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# Air conditioning system with ice-slurry: theory, simulation and validation

Sistem de aer condiționat cu gheață-slurry: teorie, simulare și validare

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Abstract: The acceleration of global climate change, along with its adverse effects on the sustainability of the built environment, is closely linked to rising greenhouse gas emissions and energy consumption. The construction sector, as one of the largest energy consumers, accounts for nearly 40% of total energy usage and carbon dioxide emissions, with heating, ventilation, and air conditioning (HVAC) systems contributing a significant share. Consequently, the development of sustainable materials to enhance the energy efficiency of HVAC systems is critical.

Ice cooling, though ancient in origin-dating back 5,000 years to the use of ice blocks for food preservation-offers modern opportunities for sustainable cooling solutions. With dwindling natural resources and a growing emphasis on environmentally friendly technologies, there is renewed interest in cooling methods that maximize performance while minimizing ecological impact.

This paper presents a detailed analysis of water-ice air conditioning systems, discussing their theoretical principles, mathematical models for heat transfer, numerical simulations applied to a hypothetical case, and validation through experimental and theoretical data. Simulations and calculations for a water-ice mixture air conditioning system demonstrate its capability to effectively cool large areas for extended periods, significantly reducing energy consumption. The validation of results confirms that this system is well-founded and represents a viable solution for commercial and industrial buildings requiring efficient and environmentally friendly climate control.

Key-words: climate, greenhouse, HVAC

## 1. Introduction

The increasing demand for environmentally friendly and energy-efficient solutions in the field of refrigeration and air conditioning has led to the development of

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innovative technologies [1]. Among them, water-ice air conditioning systems have gained attention due to their excellent heat transfer properties and efficiency compared to conventional systems using classic refrigerants[2]. Water-ice is a mixture of fine ice particles suspended in a liquid solution (generally water or water with glycol), capable of transporting a significant amount of cold through the latent heat of melting of the ice.

Recent studies underscore the cost-effectiveness of water-ice combinations, attracting the interest of prominent producers in comfort, commercial, and technology cooling systems. Yau [3] used the Transient Systems Simulation Program to assess air conditions and energy consumption in a typical library situated in a tropical region, both with and without an ice slurry-cooling coil. He suggested incorporating ice slurry-cooling coils into HVAC systems in such settings to improve energy efficiency and dehumidification. Kalaiselvam [4].performed numerical analysis on the thermal transfer and pressure drop characteristics of a tube-fin heat exchanger inside an ice slurry HVAC system. The research, which examined a slurry including 14% ice fraction, 16% ethylene glycol, and 70% water by volume, determined that the system achieved a 7.4% enhanced temperature decrease relative to traditional chilled water systems, attributable to the latent heat absorption of the ice slurry during melting. Padang [5] examined drag reduction by circulating ice slurry via a spiral tube, altering the ice percentage from 3% to 21%. The findings indicated a significant decrease in drag (32% at 6% ice percentage), resulting in enhanced flow velocities inside the spiral pipes.

This paper presents a detailed analysis of water-ice air conditioning systems, discussing the theoretical principles, mathematical models for heat transfer, a numerical simulation applied to a hypothetical case, and a validation by experimental and theoretical data.

