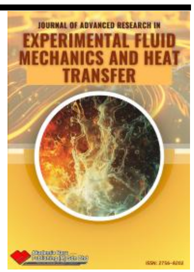
Penerbit Akademia Baru

Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer

Journal homepage: http://www.akademiabaru.com/submit/index.php/arefmht

ISSN: 2756-8202



Study on Capillary Pipe Length Variation on Fishing Refrigeration Box Performance

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ARTICLE INFO

Article history:
Received 23 April 2025
Received in revised form 15 May 2025
Accepted 11 June 2025
Available online 10 July 2025

Keywords:
Capillary pipes; refrigeration system; COP

ABSTRACT

One of the components that significantly influences the performance of a cooling (refrigerator) box onboard a fishing ship is its capillary pipes. To achieve high system efficiency, the size of the capillary pipes must be adjusted to the compressor's capacity. This is because the size of the capillary pipe significantly affects the frictional resistance, which could lead to reduced system efficiency. To find out the length of the capillary pipe that is best at reducing the temperature of the fishing refrigeration box, experiments were carried out in this study with 3 (three) variations of capillary pipe lengths with the same diameter. It was found that the best temperature drop occurred at a capillary pipe length of 2.5 m with the lowest temperature of 3.4 °C. In comparison, the less-than-maximum temperature drop occurred in the 2 m capillary pipe length with a final temperature of 13.4 °C. Changes in capillary pipe length also impact the coefficient of performance (COP) of the fishing refrigeration system. The highest COP was obtained for the case with the longest capillary pipe length.

1. Introduction

Most traditional fishermen have only utilized traditional methods to freeze their catches. The traditional method of using ice blocks is regarded as a simple and economical method. The primary purpose of freezing fish using ice blocks is to reduce the growth of bacteria. By preventing bacterial growth, the decay of the fish can be delayed. The captured fish are frequently stored in the ship's loading room (hatch). This conventional storage of the fish using the traditional freezing method could extend the fish's freshness to only one or two days [1]. Consequently, an efficient and eco-friendly cooling system is essential. A solar energy-based fish cooling system is a viable choice for this purpose. Moreover, its utilization and implementation are often more straightforward than other renewable energy sources, and it may also be effectively applied to fishing vessels [2].

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https://doi.org/10.37934/arefmht.21.1.126135

Generally, the application of cooling systems is notably varied, one example being the steam compression refrigeration system. Steam compression systems are the most commonly used refrigeration systems. In steam compression refrigeration systems with small capacity, the expansion tool that is often used is capillary pipes. A study was conducted by Homzah *et al.,* [3] on the effect of variations in capillary pipe length and diameter on COP in basic cooling system trainers. The capillary pipes used were 0.026 inches and 0.042 inches in length of 200 cm, 150 cm, 100 cm, and 50 cm, respectively. The purpose of this study was to analyze the COP in the basic trainer of the cooling (refrigeration) system and provide recommendations on the diameter of the capillary pipe and the length of the efficient capillary pipe. To achieve high system efficiency, the capillary pipe size must be adjusted to the compressor capacity because if the capillary pipe size is not suitable, the frictional resistance in the capillary pipe is not suitable, which results in reduced efficiency of the system [4].

2. Literature Review

2.1 Fishing Boats

According to the Indonesian Government regulation No. 11 of 2023, fishing vessels refer to ships, boats, or other buoyancy devices used in various fishery-related activities, such as catching fish, supporting fishing operations, fish farming, transporting fish, processing fish, fisheries training, and fisheries research/exploration. A fishing vessel is described as a vessel used to catch fish, including activities such as storing, cooling, and/or preserving fish. A fish transport ship, on the other hand, refers to a vessel specifically designed to transport, load, store, collect, store, cool, and/or preserve fish [5].

2.2 Fishing Storage

Fish is categorized as one of the most rapidly decomposing foods. Damage or degradation of fish quality could occur shortly following the fish's death. The deterioration of fish quality can be delayed with low-temperature treatment. Utilizing low temperatures through coolers and freezers can inhibit metabolic activities or bacterial activity within the fish's body. Table 1 shows the relationship between temperature, bacterial activity, and fish quality.

