AStudy of Thermal Performance of a Natural Refrigerant for Ice Machine

Putu Wijaya Sunu[1][a], I Dewa Gede Agus Triputra[1][b], I Wayan Edi Arsawan[2][c]
I Made Ari Dwi Suta Atmaja[3][d], Ketut Suarsana[4] and Hari Satiyadi Jaya[5]
[1]*Mechanical Engineering Department, Bali State Polytechnic, Badung, Bali, Indonesia*
[2]*Business Administration Department, Bali State Polytechnic, Badung, Bali, Indonesia*
[3]*Electrical Engineering Department, Bali State Polytechnic, Badung, Bali, Indonesia*
[4]*Mechanical Engineering Department, Udayana University, Badung, Bali, Indonesia*
[5]*Mechanical Engineering Education Department, Palangka Raya University, Palangka Raya, Central Kalimantan, Indonesia*

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Abstract: Today, ice is frequently used for home as well as commercial purposes, including chilling and preserving food and serving drinks, among other things. In the current study, mathematical models and practical research have been used to examine a mini-ice machine system for making cube ice that uses natural refrigerant (R-290). Due to environmental concerns, the development of natural refrigerant applications has surged recently. The most recent experiment was carried out utilizing R-290, a mini-ice maker that can crank out 50 cubes of ice every cycle. The outcome showed that the ice maker's efficiency was around 2.77 for five cycles and three repeats. As a result, this study also includes images of ice-related items. It is clear that when the number of ice production cycles increases, the quality of ice products also improves. The fifth production cycle produced the finest outcomes. The investigation's anticipated findings make it possible to widespread use of natural refrigerants, particularly for ice makers.

1 INTRODUCTION

Ice is now widely used for drinks, food preservation, and cooling, which supports all industrial sectors and a variety of other commercial and home functions, particularly in tropical nations (Thongdee and Chinsuwan, 2019). Prior to the invention of industrial commercial ice machines, ice was manufactured in big ice factories and provided to business users in the form of blocks or shaved ice. The ice industry has evolved. Ice blocks no longer dominate commercial sales, particularly among small and medium-sized businesses (MSMEs). In addition to direct consumption, ice cubes presently dominate the ice market. With a side dimension of roughly 20 mm, this type of ice is becoming increasingly popular due to its shape, which is suited for modern industry. Ice cubes are made in a vertical freezer equipped with numerous 20-mm cube molds. A bundle cube is a mold with a stainless-steel casing. Water from the ice raw material enters the freezer through a nozzle sprayed from the top of the cube bundle. A circulation pump pumps water from the bottom of the water reservoir to the nozzle. The refrigeration system's refrigerant cools the cube bundle, which serves as the evaporator. The refrigerant absorbs heat from the water as it passes. The temperature of the water progressively drops until it becomes ice. The transformation to ice begins on the outside of the mold and gradually moves within.

[a] https://orcid.org/0000-0002-6915-0475
[b] https://orcid.org/0000-0002-5054-7876
[c] https://orcid.org/0000-0002-9912-629X
[d] https://orcid.org/0000-0002-1103-528X

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The main refrigerant for the ice machine system is known to be R-134, which has a rather high global warming potential value of roughly 1300 due to its fluorine component. Climate change will accelerate as a result. As a result, the industry has begun to be encouraged to move from R-134a to a more ecologically friendly refrigerant under the Kyoto and Montreal protocols. (Gurel et al., 2020) performed a thermodynamic analysis on four different types of refrigerants as reduced GWP alternatives to replace R-134a in the refrigeration system. R-290, R-600a, R-1234yf, and R-1234ze were the alternative refrigerants investigated. As a consequence, R-600a and R-1234ze were identified as the two best contenders to replace R-134a in refrigeration applications. In contrast to the previous study, (Cleison et al., 2020) shows the ideal design, environmental analysis, and energy optimization for R-290, R-1234yf, and R-744 as R-134a replacement refrigerants. R-290 has been chosen as the best choice in terms of global warming impact and energy efficiency. Hydrocarbon refrigerants, particularly propane, butane, and isobutene, are being considered as an ecologically benign replacement to R134a. Hydrocarbon refrigerants also outperform R134a in small-capacity residential refrigerator applications (Reddy et al., 2016). In a separate application, they simulated a system employing the refrigerants R-134a, R-1234yf, R-290, R-744, and R-600a in a water heater with a heat pump using solar energy (Willian et al., 2019).

