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ПИЩЕВЫХ СИСТЕМ
ИМ. В.М. ГОРБАТОВА
РАН

ВНИИ ХОЛОДИЛЬНОЙ
ПРОМЫШЛЕННОСТИ

All-Russian Scientific Research Institute of Refrigeration Industry - branch of “V.M. Gorbatov Federal Research Center for Food Systems” of Russian Academy of Science

Investigation of heat and mass transfer processes during film flow around ice surfaces with a phase transition to create a new generation of ice banks

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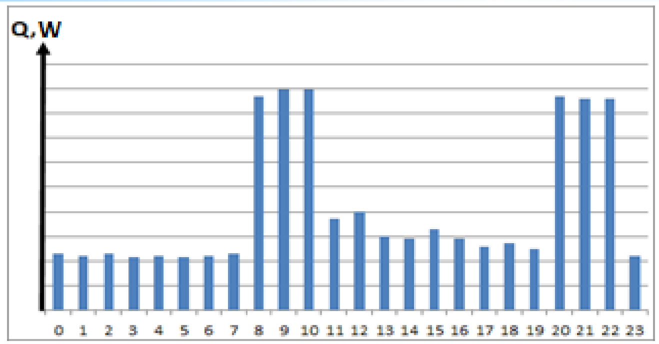
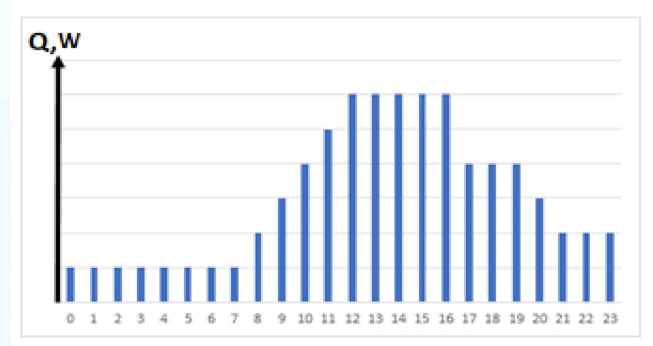
1.Relevance

Cooling of food processing facilities with a high degree of uneven heat load distribution



Typical daily distribution of heat load at a grassroots dairy enterprise



Typical daily distribution of heat load at an industrial dairy enterprise

REFRIGERATION

Cooling without ice bank

1.High equipment cost
2.High electricity price during daytime operation
3. The total refrigerating capacity of the refrigeration units should be equal to Qmax - the maximum heat load

Benefits of ice bank

1.Reduction of capital costs for refrigeration equipment
2.Reducing energy costs when using the night rate
3. The total refrigerating capacity of the refrigeration park is significantly lower than Qmax - the maximum heat load

2.Purpose of Research

Studying the processes of heat and mass transfer during film flow around ice structures with a phase transition to create heat exchangers of a new generation with a high efficiency of heat removal, coupled with the graph of the current heat load is the purpose of research.

Water ice

t_{melt}=0°C

non-toxic

$\lambda=335\ \frac{kJ}{kg}$

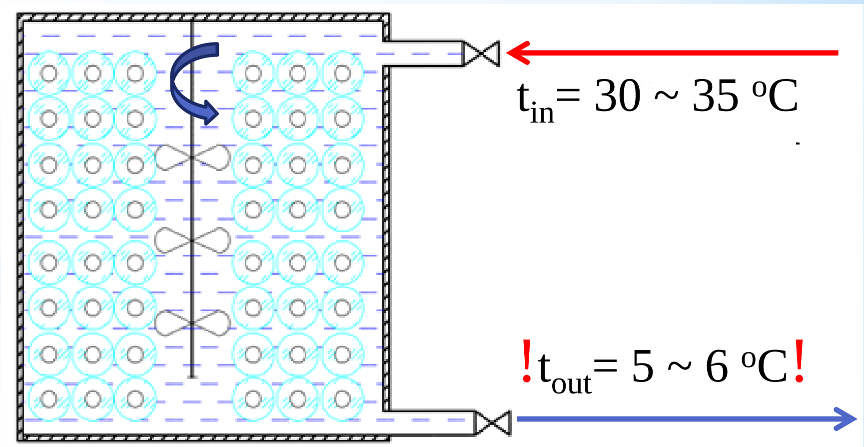
The main disadvantage of this type of ice banks is the low heat transfer coefficient when ice is melted in a large volume