Table 1
Relationship between temperature, bacterial activity, and fish quality

No.	Temperature (°C)	Bacterial activity	Fish quality
1	High temperature:		
	25-10	Very fast.	Fast deterioration, very short service life (3-10 hours).
	10-2	Slower growth.	Slow quality degradation, short shelf life (2-5 days).
2	Low temperature:		
	2-1	Bacterial growth is much reduced.	The deterioration of quality is somewhat inhibited, the durability is reasonable (3-10 days).
	–1	Activities can be suppressed.	As a minimum drop wet fish, the durability of wet fish (5-20 days).
3	Ultra-low temperatures:		
	(–2) - (–10)	Pressed, inactive.	Minimum deterioration of the quality of frozen fish, long shelf life (7-30 days).
	–18 and lower	Pressed to a minimum, bacteria are left inactive.	Better quality of frozen fish, durability up to a year.

From Table 1, it can be noted that the temperature required to cool fish has its temperature recommendation, starting from 5 °C, which is only enough to preserve the fish for 4 days, and if it is up to -1 °C, then the freshness of fish can be extended to 15 or even 20 days [6].

2.3 Refrigeration Systems

A refrigeration machine, better known as a refrigerator, is a device that functions to take heat from inside the room and release it to the outside of the room with the aim of lowering the temperature of the object or room below the ambient temperature, creating a lower temperature. Therefore, the operation of a refrigeration engine always involves the process of heat flow and heat transfer [7]. In daily life, refrigeration technology is better known in the form of products such as ice, refrigerators (household refrigerators), ice factories, and others. In the fisheries sector, an example of use is cold storage, which functions as a storage place for fish. Fish is a perishable food, and refrigeration techniques have proven to be effective in keeping it fresh so that it still looks like it was freshly caught out of the water. Therefore, the fishery sector can widely apply cooling techniques [8].

2.4 Components of the Refrigeration System

The components that make up the refrigeration system so that it can maintain the desired temperature and ensure that the product remains in optimal condition are as follows.

2.4.1 Compressor

The compressor is one of the most important components in a refrigeration system, and it functions to compress refrigerant or freon in a reversible (reversible) and isentropic (constant entropy) manner. The work or effort given to the refrigerant will cause an increase in pressure so that the refrigerant temperature will be greater than the ambient temperature, or the refrigerant will undergo a superheat phase. The compressor pumps refrigerant to all components through the piping system.

2.4.2 Condenser

The condenser will convert high-pressure refrigerant vapor into high-pressure liquid with the help of the cooling medium present in the condenser, be it air or liquid. This process involves the transfer of heat from the refrigerant to the refrigerant medium so that the refrigerant can change phase from gas to liquid. In this process, the heat coming from the room, as well as the heat generated by the compressor, will be absorbed by the cooling medium, which is then released into the surrounding environment [9].

2.4.3 Filters

The filter on the refrigeration machine is made of copper and functions as a filter to remove dirt particles carried by the refrigerant. This filtration process aims to prevent blockages in the capillary pipe, especially since the capillary pipe has a smaller diameter than other pipes. This filtered dirt can be in the form of dust residues that may be carried during the welding process, or water vapor that is still left in the system [10].

2.4.4 Capillary pipes

The simplest refrigerant rate control system is the capillary pipe. If the frictional resistance of the capillary pipe is too large because the capillary pipe is too long or too small, then the capacity of the pipe to deliver the liquid refrigerant from the condenser to the evaporator becomes smaller compared to the compression capacity. As a result, the evaporator lacks liquid refrigerant, which causes the impact to go down [11,12]. On the other hand, the liquid refrigerant in the condenser rises, so the condensing pressure rises. The effect of the evacuation is lacking [13,14]. On the other hand, if the frictional resistance of the capillary pipe is too small because the capillary pipe is too short or too large, then the capacity of the pipe to deliver the liquid refrigerant from the condenser to the evaporator becomes greater compared to the compression capacity [15]. As a result of the evaporator's excess liquid refrigerant, the pressure rises. Not all liquid refrigerants can evaporate in an evaporator. The compressor sucks the refrigerant liquid [16]. Therefore, appropriate capillary pipe sizes are essential to obtain optimal efficiency.