The R-290 result has the best performance. According to the aforesaid assessment, there is a possibility of replacing HCFC/HFCs with ecologically benign refrigerants. The usage of hydrocarbon refrigerants is fairly satisfying and suitable since it meets all of the requirements as an alternative refrigerant, with the exception of its drawbacks, which are that hydrocarbon refrigerants are highly combustible. Energy performance evaluation of hydrocarbon refrigerants (R600a, R290) and R152a as low-GWP alternatives to R134a (Global Warming Potential). Another study in the realm of ice manufacturing machines and their optimization (Pannucharoenwong et al., 2017) looked at how wavy fin optimization may boost efficiency in tubular ice production. Increased efficiency is attained by increased production and freezing process speed. The ice storage method is also related with environmental challenges, namely how to decrease peak load in the application (Jia et al., 2015; Murphy et al., 2015; Lo et al., 2016; Song et al., 2018; Hao et al., 2020). When the ice production process was examined using the direct contact approach (Wijeysundera et al., 2004; Hawlader et al., 2009), it was discovered that the thermal resistance is low and the thermal efficiency is good, but there are limitations, such as nozzle blockage.

The system comprises of two circulation pumps and a cube-shaped heat exchanger. The pump circulates the feed water to the heat exchanger, which transfers the heat to the refrigerant. To determine its performance, performance metrics from the refrigerant side will be recorded. The goal of this paper is to test and utilizing cool pack software to determine the operating parameters of an ice cube-type commercial ice maker that employs refrigerant R-290 (Sunu et al., 2017, 2020). To improve component function for ice cube manufacturing, ice cube machines are developed and manufactured to be evaluated for vapor compression cycle performance.

2 EXPERIMENTAL METHODS

In the refrigeration laboratory, a prototype of an ice cube machine was built, as shown in Fig. 1. The experimental test rig consists of an evaporator in the shape of a cube mold with 50 cubes, a water circulation pump, a water pump for pumping the source water, and a set of refrigeration equipment, which includes a compressor, condenser, and capillary tube. The hermetic compressor consumes 220 W of power, has a voltage of 220-240 V, and a frequency of 50 Hz. This ice maker is constructed using an ecologically friendly operating fluid, R-290. The use of a capillary tube on an ice maker will make it easier to start since the pressure on the condenser and evaporator is always the same while the system is not running.

The refrigerant liquid (R-290) is compressed to a superheated vapor state inside the compressor at high pressure and temperature. It condenses into a completely liquid state once it enters the condenser coils of the air-cooling condenser. The process then proceeds to the capillary tube, where it enters the evaporator as a liquid-gaseous combination with a decrease in temperature and pressure. The circulation pump circulates water, which warms the evaporator, which then returns to a superheated vapor state.

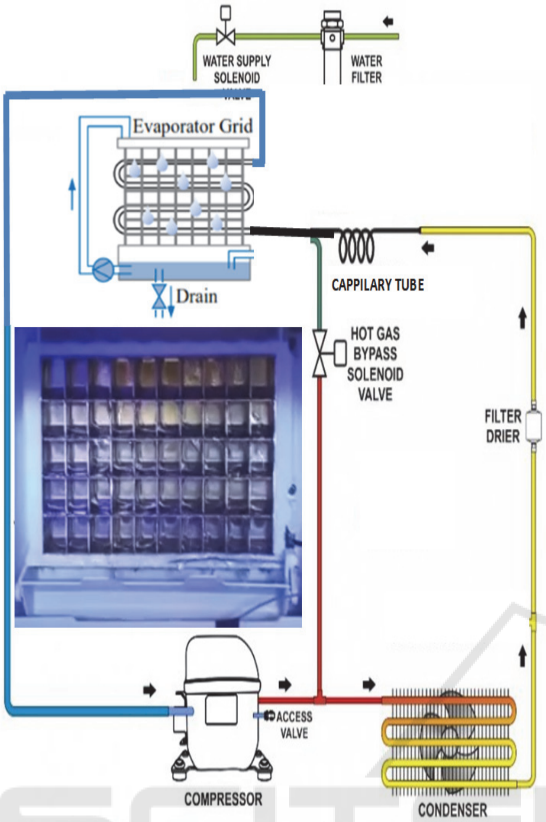

Figure 1: Experimental setup.

