Freezing point, °C	Pure	0	-13.3	-
	50% sol	-	-36.6	-33.0
Boiling point, 20°C		100	197.3	187.2
Vapor pressure at 20°C, kPa		2.3322	0.016	0.024

Flash point		115.6	107.2
Viscosity at 20°C, mPas(=Cp)	1.01	20.9	60.5

EG is slightly harmful and flammable. IN an adult, the minimum lethal dose is 1-1.5 ml/kg. It causes irritation to eyes, skin and respiratory tract when Short-term exposure. Propylene glycol (PG)is practically non-toxic to humans but slightly water-polluting (The Engineering toolbox, 2003). The minimum dose of pure PG for human adults is more than 15 times greater than EG. PG can have quite a low pH that might cause the corrosion potential (Hagg, 2005).

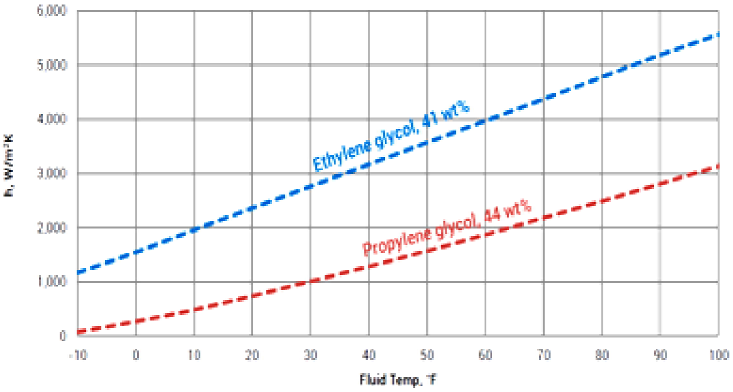

Figure 3: Thermal conductivity of ethylene glycol and propylene glycol solution(Dynalene, 2014)

Table 3: Thermal conductivity of EG and PG

Temperature (F)	**Thermal conductivity (Btu/(hrft^2)(F/ft)) at 30% Volume**	
	Ethylene Glycol	**Propylene Glycol**
10	0.238	0.235
20	0.243	0.239
30	0.247	0.243
40	0.251	0.247
50	0.255	0.251
60	0.259	0.254
70	0.263	0.258
80	0.266	0.261

- **Glycerol-Based Antifreeze Solution:** Glycerol, also called glycerin, is a substance that occurs naturally and is formed from fats and oils. It has antifreeze qualities and is frequently utilized in applications that call for non-toxic, biodegradable antifreeze. Food processing, breweries, wineries, as well as laboratory and medical equipment, all use glycerol-based antifreeze (Pan *et al*., 2018).

When selecting the ideal alcohol-based antifreeze chemical, it's crucial to take the application's unique requirements and safety concerns into account. To ensure the safe and efficient use of these substances, factors including toxicity, flammability, and environmental impact should be taken into consideration.

4. **Application of different Antifreeze Chemicals in Food Processing Industry:** Heat transfer fluids (HTFs) are used in systems for temperature-controlled storage and transportation. The necessary temperature range for storing and transporting perishable food items is maintained by HTFs, including refrigerated trucks, cold rooms, and warehouses. The HTFs move through the cooling units, absorbing heat from the storage spaces or the environment to maintain a constant and secure temperature for the food products being carried or stored. Through the many stages of manufacturing, HTFs help to maintain food safety, assure proper processing, and retain the quality and integrity of food items by accurately control temperatures (Sain *et al.,* 2019b).

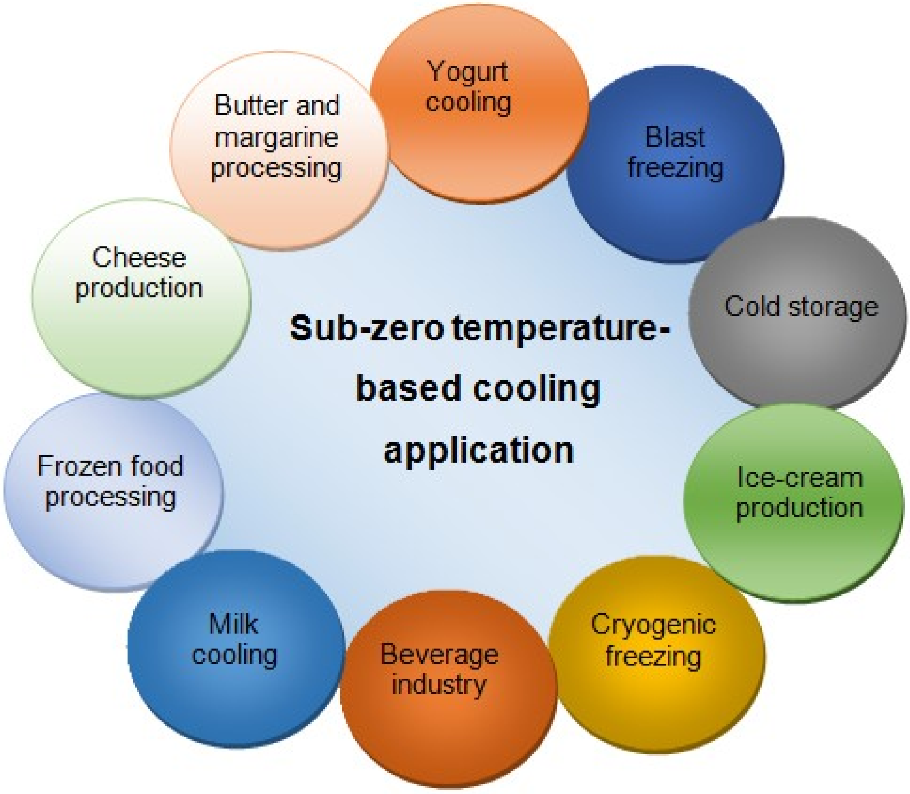

Figure 4: Subzero temperature-based cooling application

Antifreeze chemicals are used by the food processing sector in a variety of applications, especially those requiring freezing and refrigeration. These substances are used to lower the freezing point of the solution and avoid ice formation damaging the machinery. Propylene glycol is a good example of food-grade antifreeze that is non-toxic and acceptable for accidental contact with food when choosing antifreeze for use in food processing (Kara and Arslan, 2020). While ethylene glycol works well as antifreeze, it should not be utilized in applications where it might come into contact with food because it is hazardous. Following are a few frequent applications for antifreeze compounds in the food processing sector:

- **Blast Freezing:** Antifreeze chemicals are used in secondary refrigerants to decrease the freezing point and retain the cooling capacity of the system during the blast freezing process, in which the temperature is rapidly lowered to swiftly freeze food.

- **Production of Confectionery and Chocolate:** In order to ensure that the finished goods have the desired texture, appearance, and shelf life, these fluids provide accurate temperature control during the melting, tempering, and molding operations of chocolate and confectionery products. Heat transfer fluids help to ensure the uniformity and quality of chocolate and confectionery by facilitating efficient and consistent cooling during heat transfer process (Ducki *et al*., 2008).

- **Cold Storage:** Large food storage facilities have cooling systems that frequently use antifreeze to maintain the proper temperature. The antifreeze chemicals ensure consistent performance of the vapour compression refrigeration system (VCRS) by preventing coolant from freezing.

- **Dairy Industry:** Antifreeze chemicals like propylene glycol (PG) are employed in the milk refrigeration systems of dairy processing, where milk is cooled quickly to prevent bacterial growth (Bassam *et al*., 2010). Because PG is generally regarded as safe (GRAS) for accidental contact with food, this glycol is preferred.

- **Beverage Industry:** Antifreeze solutions are used in chilling and fermentation tanks in breweries and wineries to maintain a consistent temperature for quick product cooling.

- **Ice Cream Production:** Antifreeze chemicals are utilized in the cooling and freezing process of ice cream and kulfi. They facilitate lowering the ice cream mixture's temperature and regulating ice crystal size, which affects the texture of the finished product.

- **Meat and Poultry Processing:** The refrigeration systems use antifreeze solutions to keep the cool temperatures required for processing meat and poultry safely.
  In conclusion, heat transfer fluids are crucial in the food processing sector for uses including heat exchangers, freezing and chilling operations, temperature-controlled storage, and the creation of confectionery.

5. Toxicity and Environmental Aspect

- **Corrosion:** In the aqueous solution, due to dissolved ions from remaining salts corrosion would still occur. Glycols can corrode metals at high temperature and in the presence of residual oxygen from the air because they are oxidized to the respective acids at that condition. The addition of buffer systems essentially keeps the pH constant and neutralizes the acids and thus the inhibition of acid corrosion can be achieved. For example, a mixture of 100 kg EG with 475 g Na_2HPO_4, 4 l of water and 400 g KH_2PO_4 is used as an anti-freezing agent, which can be diluted 50:50 with water and this formulation will be highly anti-corrosive. The protective surface layer can be removed by erosive corrosion (Nguyen *et al*., 2022). In the region of high velocity such corrosion are most dangerous. The protective layer on the surfaces of metal are formed by molybdates, nitrites, borates, phosphates, nitrates, silicates, amines, triazoles, and thiazoles, for example neurotrophin,monoethanolamine, mercapto benzothiazole and thiodiglycol. These inhibitors are not as much effective to protect against corrosion. Therefore, triazole is used for the protection of brass parts and for ferrous metal, phosphate is used.

- **Human Toxicity:** In the antifreeze agents, ethylene glycol is the main rezone of toxicity. It is often said that glycols are related to glycerol therefore it is healthy to skin. This is not true because the catabolism is totally different due to a difference of a single atom of carbon. EG is toxic to animals and humans if ingested. EG is an animal teratogenic. PG has not any teratogenic effects, and oral toxicity is lower. However, PG is more irritating to skin than EG (Fowles *et al*., 2017).

- **Biodegradation**: The bio-oxidation of formulation containing EG have shown within 20 days. The bio-oxidation rate is stationary over the full period. Besides this, during the first 5 days of the test PG initially degrades more rapidly to an extent of 62%.

- **Recycling**: Recycling is achieved either by simply redistillation or by filtering. Only deposits are removed In the case of filtering. There are very less information about the activity of corrosion inhibitors. Re distillation is more complicated and costly than filtering however it is more effective because it recovers high quality glycol. Before the use the refined glycol must be re-inhabited. Before reuse remaining antifreeze can be purified. The antifreeze chemical can be easily treated and recycled if it is separated from waste oils.

IV. CONCLUSION

Heat transfer fluids play an indispensable role in many industries and applications that require temperature regulation in sub-zero environments. To preserve product quality, guarantee equipment dependability, and, in many circumstances, adhere to safety requirements and regulations, it is essential to be able to control temperatures at certain levels. Water is frequently the first choice as a heat transfer fluid for many applications due to its high performance and low cost, despite many difficulties. Many of the possible disadvantages can be minimized with proper system design and maintenance. However, there are some difficulties in using heat transfer fluids at temperatures below 0 °C.At low temperatures, the HTFs must still be liquid and retain their ability to transmit heat.

Additionally, they must be compatible with system components and not be susceptible to corrosion or other harm.Additionally, factors like cost, safety, and environmental impact are taken into account while choosing heat transfer fluids.The future of this field lies in the development of more efficient, safer, and environmentally friendly fluids and systems. These innovations will improve efficiency and sustainability in a variety of industries and applications.

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