2.4.5 Evaporator

An evaporator is one of the main components of a cooling system through which a refrigerant liquid flows to absorb heat from the cooled product while changing phases. The temperature of the refrigerant inside the evaporator is always lower than the ambient temperature, so heat can flow into the refrigerant. Heat from the cooling room flows in through the insulation layer. In addition, there are various other heat sources in the cooling room, such as heat from the product [17].

2.4.6 Refrigerant

Refrigerant, often called Freon, is a liquid that absorbs heat at low temperatures and repels heat at higher temperatures. Due to the temperature pressure relationship, the principle of refrigerant makes it possible to use outdoor and indoor units directly to run them well. This temperature-pressure relationship makes it possible to transfer heat. Refrigerant is very important in a refrigeration system because the refrigerant functions as a fluid that can absorb heat in the evaporator and then release the heat after entering the condenser. Refrigerant will act as a heat-absorbing and transferring medium by changing its phase. Refrigerant is a substance that easily changes its phase from liquid to vapor and vice versa when the pressure and temperature conditions are changed.

2.5 Working Principle of the Refrigeration System

The working principle of the refrigeration engine, as shown in Figure 1, starts from a compressor that functions to suck and press the refrigerant with high pressure in the form of gas flowing towards the condenser. There is a condensation process from gas to liquid. Before entering the condenser, there is a strainer that functions as a filter for dirt so that it does not enter the capillary pipe. From the condenser, the refrigerant flows into the capillary pipe/expansion valve, and then there is a decrease in temperature and pressure [18].

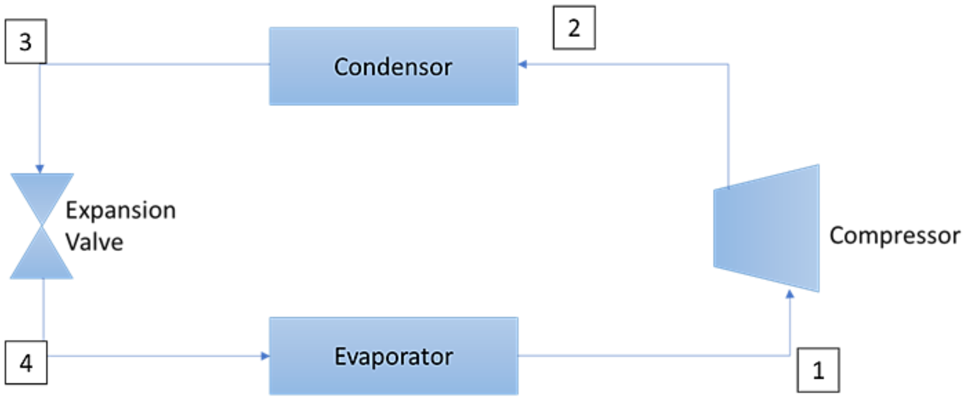

Fig. 1. Refrigeration system working cycle

The working processes follow the following order.

i. Process 1-2 (compression) is the process of compression of refrigerant vapor from the initial state of low pressure and temperature, which is compressed reversibly and isotopically so that the pressure and temperature become higher than the ambient temperature.
ii. Process 2-3 (condensation) occurs in the condenser where the refrigerant vapor with high pressure and temperature then enters the condenser to release heat into the environment until it changes phase into high-pressure liquid refrigerant.
iii. Process 3-4 (expansion) is when the liquid refrigerant that is still at high pressure then enters the expansion device to lower the pressure so that the temperature drops (lower than the ambient temperature), and part of the liquid refrigerant changes phase to steam.
iv. Process 4-1 (evaporation) occurs in the evaporator, which is the process of evaporation of liquid refrigerant into saturated steam again due to the addition of heat from the load in the evaporator, to then re-compressed in the compressor.

2.6 Coefficient of Performance (COP)

Coefficient of Performance (COP) is a comparison between the beneficial refrigeration produced by the refrigeration system to remove heat from the environment and the energy expended by the compressor. The COP is a dimensionless quantity. The COP is the amount of energy that is useful, i.e., the refrigeration effect, which is divided by the work required by the system (compression work). The greater the COP value, the more efficient a refrigeration machine is. To measure the COP of the refrigeration system, the impact of refrigeration is divided by the compression work, as follows [19].

$$COP = \frac{Q_{ev}}{W_{comp}} \tag{1}$$

where Q_{ev} is refrigeration capacity (kW) and W_{comp} is compressor working (kW).