α= 300 ~ 500 W/(m^{2*}°C) ⟶ ↑ t_{out}

Problems to be solved:

- **development of an experimental stand**
- **development of research methods**
- **experimental research**
- **determination of the influence of the flow rate and temperature of the supplied water on the efficiency of heat and mass transfer**
- **processing of experimental data and analysis of the results.**

Volumetric melting ice bank



Volumetric ice bank discharge process

3.Advantages of film melting

Film flow without phase transition

Application: Spray - type heat exchangers

Feature: High efficiency of heat transfer

Existing dependencies:

$$\alpha = a\frac{\Gamma^{0,257}}{H^{0,05}}(1+bt)\ (Ploeg)$$

$$\alpha = 40\frac{\Gamma^{0,4}}{d^{0,6}}\ (\text{Adams})$$

$$\alpha = 122 l^{0,4} (\text{Semilet})$$

$\alpha > 5000$ W/(m^2*ºC)

Volumetric melting

Application: Volumetric melting ice banks

Feature: Phase transition of ice in the volume of liquid

α= 300 ~ 500 W/(m^2*ºC)

Film flow around melting surfaces

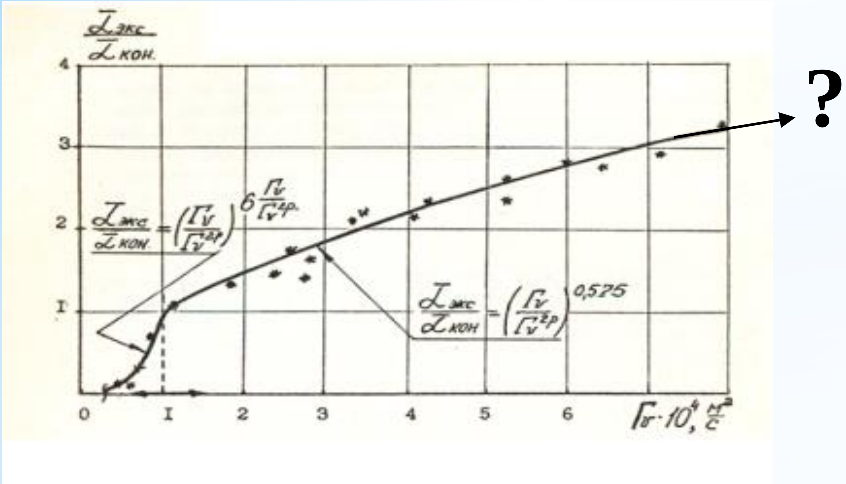
Application: Film Ice banks

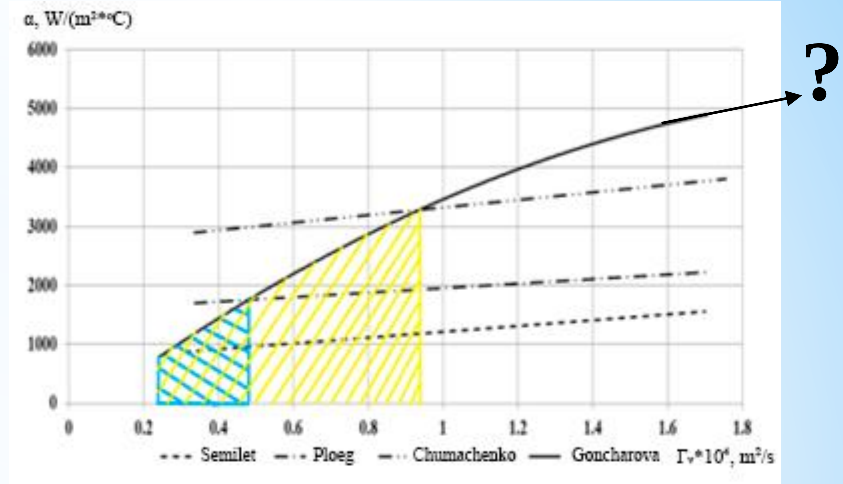
Feature: High efficiency of heat exchange + phase transition of ice

