International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:8, No:6, 2014

Energy Saving Potential with Improved Concrete in Ice Rink Floor Designs

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***Abstract*—**The ice rink floor is the largest heat exchanger in an ice rink. The important part of the floor consists of concrete, and the thermophysical properties of this concrete have strong influence on the energy usage of the ice rink. The thermal conductivity of concrete can be increased by using iron ore as ballast. In this study, the Transient Plane Source (TPS) method showed an increase up to 58.2% of thermal conductivity comparing the improved concrete to standard concrete. Moreover, two alternative ice rink floor designs are suggested to incorporate the improved concrete. A 2D simulation was developed to investigate the temperature distribution in the conventional and the suggested designs. The results show that the suggested designs reduce the temperature difference between the ice surface and the brine by 1-4˚C, when comparing with convectional designs at equal heat flux. This primarily leads to an increased coefficient of performance (COP) in the primary refrigeration cycle and secondly to a decrease in the secondary refrigerant pumping power. The suggested designs have great potential to reduce the energy usage of ice rinks. Depending on the load scenario in the ice rink, the saving potential lies in the range of 3-10% of the refrigeration system energy usage. This calculation is based on steady state conditions and the potential with improved dynamic behavior is expected to increase the potential saving.

***Keywords*—**Concrete, iron ore, ice rink, energy saving.

I. Introduction

THE ice rink floor is one of the most important structures in an ice rink. The events take place on the ice rink floor and the absorbed heat to the ice is removed by the refrigeration system. This absorbed heat mainly comes from the indoor air (convection), moisture from the air depositing (diffusion) and the ceiling and walls (radiation). A typical ice floor structure is shown in Fig. 1 including the different layers and components [1]. Naturally a layer of ice (≈30-40mm) is located on the top followed by a concrete layer (≈100-150mm) with the embedded cooling pipes (normally from polyethylene plastic or cross-linked polyethylene material), which have ≈100mm pitch. However, due to construction-related limitations the concrete layer sometimes is divided into two sub-layers, below and above the cooling pipes. A base layer is first made to ensure the stability and strength of the structure followed by a thinner top layer including the embedded cooling pipes. Under the concrete layer there is an insulation layer (≈100mm normally from extruded polystyrene foam) to reduce the ground heat conduction. The insulation is located on two layers of ≈500mm gravel fill and foundation soil. Some heating pipes are embedded in the gravel fill layer to protect the ground from freezing. Apart from a typical ice floor structure, depending on the purpose and applicability, other types of ice floors are also used in ice rinks construction [1], [2].

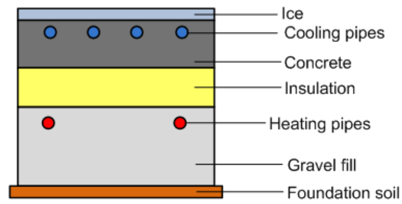

Fig. 1 A typical ice pad structure

Indirect systems are the most conventional refrigeration layout for the ice rinks (Fig. 2). This system includes two separate loops [3]. The primary loop includes a compressor, a condenser, an expansion valve and evaporator. The evaporator absorbs the heat from the secondary loop. A primary refrigerant (often ammonia) cools a secondary refrigerant (often brine) and the secondary loop uses a pump to circulate the brine.

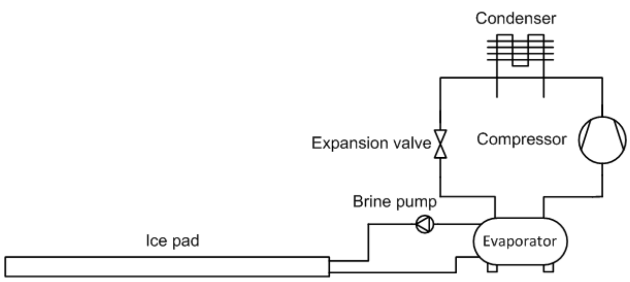

Fig. 2 A typical indirect refrigeration system for ice rinks

The thermal resistance of the structure between the ice surface and the brine is an important parameter during the process of ice forming (Fig. 1). The higher the thermal resistance for this structure, the lower the temperature for the brine and consequently the evaporation temperature will be lower. The lower the evaporation temperature leads to the lower specific cooling capacity; as a result, the efficiency of the refrigeration system is reduced. In particular, the coefficient of performance (COP) of the primary loop decreases when the evaporation temperature is reduced, and