3. Methods

3.1 Research Location

This research was conducted at the Fluid Dynamics and Energy Systems Laboratory, Department of Marine Engineering, Faculty of Engineering, Hasanuddin University.

3.2 Refrigeration Dimension dan Materials

The dimensional data of the refrigeration system can be seen in Table 2, which was taken by direct measurements. The materials used in the refrigeration system were from the outermost layer, first aluminum composite, then polyurethane, and the innermost layer, namely fiberglass. The material illustration and its thickness are illustrated in Figure 2.

Table 2
Refrigeration box dimension

Dimension	Value (m)
Length	0.79
Breadth	0.40
Height	0.49

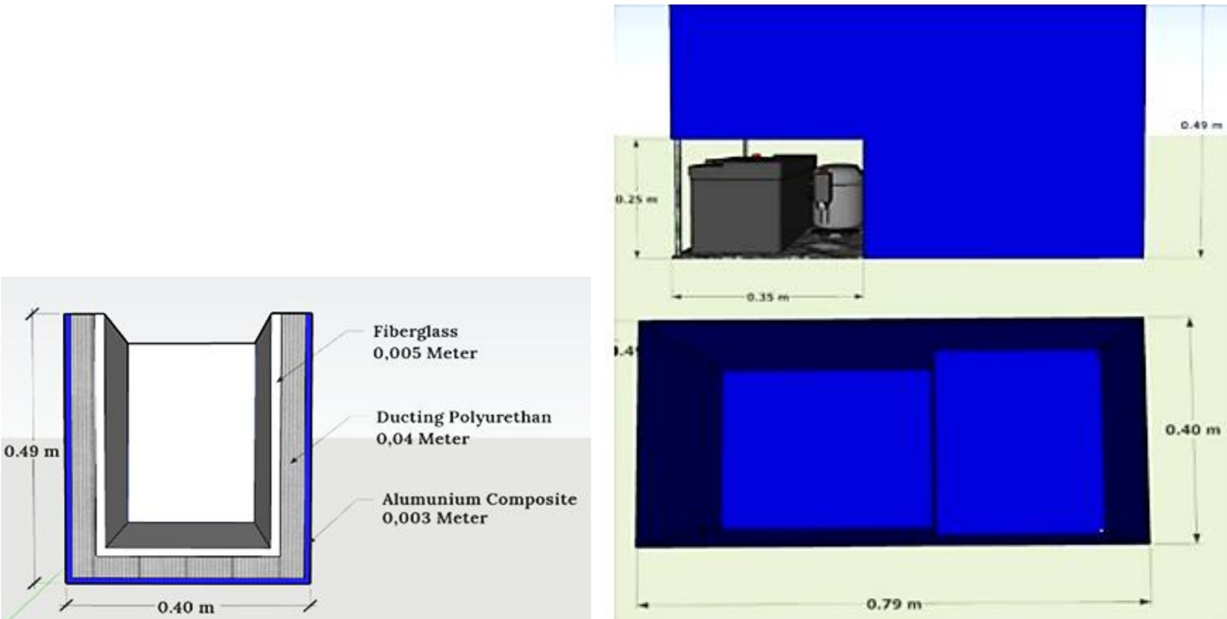

Fig. 2. Refrigeration system dimensions and materials

3.3 Capillary Pipe Variations

Proper capillary pipe length adjustment is essential to balance refrigerant flow control and energy efficiency. In this study, 3 (three) variations of capillary pipes with different lengths and the same diameter of 1.77 mm were used, as shown in Table 3. The location and installation of the capillary pipes used in the present study for the 3 (three) cases are shown in Figure 3.