Existing dependencies : **?**

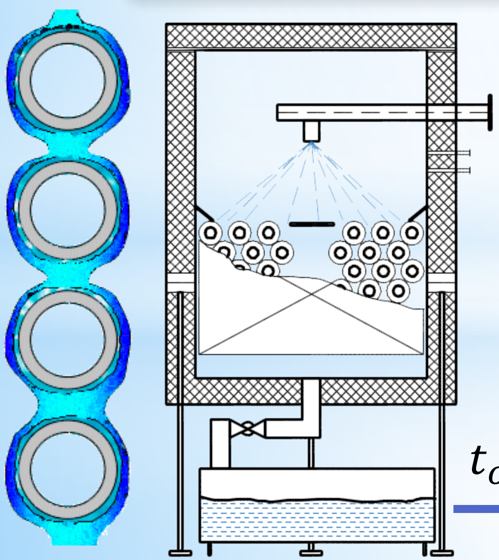
α= 7000 W/(m^2*ºC)

4.Results of the literature review





Data obtained in the study of horizontally separated flow around coaxially located cylindrical ice surfaces.



$t_{out} = const$

Sketch of a film coaxial ice bank

Main operating parameter

$$\Gamma_v = \frac{G}{2 * \Pi} \left(\frac{m^2}{s}\right)$$

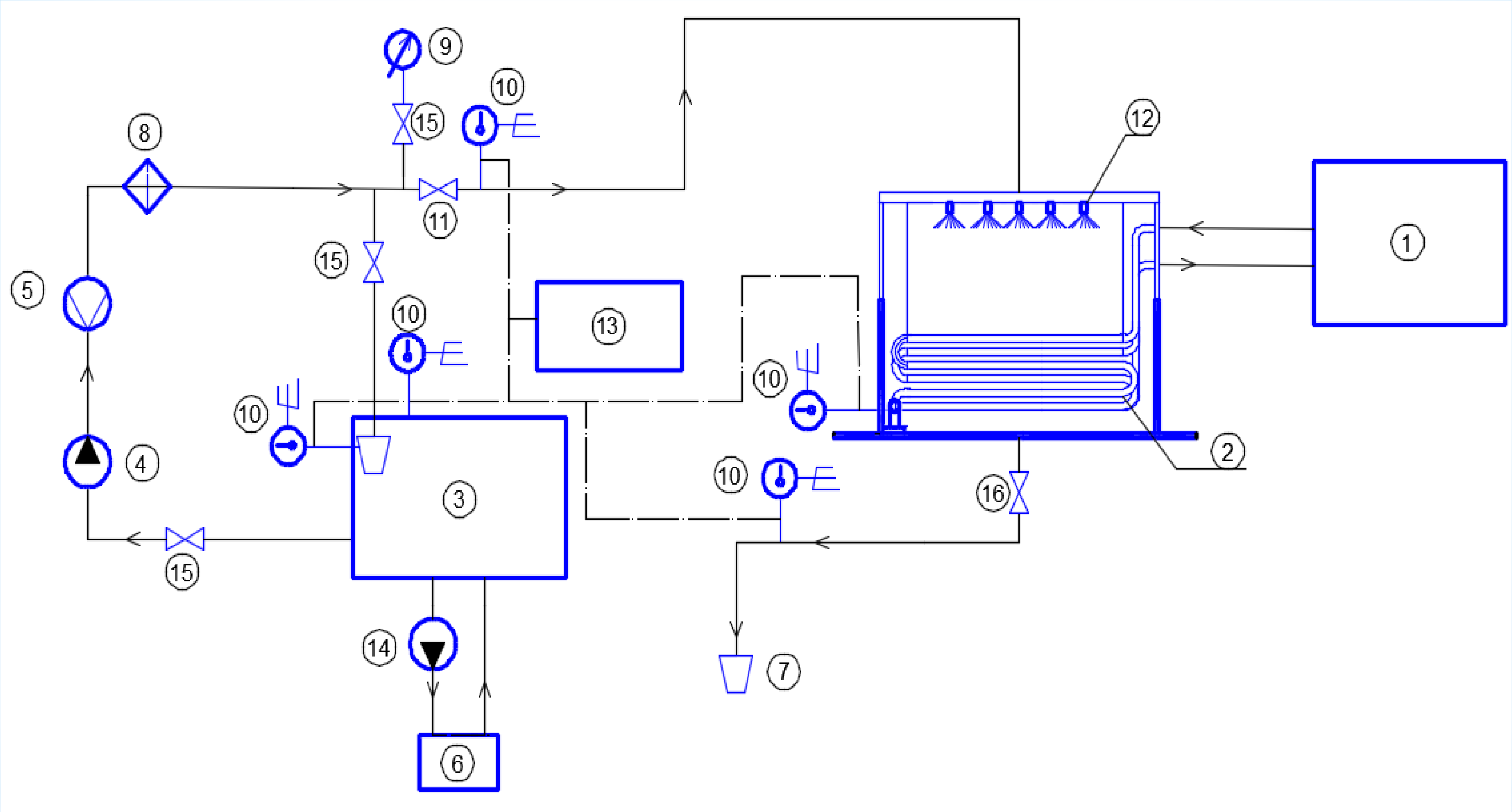
G – flow rate $(\frac{m^3}{s})$

Π – linear perimeter m

Thermal balance for a cooled fluid flow

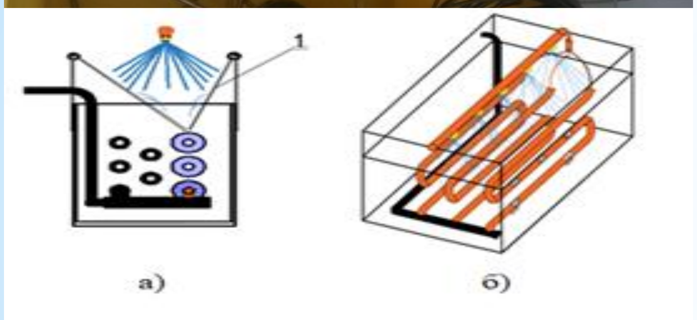
$$\frac{m_{в_i} * Cp_i * (t_{in_i} - t_{out_i})}{\Delta\tau} = \frac{r * m_{m_i} + m_{m_i} * Cp_i * (t_{out_i} - t_0)}{\Delta\tau}$$