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the pumping power increases in the secondary loop when the brine temperature is decreased (due to increase in the viscosity). Hence, the ice rink floor structure has a strong effect on the performance of the refrigeration system in ice rinks which has attracted some attention in the literature.

An experimental set-up was described by Mun and Krati [4] to evaluate the refrigeration loads for an ice rink under laboratory conditions by measuring the temperatures at various locations within the floor. The experimental results showed that the addition of the thermal insulation reduced the refrigeration load.

Ouzzane et al. [5] reported preliminary measurements performed in an indoor ice rink such as cooling load, the air temperatures at several locations and the ice and the brine temperatures. They used the experiments to verify their numerical model.

Somrani et al. [6] investigated the heat transfer in the ground and the ice layer by two analytical and numerical models and later validated their models with measurement values in a small-scale ice rink model under laboratory conditions. They found that thermal insulation below the ice rink floor, the ice thickness, the brine temperature; in addition to, the temperature and the heat transfer coefficient for the air above the ice sheet strongly affect the freezing time and the long- term ice layer temperature.

A thermal model for an ice rink floor was reported by Mun and Krati [7], in which they validated their model against the experiments under the laboratory conditions. Two control strategies, the ice surface temperature and the brine temperature, were investigated. They reported that although the ice surface temperature control uses slightly higher refrigeration energy (~1%), it is preferable by the designers due to providing better ice quality especially in the newly constructed indoor ice rinks.

Brown and Pearson [8] developed a model to study the effects of pipe diameter and pitch, thickness of ice and concrete, position of pipes in concrete slab, on surface ice and refrigerant temperatures.

The ice rink floor construction itself has not been subjected of much development in recent years. The ice rink floor is the largest heat exchanger in the ice rink and as described has a significant impact on the energy usage and the ice quality. The ice rink floor is primarily a structure consisting of different layers (Fig. 1) where heat is transferred through them by means of conduction. Consequently the material property is one of the key parameters to investigate in order to improve the system performance. This study is focused on the development of an improved concrete material and its application in a rink floor structure. Thermal conductivity of the improved concrete was measured by the Transient Plane Source (TPS) method. Moreover, two ice rink floor structures using the improved concrete are suggested and the refrigeration system performance is compared with the reference design.

II. Improved Concrete and Floor Design

A major part of the rink floor construction consists of concrete (Fig. 1); consequently, the properties of this concrete will be of great importance for the performance of the rink floor from a heat transfer point of view. The thermal conductivity is the parameter of primary interest. This property can be adapted by means of the concrete ballast. Generally the concrete used is simply made out of the available ballast, which normally implies locally produced sand. By replacing the normal ballast with a high conductivity component, as in this case - iron ore, the conductivity of the concrete may significantly be improved. Iron ore includes high quantity (greater than ~60%) of hematite (Fe_2O_3) or magnetite (Fe_3O_4) and metallic iron can be extracted from them. Measurements showed thermal conductivity of hematite and magnetite respectively are 6.4 W/mK and 4.5 W/mK at 20˚C [9].

To reach the best possible performance, i.e. highest thermal conductivity, the ballast needs to be composed of different particle sizes. This will allow a geometrical matching when mixed which increases the density and thereby the conductivity. An extensive development work has been invested in finding the optimum particle sizes followed by thermal conductivity tests [10]. The exact type and amount of added iron ore is the intellectual property of the Energi & Kylanalys AB Company and patent application for this material through the Swedish Patent and Registration Office (PRV) is ongoing. Except for the ballast the selected improved concrete is composed of regular components required for this specific application.