Table 3
Capillary pipe length variations

Variations	Size (m)
A	2
B	2.5
C	3

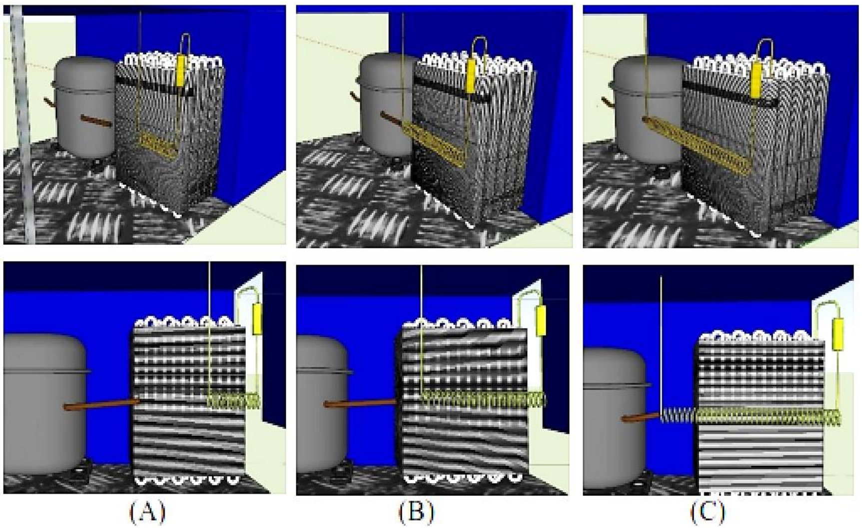

Fig. 3. Capillary pipe's location and installation

4. Results and Discussion

4.1 Refrigeration System Experiment Results

Data collection was carried out by measuring the temperature of the refrigeration system hatch. Temperature measurement was carried out using a digital thermometer placed inside the refrigeration box. Data collection was repeated 3 (three) for each case investigated in the present study. Each data collection was conducted for 180 minutes. Figure 4 shows the results of experiments for the case of capillary pipe lengths of 3 m. This figure shows a significant temperature drop in the first 60 minutes of start-up in each experiment, but the temperature stabilizes in the last 60 minutes. In the first experiment, the lowest temperature obtained was up to 5.3 ℃, while in the second experiment, the lowest temperature obtained was 5.6 ℃, and in the third experiment, the lowest temperature obtained was 5.2 ℃.

Subsequently, Figure 5 shows the temperature obtained for the second case, where the capillary pipe length was 2.5m. In this figure, the same tendency as the first case, where a very significant temperature drop occurred in the first 60 minutes, and then remained relatively stable in the last 60 minutes, can be observed. In this second case, all 3 (three) experiments obtained the lowest temperature up to 3.4 ℃.