This is a preliminary study to determine the suitability of R-290 as an alternative refrigerant in ice machine systems. The test findings include information on pressure, temperature, electric current, and time of ice formation. The temperature and pressure data points collected are the evaporator's exit temperature, the compressor's exit temperature, the condenser's exit temperature, the evaporator's inlet temperature, the temperature of the water leaving and entering the evaporator, and the low and high pressures of the refrigeration system. Five rounds of the ice-making process are recorded. Figure 2 depicts the process of heat entering and exiting the system, as well as the work done by the compressor, allowing the COP of the refrigeration system to be calculated as follows:

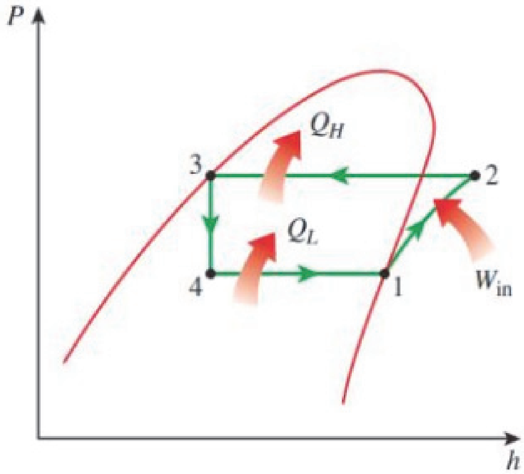

Figure 2: P-h Diagram.

The following is the fundamental formula for estimating the performance of the refrigeration system:
In the evaporator, heat is absorbed.

$$Q_e = h_1 - h_4 \quad (1)$$

Coefficient of performance (COP),

$$COP = Q_e / (h_2 - h_1) \quad (2)$$

Where Qe is heat absorbed by evaporator [kJ/kg]; h1 is enthalpy of R-290 at outlet evaporator [kJ/kg]; h2 is enthalpy of R-290 at outlet compressor [kJ/kg]; h4 is enthalpy of R-290 at outlet capillary tube [kJ/kg]; and COP is Performance coefficient.

K-type thermocouples attached to the copper tube wall and inserted within the water were used to measure the temperatures of the water. All temperature data was translated to digital form and saved in computer memory using a data logger with a frequency of 1 Hz. A digital ammeter with a data collecting precision of 0.1 A was utilized to monitor the compressor's current. Two analog pressure gauges were utilized to monitor the refrigerant pressure at each refrigeration system state point in the cycle. The goal of this investigation is to determine the theoretical value of an ice cube refrigeration system's coefficient of performance (COP). The temperature is used to calculate the enthalpy of each location and its COP.

3 RESULT AND DISCUSSION

Every minute, data from all of the experimental variables was collected. The theoretical parameters of system performance were then computed using equations 1-2. Figure 3 depicts the analysis display on the Coolpack 1.5 program. The pressure-enthalpy thermodynamic study of the refrigeration system from the first to the fifth cycle is shown in Figure 3. Figure 3 shows that the cycle line is near the bottom of the first cycle. This is due to the fact that the average system pressure is still lower than in previous cycles, and the system has not yet achieved operational stability.

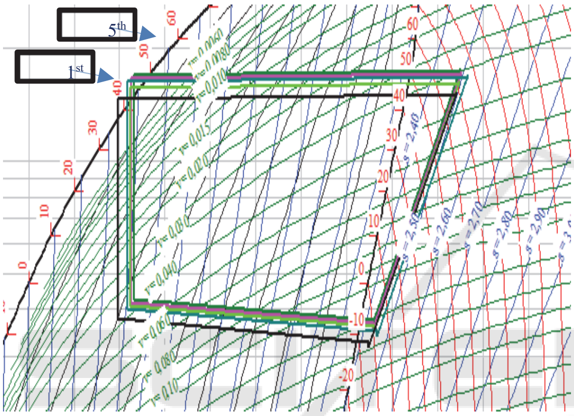

Figure 3: The p-h diagram from coolpack 1.5.

The quantity of heat absorbed by the evaporator, compressor work, and the performance coefficient (COP) of the refrigeration system all indicate this operating situation. As shown in Figure 4, as the working time increased, the cooling load dropped somewhat as the temperature of the ice water fell. As seen in Figure 5, this circumstance reduces the amount of work done by the compressor.

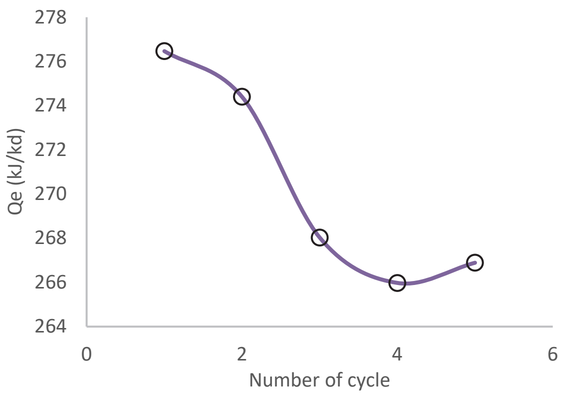

Figure 4: Heat absorp by the evaporator system per-cycle.