To be approved in real applications a material as described above needs to be tested according to specific standards to meet strength and freezing cycling requirements. The improved concrete has passed these tests and is approved for use ice rink applications.

III. Thermal Conductivity Measurement

Transient Plane Source (TPS) is a technique for simultaneously determining thermal conductivity and thermal diffusivity of materials [11], [12]. In this study the instrument Hot Disk TPS 2500 S with the sensor 5501 were used [13] to measure these properties for the concrete samples. The sensor (the plane source) is sandwiched between two identical specimen and acts as a heater and also records (transiently) its temperature increase meanwhile. The sample and the sensor must have uniform temperature before applying the prearranged power and time. The setup and arrangement to measure thermal conductivity of concrete samples is shown in Fig. 3. The sensor is located between two identical concrete samples by using the special sample holder developed by the manufacturer (Figs. 3 (a) and (b)), and the set-up is covered by a cap (Fig. 3(c)) to keep temperature stability and to reduce possible obstructive effects.

To check the validity of the TPS technique the thermal conductivity, thermal diffusivity, and volumetric specific heat of a sample of stainless steel (SIS 2343) were measured. The results for stainless steel are shown in Fig. 4. The measured values are compared with the reported experimental data (EXP) [14]; in addition to, the values of identical stainless steel reference (SIS) [15]. As the graphs shows measured thermal conductivity and volumetric specific heat are within 2% and the thermal diffusivity is within 4% compared with the references.

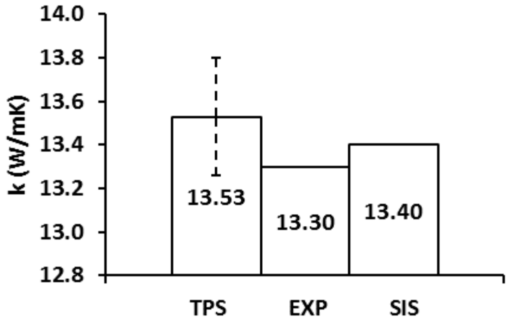
The properties of conventional concrete (Con 1) and an improved concrete (Con 2) were measured with TPS method and their values together with their measured density are summarized in Table I. The results show the increases of 58.2%, 15.5%, 37.0% and 61.4% in thermal conductivity, thermal diffusivity, volumetric specific heat, and density respectively for improved concrete compared to conventional concrete. Increase in thermal conductivity of improved concrete over the conventional concrete is beneficial for lowering heat resistance of the ice slab. Moreover, the increased thermal diffusivity allows the ice rink slab to respond to load and temperature changes more rapidly, although the thermal mass is potentially higher.

(a)

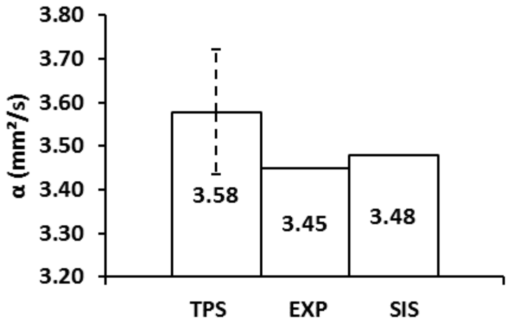
(b)

(c)

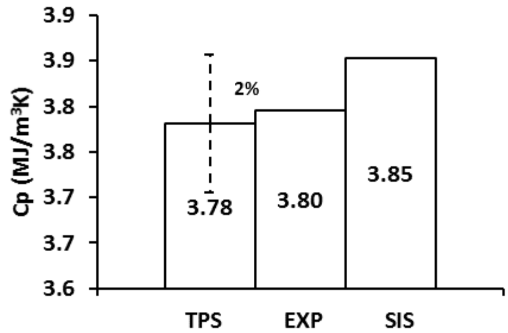
Fig. 3 The setup and arrangement to measure thermal conductivity of concrete samples