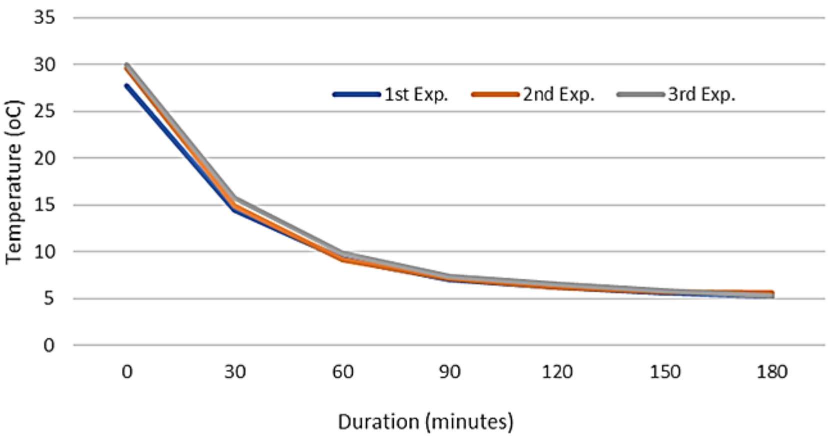

Fig. 4. Temperature obtained for capillary pipe length 3 m

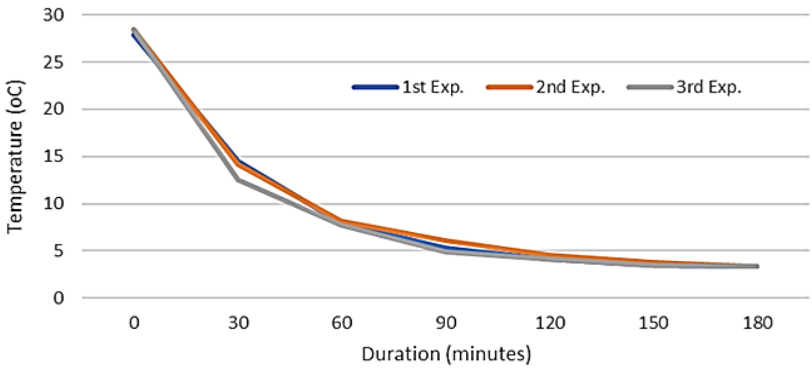

Fig. 5. Temperature for a capillary pipe length of 2.5 m

Figure 6 shows the experiment results for the 3rd case, where the capillary pipe length was 2 m. This figure showed no difference in the tendency of temperature drop, especially in the first and last 60 minutes of the experiment, as compared to the first and second cases. Moreover, in the first experiment, the lowest temperature obtained was 12.8 ℃, while in the second experiment was 13.4◦C. In comparison, the lowest obtained temperature in the last experiment was also 13.4 ℃. Figure 7 shows the comparison of the average temperature obtained in each case. Based on Figure 7, it is clear that the best temperature drop occurs at the length of the capillary pipe of 2.5 m, where for 180 minutes the test obtained a final temperature of 3.4 ℃, while the temperature drop that is less than optimal occurs in the variation in the length of the capillary pipe of 2 m with a final temperature of 13.4 ℃.

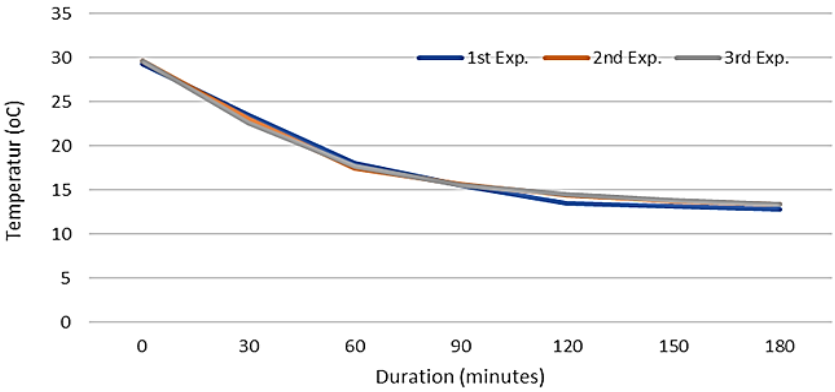

Fig. 6. Temperature for capillary pipe length 2 m

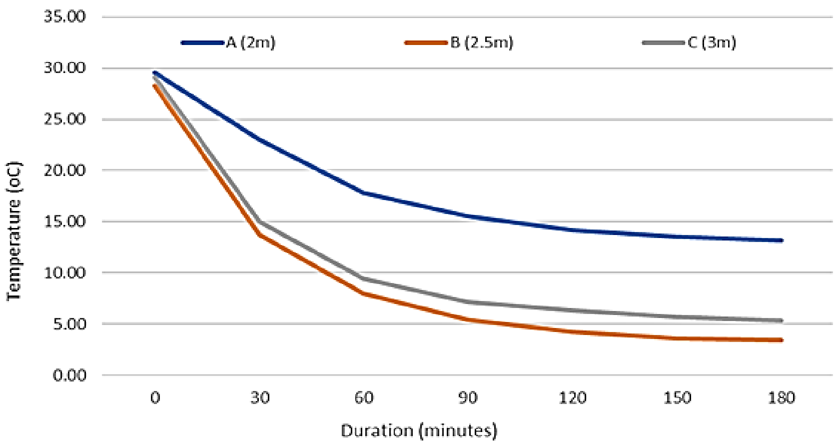

Fig. 7. The rate of temperature decreases at different capillary pipe lengths

Figure 8 shows the COP value calculated from the experimental data. It can be seen that even though the second case obtained the lowest temperature compared to the first and third cases, the COP calculation shows that the longer the capillary pipe, the lower the COP value. This happens because longer capillary pipes increase refrigerant flow resistance, causing the compressor to work harder and require greater power consumption, thus lowering the COP value.