5.Scheme of the experimental stand



Scheme of the experimental stand: 1 - Compressor-condensing unit, 2 - Ice bank, 3 - Storage tank, 4 - Pump with frequency changer, 5 – Mass flow meter, 6 - Heater, 7 - Measuring tank, 8 - Filter, 9 - Manometer, 10 - Electronic thermometer, 11 - Regulating valve, 12 - Nozzles, 13 – Data recorder, 14 - Submersible pump, 15 – Shut-off valve, 16 - Flush valve

6. Experimental stand



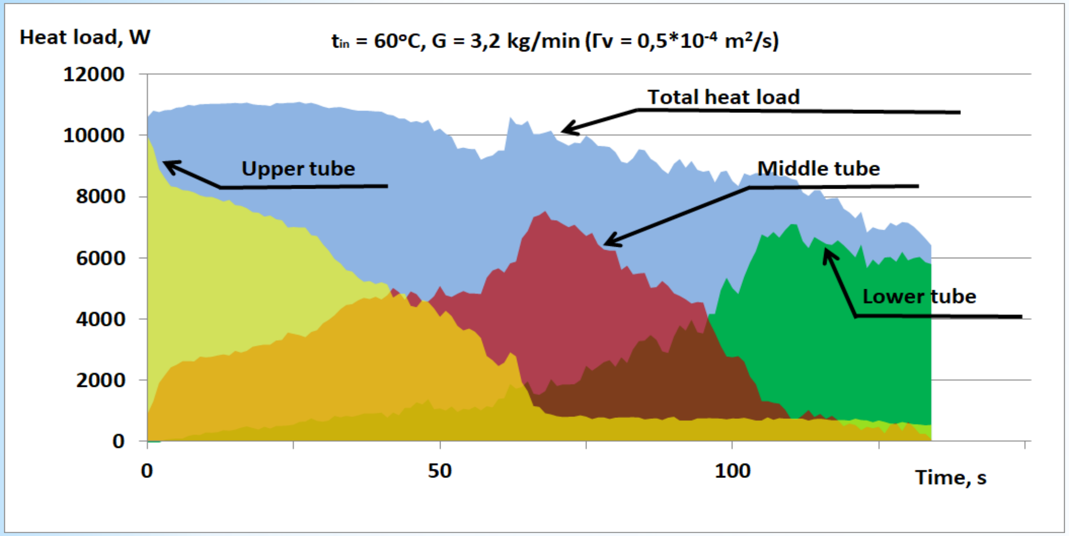
Film heat exchanger with flat coils (PTA): a) water distribution during irrigation of one section; b) a three-section heat exchanger with water supply through nozzles: pos. 1 - slotted water distributor