(a) Thermal conductivity



(b) Thermal diffusivity



(c) Specific heat

Fig. 4 Thermal conductivity (a), thermal diffusivity (b) and specific heat (c) of stainless steel

TABLE I
THERMAL CONDUCTIVITY AND THERMAL DIFFUSIVITY OF CONCRETE

Materials	k (W/mK)	α (mm²/s)	Cp (MJ/m^{3}K)	ρ (kg/ m^3)
Con 1	1.769	0.989	1.789	2264
Con 2	2.806	1.142	2.451	3637

IV. ICE RINK FLOOR DESIGN AND MODELING

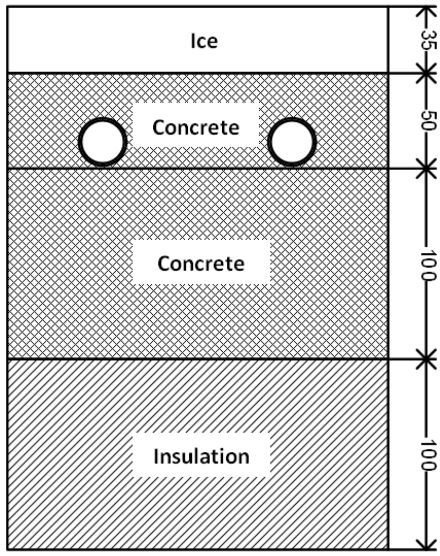
The improved concrete can be integrated in different rink floor designs. Basically two alternative ways to apply the improved concrete in ice pad are suggested. In the first alternative, the original ice pad structure (Model A, Fig. 5 (a)) is changed slightly. In fact, the concrete layer is divided into two layers. The bottom layer consists of the standard concrete and the active top part from the improved concrete. This structure is called Model B in Fig. 5 (a).

In the second alternative the original design (Model A, Fig. 5 (a)) is subjected to major changes (Model C in Fig. 5 (b)). Indeed a different and thicker layer of insulation material is used to reduce the amount of improved concrete, since it is more expensive than the convectional concrete. To guarantee the strength of the ice rink floor the traditional insulation material is replaced with expanded glass. Crashed fracture of expanded glass offers low density, reasonably low thermal conductivity, and high internal friction [16], [17]. These properties give the construction good strength, acceptable cost, and good load compensation. The latter is very important especially for rink floors built on the poor grounds.

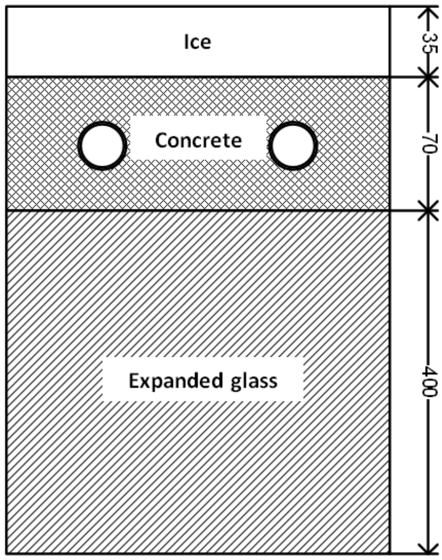
A 2D simulation was developed in COMSOL Multiphysics 4.3b in order to investigate the effect of the improved concrete layer (Model B), as well as the new suggested floor design (Model C) in comparison to the original design (Model A).

The brine is assumed to circulate in the cross-linked polyethylene (PEX) pipes with dimensions of D25×2.3mm and thermal conductivity of 0.38 W/mK [18]. These pipes are embedded in the 50mm thick concrete layer, which is maintained on another 100mm concrete layer in Model A and B. The PEX pipes are embedded in a single layer of 70mm concrete in Model C. In terms of insulation a 100mm layer of extruded polystyrene with thermal conductivity of 0.027 W/mK [15] in Model A and B, and a 400mm layer of Hasopor standard, which is commercially available expanded glass with thermal conductivity of 0.110 W/mk [19] in Model C is used. A layer of 35 mm thick ice with thermal conductivity of 1.88 W/mk [15] is used on top of the rink floor. The heat gained by the ice sheet is absorbed by the secondary refrigerant in the pipes. The measurements values of thermal conductivities of normal and improved concrete (Table I) were used in the model.

