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Evaluation of small-capacity cube ice maker models with tube-in-tube evaporator technology and R22 refrigerant and selection of the model suitable for Vietnam conditions

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----------ABSTRACT----------
Currently, in the world in general or Vietnam in particular, there are many types of cube ice maker with different capacity ranges from large capacity to small capacity to meet the needs of from industrial production to household scale. The tubular ice making machines are manufactured by many brands such as Linde, Doelz (Germany), Vogt, Escher (USA), and some firms of French, Korean, but the general operation principle of these machines is the same. and have a working principle, mainly using a flooded liquid evaporator. At present, the Institute of Energy Science - Vietnam Academy of Science and Technology has successfully used a tube-in-tube evaporator technology to help reducing the amount of refrigerant circulating in the system for saving energy, reducing energy consumption per unit of product. The above advantages contribute to reducing environmental pollution, saving energy and reducing production costs
KEYWORDS;-Cube ice, ice maker, small capacity, tube in tube, energy saving

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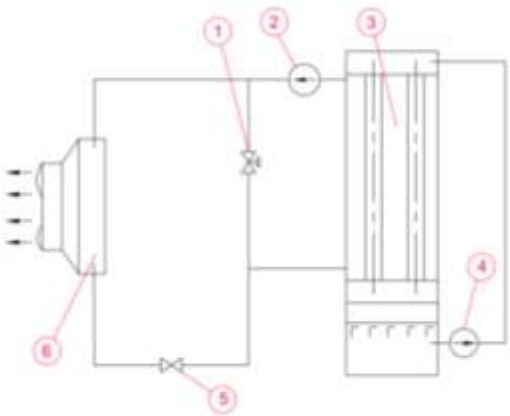
I. INTRODUCTION

Cube ice making machine (also called Cube ice machine) uses process of freezing water, turning water from liquid to solid at the atmospheric pressure through intermediate agent is refrigerant. Refrigerant is a mixture of organic substances such as C, H, Cl characterized by low boiling point and low condensation temperature; The ability to absorb heat and release heat rapidly should be used as an intermediary in the producing process. Refrigerant circulating refrigeration in a closed system includes 4 main devices: compressor, condenser, throttle valve, evaporator (cooler), the operation of the refrigerant in the system make changing the state of the refrigerant, at the evaporator, the refrigerant at low temperature, low pressure will exchange heat with water through the tube wall, refrigerant receives heat of water and changes the state of water from liquid state to solid state at atmospheric pressure. Then the refrigerant evaporates and goes out of the evaporator, then continuously performing a cyclic cycle in the system. Water after losing heat changes from liquid state to solid and then taken out to form cube ices for daily use or for food storage.

II. EQUIPMENT AND OPERATION PRINCIPLES

The technology of tubular cube ice machine uses tube-in-tube evaporator.



1. Solenoid valve for letting out cube ice
2. Compressor
3. Evaporator (mill-ice)
4. Pump for pumping cold water
5. Throttle valve
6. Condenser

Figure 2.1: Operation principle of a tubular cube ice machine using R22 and evaporator according to the principle of tube-in-tube