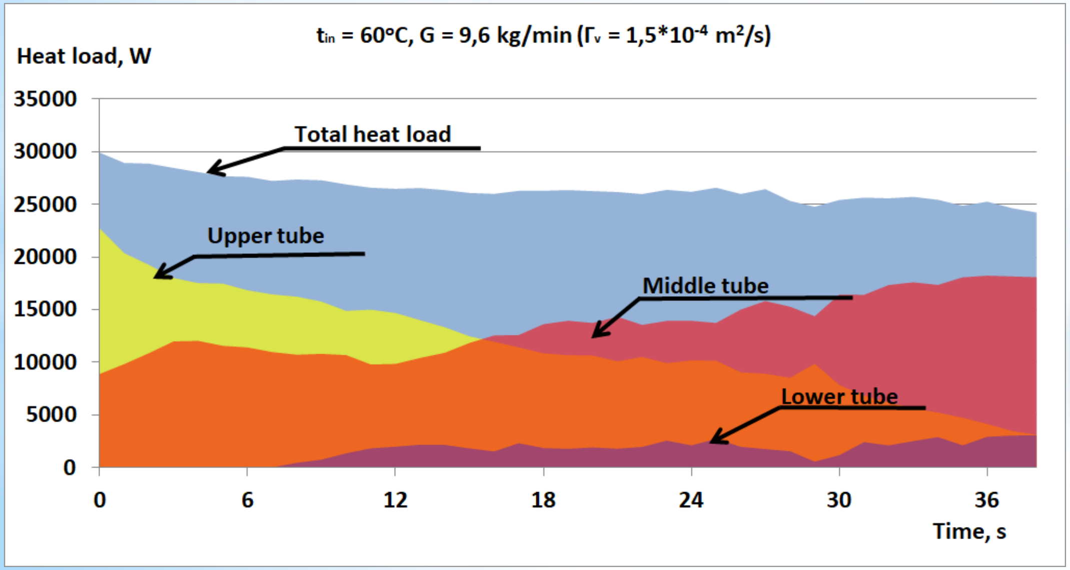
Coaxial film heat exchanger

It is necessary to determine:
-Discharged heat Load Q
- Heat transfer coefficient α

The study was carried out with the financial support of the Russian Foundation for Basic Research within the framework of scientific project No. 20-08-00120

7.Discharged heat load





Diagrams of heat load distribution between pipes of one FHE section S=0,078 m^2 .

Range of change of operating parameters

Parameter	Regulation range
Water inlet temperature	from 20 °C to 60°C
Flow rate of water	from 3,2 kg/min to 9,6 kg/min
Density of irrigation	from $0,5*10^{-4}$ m^2/s to $1,5*10^{-4}$ m^2/s

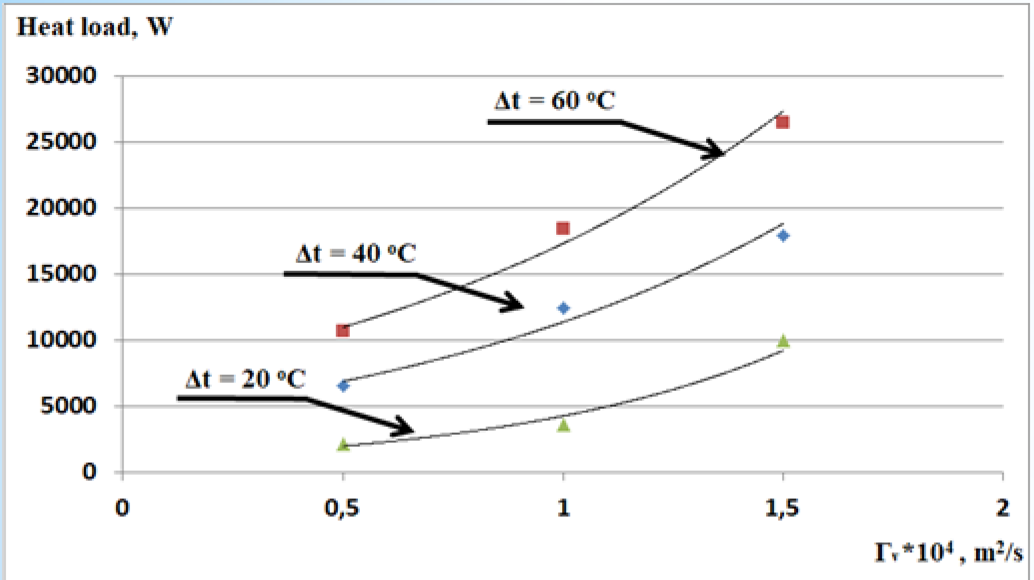
Specific heat load [kW/m^2]