The temperatures for the surface of the ice and the bottom of insulations are assumed to be constant and -3°C and +5°C, respectively. Moreover, heat flux is assumed to be constant at the inner surface of the tubes and the steady state condition is modeled. Such boundary conditions are close to reality in rink floors and it is sufficient for this comparative study.



(a) Models A and B



(b) Model C

Fig. 5 Ice pad models A, B and C

V. Results and Discussion

A. Temperature Distribution

An example of the temperature distribution for Model A is shown in Fig. 6. Moreover, the temperature distribution at cross-section A for both Model A and B are plotted in Fig. 7. The result of Model A shows a pipe inner temperature of around -8.49°C is required to maintain ice surface equal or lower than -3°C. For similar condition for Model B and C the temperatures are -7.52°C and -7.47°C accordingly.

Although the temperature along the perimeter of the tube is expected to be almost uniform in practical applications, the results from the model is different (Fig. 7). This can be attributed to the constant heat flux boundary condition that was defined on the wall of the tube in the model.

The case above was calculated for the heat flux of 100 W/m^2 (W per m^2 of ice surface). In reality, a small to medium sized ice rink operates up to heat flux around 150-200 W/m^2, and the heat flux is often greater in large ice rinks and can be reached up to 300 W/m^2 [20]. Fig. 8 shows the results for different heat fluxes. Based on the results both suggested ice pad structures (Model B and C) show higher brine temperatures than the original ice pad (Model A). However, there is almost no difference can be seen between the results from Model B and C. By increasing the heat flux from 100 W/m^2 to 400 W/m^2 the difference between the required brine temperatures of the suggested ice pad structures and the original one gets larger (≈1˚C to ≈4˚C). In the same manner at greater heat flux values the effect of the higher thermal conductivity for the improved concrete becomes more noticeable as the suggested ice pad designs require up to 5˚C higher brine temperature