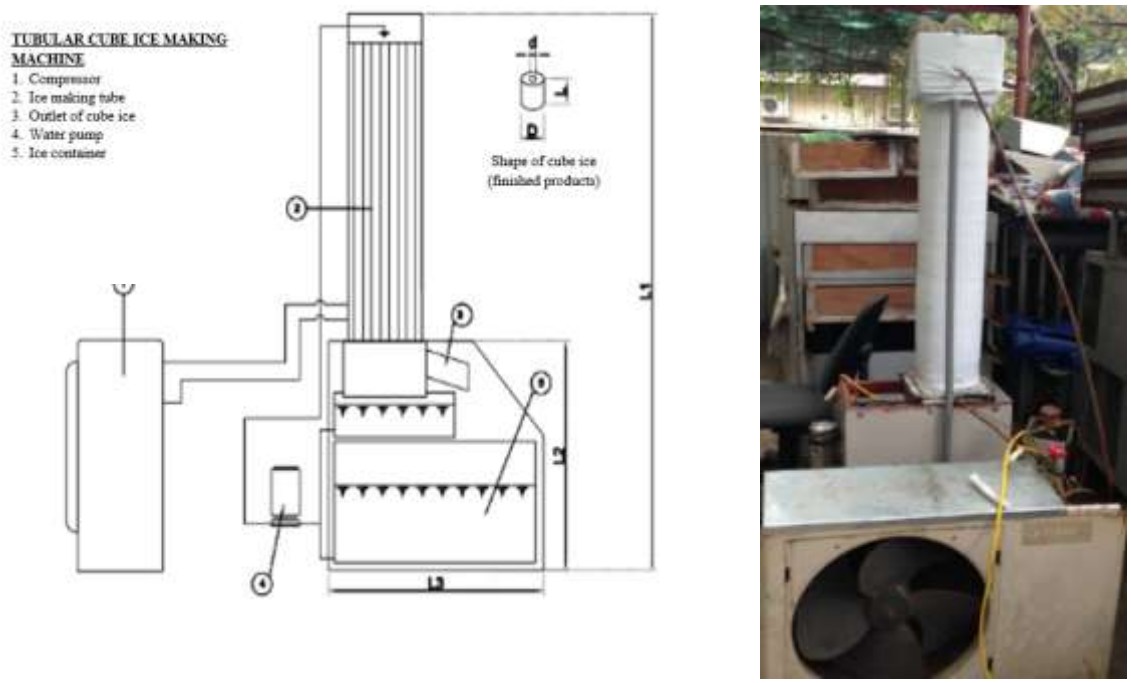


Figure 2.2: Tubular cube ice machine using R22 and evaporator according to the principle of tube-in-tube

Principle operation:

Refrigerant agent cycle: The refrigerant moves around in a closed duct system. Compressor (2) draws the refrigerant from the evaporator (3) - tubular mill-ice, then performs adiabatic compression and pushes to the condenser (6), where the vapor of the refrigerant releases heat to change its state from steam to liquid under constant pressure conditions, then the refrigerant is passed through the throttle (5) to reduce pressure, reduce the temperature to go to boiling liquid state and go into the evaporator – mill-ice (3) to carry out the process of freezing water in evaporator tubes. After that, the refrigerant is attracted by the compressor (2) and continue to perform a closed loop.

Water cycle: Water is pumped by pump (4) from the tank to the water divider at the top of the mill-ice (3). The water is then distributed into tubes in the mill-ice. Here the water enters the innermost tube, the agent R22 enters the narrow gap between the two tubes (fixed in tube-in-tube before). The process of reverse movement of two fluid flows (water and refrigerant) through the baffles of the pipes in the mill-ice (3) conducts the heat exchange process; agent absorbs heat to be evaporated and water spreads heat to be compensated. The process takes place continuously until the cube ice is formed in the pipes that meet the size requirements, then turning to letting out cube ice stage. After letting out cube ice, the machine resumes for the next cube ice making batch, the process above is continuous.

III. RESULTS AND DISCUSSION

The testing of a small capacity tubular cube ice machine model using gas R22 and evaporator operating under the principle of tube-in-tube has the following results:

- The total amount of R22 agent loaded in the system is: 0.9 kg
- Time of Ice making/batch: 18 - 20 minutes
- Time of letting out cube ice: 2-3 minutes
- Total amount of cube ice made in 1 hour: 7-8 kg/h
- Energy consumption rate: 0.118 kWh / kg

Compared with similar machines using a flooded liquid evaporator, the parameters of cube ice machine designed by IES have decreased some of the following criteria: Gas usage rate using R22: G1 = 0.9/1.33 = 0.68 kg/HP; Energy consumption rate (electricity): D1 = 0.94/8 = 0.111 kWh/kg; For Ice Horse machine of Lam Son: The capacity of 20 HP has the amount of R22 used about 170kg, the total power consumption of about 14.5 kWh produces 105 kg so the indicators are as follows: GLS = 170/20 = 8.5 kg/HP, D¬LS = 0.138 kWh/kg; For NeotNC 2518 made in Korea has a capacity of 12000BTU; production 150 kg in 24 hours, electricity consumption of 1.2 kWh, thus GNC = 6.25/1.33 = kg/HP, Dn = 1.2/6.25 = 0.19 kWh/kg. Thus, compared to the same-use machines for making cube ice and using R22 as intermediate agent, the small capacity tubular cube ice machine of IES has gas usage rate GIES = 1/12 GLS; GIES = 1/7 GNC; power consumption DIES = 73% DLS;

DIES = 62% DNC, thus compared to other machines with the same purpose of making cube ice and using the same R22 as intermediate agent, IES's small capacity tubular cube ice machine has guaranteed the following criteria: reduce the amount of gas R22 circulating in the system and reduce energy consumption per unit of product. This helps reduce product costs, reduces equipment costs and helps reduce environmental pollution by limiting the amount of gas R22 circulating in the system.