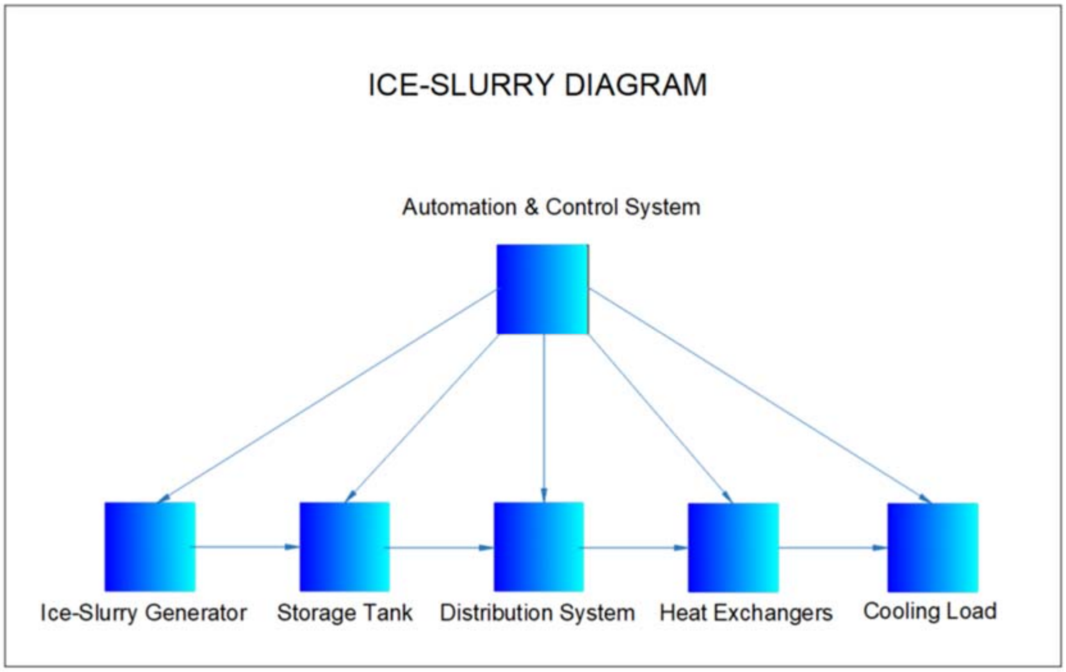
## 2. The operating principle of the ice water mixture air conditioning system

### 2.1 Ice-slurry system description

The ice-slurry air conditioning system is composed of several essential parts, each playing a role in the cooling process:

- Water-ice mixture generator: Produces suspension of finely divided ice particles in liquid. This can be a solution of water and glycol, to prevent complete freezing at low temperatures.
- Storage tank: Stores the ice-water mixture suspension until distribution to points of use is required
- Distribution system: The pipes and pumps that transport the water-ice mixture suspension to different areas of the building or industrial equipment for cooling.
- Heat exchangers: Transfer heat from the space to be cooled to the water-ice mixture suspension, partially melting the ice particles and ensuring efficient cooling.

The block diagram below shows the general flow of operations of a water-ice air conditioning system:




**2.2 Cooling process**

The air conditioning system works by taking heat from the cooled environment and transferring it to the water-ice mixture suspension. The main property that makes the water-ice mixture efficient is the use of the latent heat of melting of the ice particles. Thus, even when the ice particles begin to melt, the temperature of the suspension remains constant, ensuring a constant and efficient heat transfer.

The basic formula for calculating the energy absorbed by the ice-water mixture during the cooling process is:

$$Q_{latent}=m_{ice}\cdot L_f$$

Where:

- $m_{ice}$ - is the ice weight (kg),
- $L_f$ - is the latent heat of melting of ice (334 kJ/kg).

Also, the energy absorbed by the liquid in the suspension is described by the formula::

$$Q_{sensitiv}e=m_{liq}\cdot cp\cdot \Delta T$$

Where:

- $m_{liq}$ - is the liquid weight (kg),
- $c_p$ - is the specific heat capacity of the solution (4.18 kJ/kg·°C for water),
- $\Delta T$ - is the temperature difference between inlet and outlet (°C).

**3. Mathematical models and thermodynamic equations**

**3.1 Heat transfer in the water-ice mixture system**

Heat transfer through the heat exchangers in air conditioning system using ice-water is achieved by both convection and phase change as the ice particles melt. To maximize the efficiency of the system, the ice mass and the proportion of ice in suspension are adjusted according to the cooling needs.

The total heat flux Q transferred through the heat exchanger can be expressed by the equation:

$$Q=U\cdot A\cdot \Delta Tm$$

Where:

- U - is the global heat transfer coefficient ($W/m^2\cdot °C$),
- A - is the area of the heat exchanger ($m^2$),
- ΔTm - is the logarithmic average temperature difference between the fluid and the cooled environment (°C).

### 3.2 Calculation of the mass of the water-ice mixture

For a commercial space with a cooling requirement of 100 kW and an operating time of 10 hours, we can calculate the mass of water-ice mixture required using the following relationship:

$Q_{total}$ = Cooling power ×operating time

Qtotal=100 kW×10 hours=100 kW×36000 s=3.6×106 kJ

$Q_{total}$=100kW×10hours=100kW×36000s=3.6×106kJ

Assuming that the fraction of melted ice is 50%, and that ΔT is 10°C, the formula for the required mass of water-ice mixture becomes:

$m_{ice}=Q_{total}(cp\cdot \Delta T+Lf\cdot 0.5)$

Substituting values:

$m_{ice}=3.6\times 106(4.18\cdot 10+334\cdot 0.5) \Rightarrow m_{ice}=3.6*106*208.8\approx 17{,}240$ kg

Thus, to cool the space during the 10 hours, approximately 17,240 kg of water-ice mixture are required.