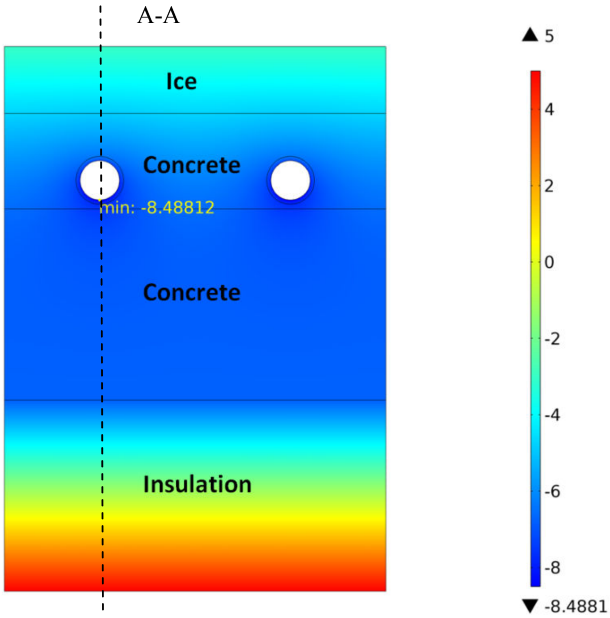


Fig. 6 Temperature distribution plot for Model A for heat flux 100 W/m2

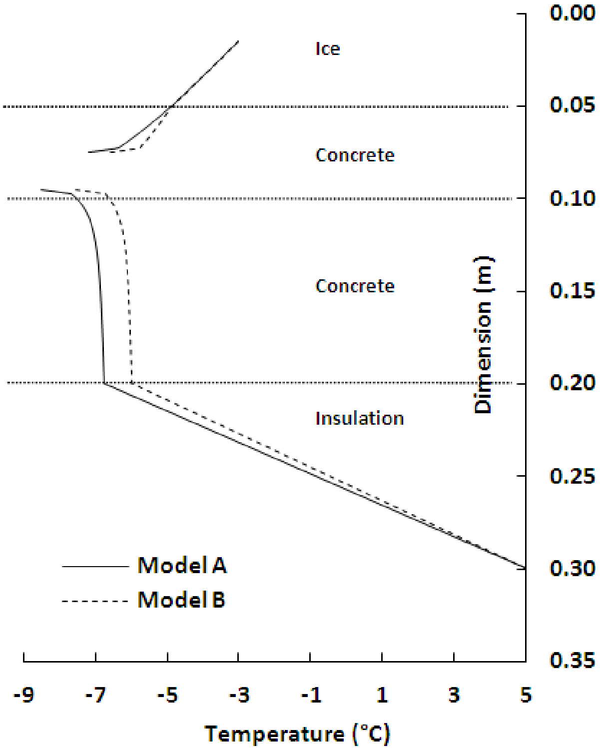


Fig. 7 Model A and Model B temperature distribution comparison at cross section A-A in Fig. 6

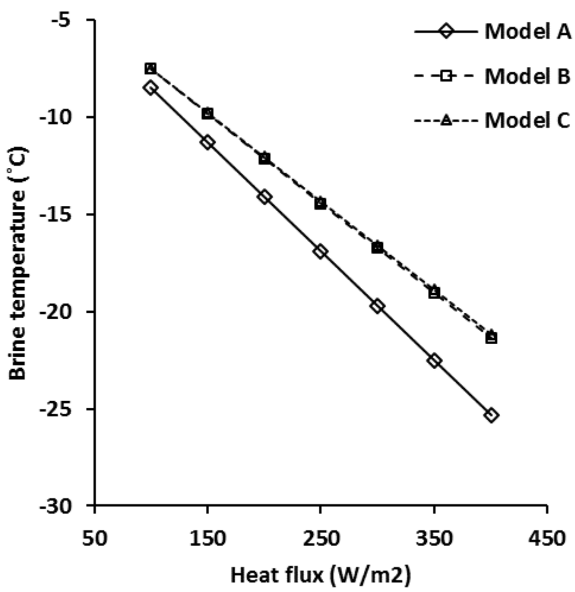


Fig. 8 Brine temperature at different heat flux

B. The Influence of Improved Ice Rink Floor Design on the Refrigeration System

The change in the brine temperature by replacing the original concrete (Model A) with the improved one (either Model B or C) directly influences the efficiency of the refrigeration primary cycle and the pumping power in the secondary loop (Fig. 2). The common way to express the efficiency of refrigeration is Coefficient of Performance (COP). COP is defined as the ratio of extracted heat (by evaporator) to the consumed energy (by compressor).

Fig. 9 shows the increase in COP in percentage when the improved design (Model B in Fig. 5) is replaced the reference design (Model A) at varying heat flux. A single stage ammonia system was assumed for the primary refrigeration cycle with the fixed condensing temperature of 35˚C and a compressor isentropic efficiency of 70% for calculation [21]. The graph shows, on the x-axis, the total heat flux to the floor in the range of 100-400 W/m^2, which indicates that by increasing the heat flux the advantage of using the improved concrete material, is greater. For example, the difference is 3.1% at 100 W/m^2 and 8.4% at 300 W/m^2.