With the above results, the Institute of Energy Science - Vietnam Academy of Science and Technology has built and tested 04 models of small capacity tubular cube ice machine with parameters according to Table 3.1.

Table 3.1: Parameters of small capacity tubular cube ice machine using R22 medium with evaporator operated according to the tube-in-tube principle.

	Unit	Model 1	Model 2	Model 3	Model 4
Capacity of tubular cube ice machine	kg/h	8 - 10	16 - 20	30	80
Manufacturing cost of cube ice making machine	VND	9000000	15000000	22000000	60000000
Cube ice machine price (expected)	VND	10800000	18000000	26400000	72000000
Maintenance costs (10% of the machine purchase)	VND	900000	1500000	2200000	6000000
Operating wages	VND/month	500000	1000000	2000000	4000000
Electric consumption	kWh/h	1.0	1.6	2.5	7.0

Table 3.2: Calculation of economic and financial efficiency of models (basic plan);

Items	**Unit**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Investment	VND	10800000	18000000	26400000	72000000
Cost of O&M (5% investment)	VND/year	1080000	1800000	2640000	7200000
Labor cost	VND/year	6000000	12000000	24000000	24000000
Electricity consumption	kWh	4000	6400	10000	28000
Electricity price	VND/kWh	2500	2500	2500	2500
Electric bill	VND/year	10000000	16000000	25000000	70000000
Total cost (C)	VND/year	17080000	29800000	51640000	101200000
Production of cube ice	kg/year	32000	64000	120000	320000
Ice selling price (expected)	VND/kg	800	800	800	800
Revenue (B)	VND/year	25600000	51200000	96000000	256000000
Cash flow (B-C)	VND/year	8520000	21400000	44360000	154800000
Discount factor	%	10.00	10.00	10.00	10.00
NPV	VND	9443617	57384397	128872092	468012538
B/C		1.19	1.48	1.64	2.13
EIRR		59%	1.16	1.67	2.14
Payback time	year	1.27	0.84	0.60	0.47

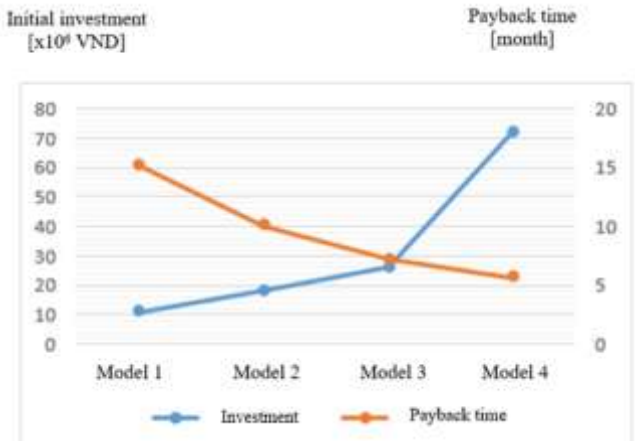


Figure 3.1. The chart shows the investment cost and payback period of the 4 models with different capacity ranges

From the calculation table of financial and economic efficiency of the above models, we have a graph of the cost of cube ice machine and payback period (Figure 3.1); If the machine's capacity increases, the payback period decreases as follows: When the machine capacity is doubled, the investment cost increase by 66%; payback period decreases by 33.4%; Product cost decreases by 13.33% compared to model 1. Thus, with most economic conditions of the Vietnamese people, cube ice machine model 2 with a capacity of 16 – 20 kg/h is suitable for the conditions of households, household group and some small-scale hotels, which can combine both cube ice making and heat source for the purpose of drying clothes or hot water.

IV. CONCLUSION

In Vietnam, the demand for cube ice for domestic and production purposes is huge, thus cube ice maker use tube-in-tube technology of the Institute of Energy Science, the Vietnam Academy of Science and Technology is suitable for households and household groups, with low cost, model 2 with a capacity of 16 - 20kg/24h, total power consumption of 1.6kW, investment cost of about 18,000,000 VND; payback period in 10.08 months; Energy consumption rate: 0.118 kWh/kg is perfectly suitable for Vietnamese household conditions.

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