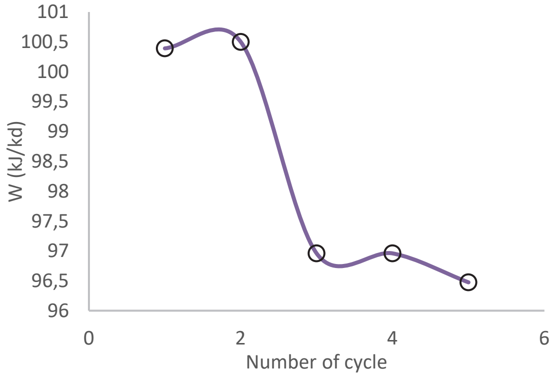

Figure 5: Theoritical work of compressor refrigeration system per-cycle.

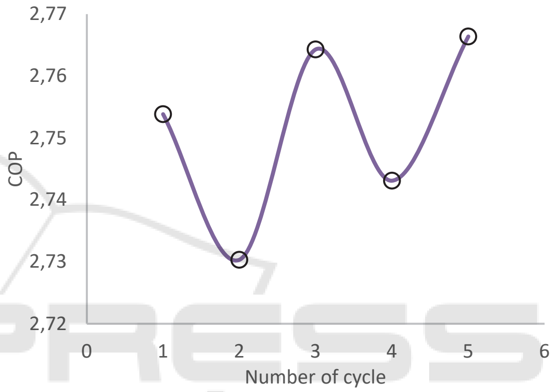

Figure 6: COP refrigeration system per-cycle.

Figure 6 depicts the entire system, with the COP value gradually increasing. This phenomenon is induced by the evaporator's temperature and the temperature of the ice water, which are both growing cooler, reducing the system's cooling burden.

Figure 7 depicts the ice quality generated throughout each ice-making cycle. As the number of cycles rises, there is a visible improvement in ice cube cooling, particularly at the level of ice thickness.

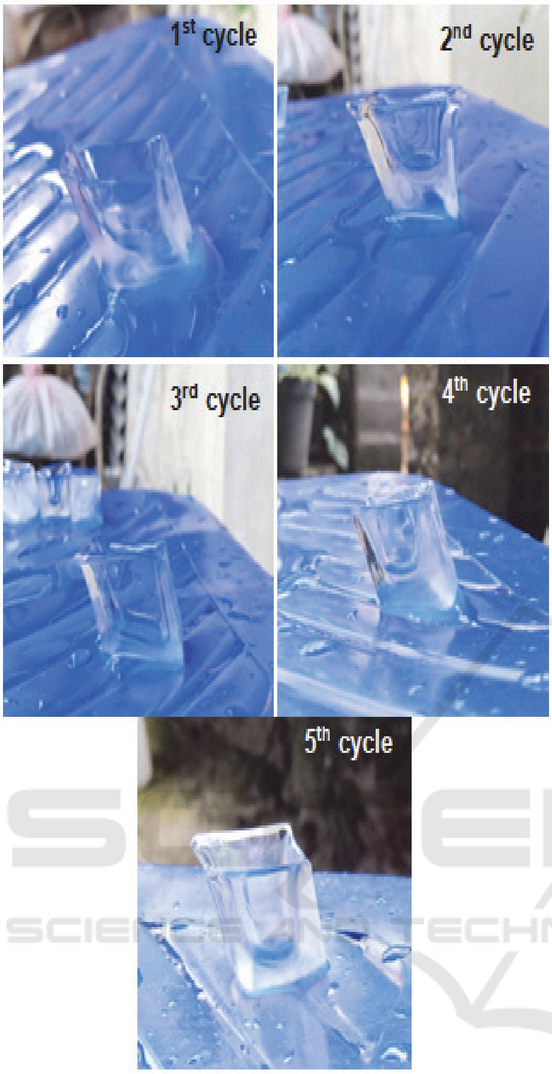

Figure 7: Ice display per cycle.

4 CONCLUSIONS

The goal of this research is to acquire experimentally the operating parameters of an ice cube type commercial ice maker that employs R-290 refrigerant. An experimental setup was created to validate the influence of the number of ice-making cycles on the refrigeration system's performance parameters and the visual look of the ice cubes. Based on the findings of this study, it is possible to conclude:

1. The suggested technology may be used for environmental sustainability by employing the natural refrigerant R-290.
2. Based on current operating circumstances, the best COP achievable is around 2.77, which occurs during the fifth ice-making cycle.
3. As the number of cycles increases, the aesthetic attractiveness of the resultant ice cube improves.

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