Moreover, the brine temperature increase (Fig. 8) directly influences the pumping power in the secondary loop. The pumping power is defined as:

$$P = (\Delta P)\dot{\forall} \tag{1}$$

where ΔP and $\dot{\forall}$ are the pressure drop and the volumetric flow rate. The pressure drop for a tube with definite length and diameter L and D is defined as:

$$\Delta P = f\frac{\rho u^2}{2D}L \tag{2}$$

where ρ and u are respectively the fluid density and mean velocity. Moreover, f is the friction factor, which in fully developed turbulent flow (the most probable case for ice rink cases) is expressed as:

$$f_{Turb} = 0.316\,\mathrm{Re}_D^{-1/4} \qquad \mathrm{Re}_D \le 2\times 10^4 \tag{3}$$

Hence, the pumping power in the tubes (at given volume flow rate) in turbulent flow, considering the definition of Reynolds number, is a function of $\mu^{0.25}$ [15], [22], where μ is the viscosity of working fluid. For the calcium chloride/water (25% by weight) [23] as the secondary refrigerant this decrement in the brine temperature cases approximately the reduction of 1-5% in the pumping power in the heat flux range 100-400 W/m^2.

Although the improved concrete material increases the cost of the ice rink floor construction, the potential of energy saving is considerable. For the future work a model of dynamic simulation of energy system with various occupying scenarios is suggested to be developed in order to fully assess the advantages of replacing the improved design with the original one. Although the material cost is higher it will be beneficial by a lower refrigeration system investment and operation energy cost.

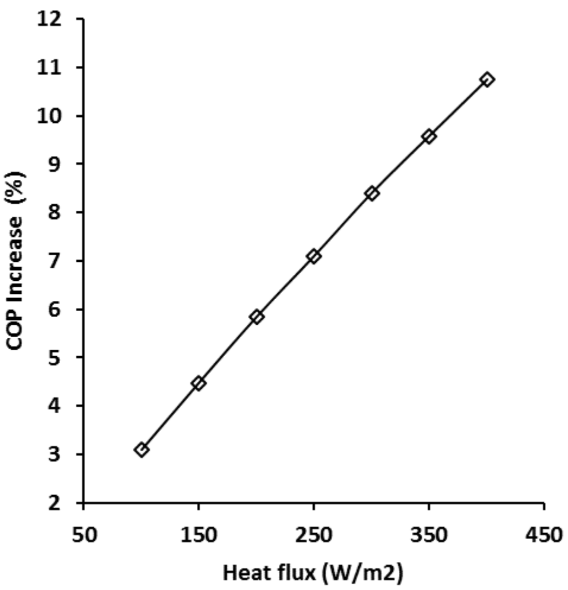


Fig. 9 The influence of improved ice pad on refrigeration system performance

VI. Conclusion

The ice rink floor is one of the most important structures of an ice rink since this is where the action takes place there. The temperature and the quality of ice must be maintained by means of a secondary refrigerant (often brine) by transferring the absorbed heat. Concrete is the material normally used in the rink floor which occupies the space between the brine pipes and the ice surface. The thermal resistance between this concrete and the tubes, containing brine, is an important parameter. Based on the measured data by TPS method adding iron ore to concrete may increase its thermal conductivity up to 58.2%. In order to study the potential of this improved concrete, two new ice pad structures were suggested. A 2D simulation was developed in COMSOL to determine the brine temperature in the original and the suggested models.

The brine temperatures in the suggested models could be increased by 1-4˚C at the heat flux changes in the range 100-400 W/m^2. By increasing the temperature, the viscosity of the brine is reduced and a lower pumping power is required in the secondary loop. Moreover, the coefficient of performance (COP) of the primary cycle increases by increasing the evaporation temperature. By assuming a fixed condensing temperature of 35˚C and a compressor isentropic efficiency of 70%, depending on the load scenario in the ice rink, the saving potential lies in the range of 3-10% of the refrigeration system energy usage. This calculation is based on steady state conditions and the potential with improved dynamic behavior is expected to increase the potential saving. The required pumping power to pump calcium chloride/water (25% by weight) could be reduced up to 5% for turbulent flow for the heat flux of 400 W/m^2.

The potential of incorporating the improved concrete in the rink floor of ice rinks is considerable. As next step it is suggested to develop a dynamic simulation model and a cost analysis for energy system of ice rinks to study the influence of the improved design with different activity and load scenarios.

ACKNOWLEDGMENT

The authors would like to thank Prof. Björn Palm for his helpful suggestions thorough review of our manuscript.

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