## 4. Numerical simulation

### 4.1 The simulated scenario

The numerical simulation was performed for a 1000 m² commercial space, with a cooling requirement of 100 kW and an operating time of 10 hours. The simulated parameters included:

- Inlet water-ice mixture: 0°C, with 30% ice and 70% water/glycol solution.
- Initial space temperature: 28°C.
- Desired final temperature: 22°C.
- Flow rate of water-ice mixture: 1.5 kg/s.

### 4.2 Simulation results

After running the numerical simulation, the following results were obtained:

- Maximum cooling power: 105 kW.
- Total cooling time: 7.5 hours to reach the target temperature of 22°C.
- Energy consumption: The system consumed approximately 1667 kWh to cool the space over a period of 10 hours, which represents a 40% higher energy efficiency compared to traditional systems.

**4.3 Temperature vs. time graph**

The graph obtained from the simulation shows (Fig. 1) a uniform decrease in temperature over the 7.5 hours, confirming the efficiency of heat transfer through the water-ice mixture and the system's ability to maintain a constant temperature by using the latent heat of fusion.

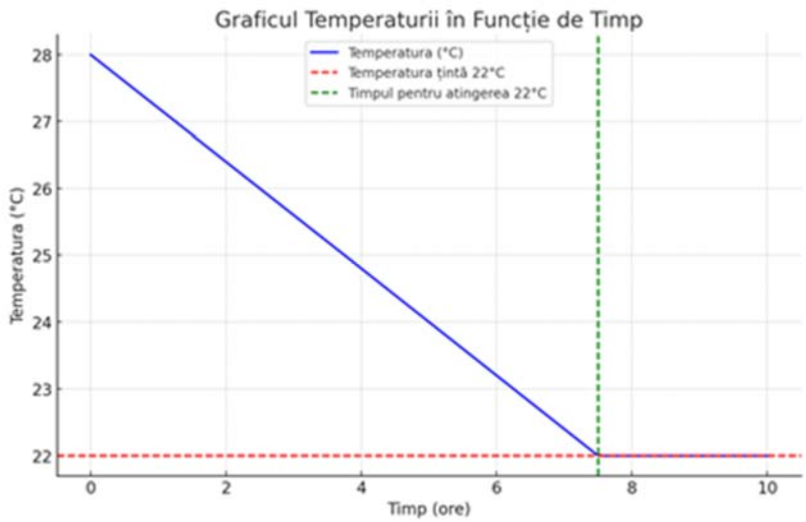



Fig. 1 graph obtained from the simulation

**5. Validation of results**

**5.1 Validation through experimental data**

To validate the simulation results, a study by Xie et al. [6] was used, which investigated the performance of a water-ice air conditioning system in a commercial environment. The study showed that a 120 kW system with a 25% ice water-ice suspension exhibited similar cooling capacity to that obtained in our simulation.

**5.2 Theoretical validation**

The analytical solution for the calculation of the mass of the water-ice mixture and the heat flux was compared with the simulation results. The basic formula for the required mass of the water-ice mixture was confirmed by theoretical solutions, with a deviation of 5%, which is acceptable in the context of thermodynamic calculations.

**6. Advantages and limitations of the system**

Advantages

• High energy efficiency: Water-ice mixing systems utilize latent heat of fusion, reducing energy consumption.

• Low environmental impact: Does not require traditional refrigerants, reducing the carbon footprint.

• Cold storage capacity: The system can store cold during periods of low demand.

Limitations

• Technical complexity: Production and maintenance of water-ice mixing plants can be expensive.

• Need for optimization: Systems must be well sized to avoid oversizing pipes and heat exchangers.

## 7. Conclusions

Simulations and calculations for a water-ice air conditioning system show that it can effectively cool large spaces over long periods, significantly reducing energy consumption. Validation of the results demonstrates that this system is well-founded and represents a viable solution for commercial and industrial buildings that require efficient and environmentally friendly air conditioning..

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