Comparative characteristics

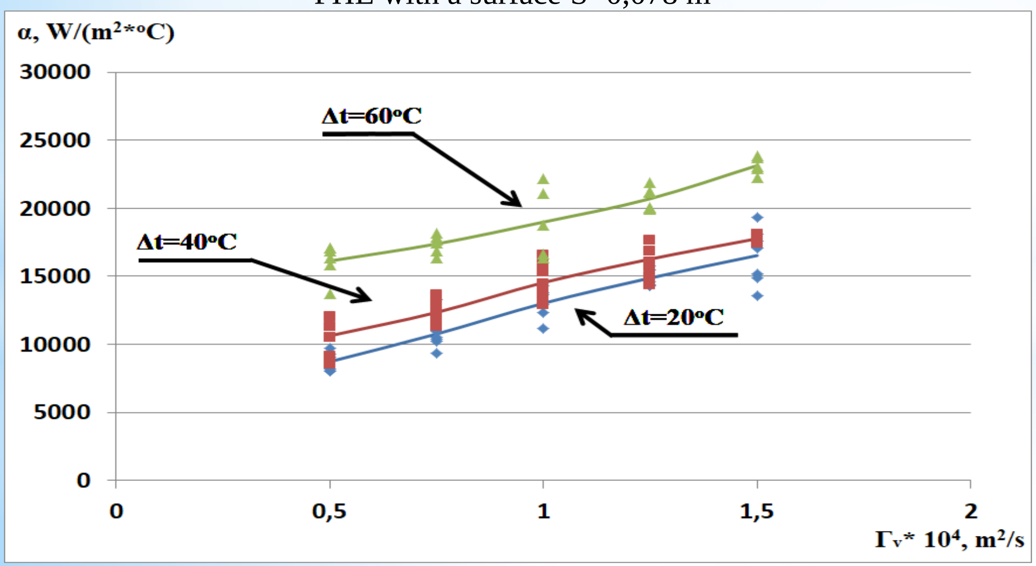
Plate heat exchangers :
from 12 to 65 kW/m^2

Film heat exchanger (FHE):
from 120 to 320 kW/m^2

8.Efficiency of heat transfer



The graph of the dependency of the heat load removed by one section of the FHE with a surface S=0,078 m^2



Dependency of the heat transfer coefficient on the density of irrigation

Newton-Richman law

$$q = \alpha(t_{liq} - t_s)\ \frac{W}{m^2}$$

α – proportion coefficient

α=f(Re, Δt)

$$F_{ice} = var \longrightarrow F_{FHE}$$

$$\alpha = \frac{Q_i}{(t_{liq} - t_{ice})F_{FHE}}$$

9.Conclusion

The advantage of the film ice bank has been experimentally proven with respect to the volumetric ice bank:

- the ability to cool water from a temperature of 60 ° C to 1 ° C in one pass;
- an experimental dependency of the heat transfer coefficient for a film ice bank on the irrigation density has been obtained.

In the investigated range, the values of the heat transfer coefficient are ~22000 W/(m^2*°C) reduced to the surface of the heat exchanger and ~7000 W/(m^2*°C) in relation to the melting surface, and in ice banks with volumetric melting do not exceed 300 - 500 W/(m^2*°C).

Specific heat load of FHE reaches 320 000 W/m^2, significantly exceeding the same value for plate heat exchangers, which, according to open sources is from 12 000 to 65 000 W/m^2

Fields of application:
-Dairy industry
-Brewing industry
-Air conditioning
-Emergency and abnormal surges in thermal load
-Cooling of systems with a pulsed heat sources (cooling of lasers, etc.)

Thank you for your attention!

Additional materials

Use of the natural cold of outside air