Effect of Additives Having Different Functional Groups on the Ice Adhesion and Their Ice Packing Factor Measurement

Jong-Hyeon Peck[1], Chaedong Kang[2], Hiki Hong[3], Akio Saito[4]

[1] Korea Institute of Industrial Technology, Korea
[2]Dept. of Mechanical Engineering, Chonbuk University, Korea
[3]School of Mechanical and Industrial System Engineering, KyungHee University, Korea
[4] Dept. of Mechanical Sciences and Engineering, Tokyo Institute of Technology, Japan

Keyworld: Functional group, Ice slurry, IPF(Ice Packing Factor), Ice adhesion

Abstract: To prevent an ice adhesion on the cooled wall is important factor to produce the ice slurry without mechanical scrappers, continuously. In this study, the effect of additives having different functional groups such as carboxyl(-COOH), hydroxyl(-OH), amine(-NH_2) and nitrate(-NO_3) to ice adhesion on the cooled wall is investigated during making the ice slurry. Because the IPF should be predicted from freezing point of solution, the predicted IPFs have been compared with the IPF values on cooling state of solutions containing the different additives. The solution having EG, PG, and 1,6-hexanediol shows a good resistance for the ice adhesion on the cooled wall as well as the high IPF value. The solution having ethylenediamine and 1,3-propanediol was also effective.

Recently, the dynamic cold thermal storage system with mechanical moving parts is very popular to make the ice slurry. However, due to high energy consumption and some problems such as the durability of moving parts, this system has a limitation to use effectively. To overcome these shortcomings, many researchers have studied the new method to make the ice slurry without additional mechanical parts.

In this paper, we have modified the solution using the several additives having different functional groups and investigated their usefulness for preventing a phenomenon of the ice adhesion on cooled wall.

For this experiment, we chose the soluble chemicals having different functional groups [carboxyl (-COOH), hydroxyl (-OH), amine (-NH_2) and nitrate (-NH_3)]. Table 1 represents the chemicals used in this study. Generally, the EG concentration in the water is sustained as about 7 wt-%(hereinafter referred to ‘Solution I’) to make ice slurry by using the mechanical scraper. Therefore, we have set the additive concentration in distilled water as 7 wt-%. The compositions of the solutions are shown in Table 2 and the weight of sample solution was fixed as 950 g to all tests.

Table 1. Materials with functional group

Function Group	Chemical Materials
Carboxyl(-COOH)	Lactic acid, Succinic acid, Glycine
Hydroxyl(-OH)	1,6-Hexanediol, 1,3-Propanediol
Amine(-NH_2)	Monoethanolamine, Ethylenediamine, Triethyleneamine
Nitrate(-NH_3)	Manganese nitrate hexahydrate, Magnesium nitrate hexahydrate

The beaker filled with the solution is immersed and cooled down in the low temperature bath. The supercooling degree is broken when the sample temperature was decreased about 1 K. We observed the ice adhesion on the wall around end point of experiment. Using the stirring power, the number of revolutions of stirrer and conditions in upset beaker, we estimated the physical properties of formed ice adhesion.

For 1,6-Hexanediol 1.5 wt-%, Propyleneglycol 1.5 wt-% and Ethyleneglycol 4 wt-% (hereinafter referred to ‘Solution II’) as additives, we conformed that they can play role as inhibitor to form the ice adhesion on the cooled wall. The 1,3-Propanediol and Ethylenediamine were also effective to prevent ice adhesion on the wall. However, in case of the EG,

Table 2. Composition of an aqueous solution

Type	Water	EG	PG	Additive
1	93	-	-	7
2	93	4	-	3
3	93	4	1.5	1.5

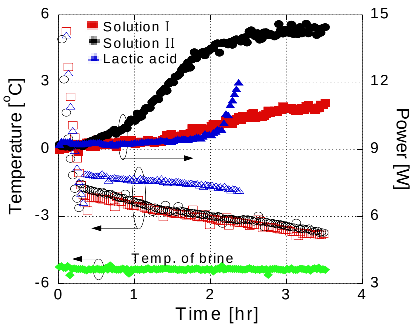

Figure 1. Time history of temperature and power

(a) Ice adhesion (b) Non-ice adhesion

Figure 2. Snapshot of ice adhesion on cooled wall

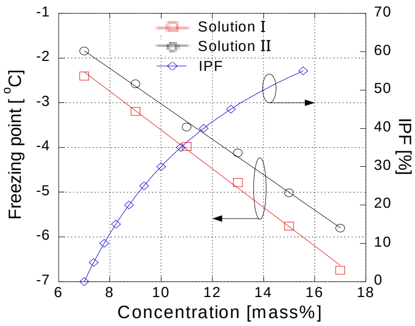

Figure 3. Relation of freezing point and IPF about concentration on aqueous solution

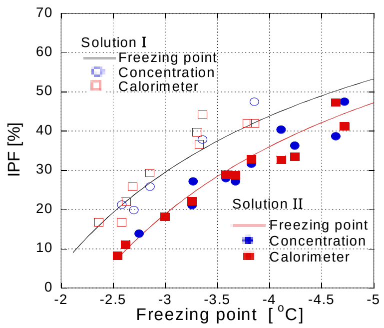

Figure 4. Comparison of measured IPF values

Nitrate, and Lactic acid, we observed the ice adhesion, which has several grade about ice hardness on the cooled wall, but the hardness of ice adhesion depended on the type of additives.

The amount of ice slurry in the solution and the hardness of ice adhesion on the wall should be predicted by using the stirring power (Figure 1). That is, the steepness of slope on the power vs. time graph means that the rate of ice slurry production and its quantity are large. After the breaking of supercooling, the slope of Latic acid was continued without any significant change and suddenly rose at the end point. This result should be came from the increased friction force between the stirrer and the ice layer attached to the cooled wall. Figure 2 shows two typical cases of ice slurry after finishing the experiments.

In this paper, we also presented the methods for IPF measurement. The IPF can be calculated by the concentration of solutions or by calorimeter method. First of all, the solution concentration is calculated from its freezing point and the refractive index of the solution. Second, we can obtain IPF values from the solution concentration. Figure 3 shows the relationships between freezing point, concentration and IPF value.

The calorimeter method is one of the direct methods for IPF calculation used the heat balance between ice slurry solution and the hot water. When above two parts are mixed homogeneously, the released heat of hot water will be used for calculation of IPF value.

Compared each method, predicted and measured IPF values are similar pattern as a result in Figure 4. At the same freezing temperature, IPF value of solution with Solution I is approximately 10% smaller than the IPF values of Solution II (Figure 5 & Figure 6).

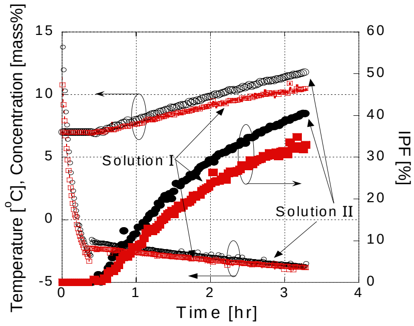

Figure 5. Prediction of IPF and concentration by freezing point about Solution I and II

(a) Solution I (b) Solution II

Figure 6. Snapshot of ice slurry on continuous ice formation at same temperature

Hong et al.(2004), Ice adhesion of an aqueous solution including a surfactant with stirring on cooling wall : ethylene glycol - a silane coupling agent aqueous solution, IJR, Vol. 27, pp.985-992

Stewart et al.(1987), Development of improved ice-making techniques for storage heat pumps, Final report RP-483.

Tsuchida et al.(2002), Ice formation process by cooling water-oil emulsion with stirring in a vessel, IJR, Vol. 25, pp.250-258.