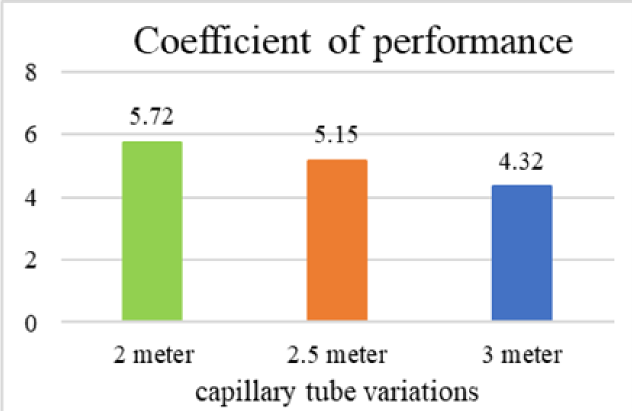

Fig. 8. The COP results comparison

4.2 Discussion

The capillary pipes in the refrigeration system affect the temperature in the evaporator because they affect the refrigerant's pressure and flow rate. In a 2 m capillary pipe, the refrigerant pressure remains high, resulting in a higher temperature (12.8 °C) because heat absorption is less effective. In a 2.5 m capillary pipe, the pressure drop occurs optimally, resulting in the lowest temperature (3.4 °C) due to the good balance between pressure and flow rate so that the refrigerant absorbs heat more effectively. However, in a 3 m capillary pipe, even though the pressure is lower, the flow rate becomes too slow, causing a slightly higher temperature (5 °C) than in a 2.5 m pipe. It can be seen that the lowest temperature obtained was 3.4, and the length of the capillary pipe was 2.5 m. Thus, at a temperature of 3.4 °C, the fish will have a slow deterioration for about 2 to 5 days.

From the experimental results, it can be observed that the longer the capillary pipe, the smaller the COP value because the greater pressure drop along the pipe reduces the flow rate of the refrigerant to the evaporator. With slower flow rates and lower pressures, the compressor has to work harder to maintain the cooling cycle. This increased compressor workload results in greater energy consumption while reducing the resulting cooling effect. As a result, the COP becomes smaller as the energy used increases. The greater the COP value, the more efficient a refrigeration system is.

4. Conclusions

The variation in the length of the capillary pipes significantly influences the decrease in temperature of the fishing cooling box. Based on the results of experiments that have been carried out with the use of different capillary pipe lengths, the lowest cooling system hatch temperature of 3.4 °C at the length of a capillary pipe length of 2.5 m, and the highest temperature is 13.4 °C at the length of a capillary pipe length of 2 m. Changes in the length of capillary pipes also have an impact on the coefficient of performance (COP) of the fish cooling system. In a capillary pipe with a length of 2 m, the resulting COP was 5.72. When the length of the capillary pipe was increased to 2.5 m, the COP decreased to 5.15. Furthermore, with a capillary pipe length of 3 m, the COP again decreased to

4.32. It can be concluded that the longer the capillary pipe is, the greater the pressure drop, which can increase the workload on the compressor, thus lowering the overall system efficiency (COP).

References

[1] Sovanda, Bravo Yovan, and Alam Baheramsyah. "Studi perencanaan jacketed storage system memanfaatkan CO_2 cair sebagai refrigeran." *Jurnal Teknik ITS* 2, no. 3 (2013): G209-G212.

[2] Mahmuddin, Faisal, Syerly Klara, and Muhammad Banda Selamat. "Penerapan teknologi pendingin ikan berbasis energi surya pada masyarakat nelayan di Desa Turungan Kecamatan Mattiro Sompe Kabupaten Pinrang." *Jurnal Riset & Teknologi Terapan Kemaritiman* 1, no. 2 (2022): 59-64.

[3] Homzah, Ozkar Firdausi, Hendradinata Hendradinata, and Beta Akui. "Pengaruh variasi panjang dan diameter pipa kapiler terhadap cop pada trainer sistem pendingin dasar." *PETRA: Jurnal Teknologi Pendingin Dan Tata Udara* 3, no. 1 (2017): 15-22.

[4] Alfa, Mufty Luay Salsabilla, Triaji Pangripto Pramudantoro, and Arda Rahardja Lukitobudi. "Kaji eksperimental pengaruh variasi diameter pipa kapiler terhadap performansi coolbox menggunakan R-134a." In *Prosiding Industrial Research Workshop and National Seminar*, vol. 14, no. 1, p. 96-102. 2023. https://doi.org/10.35313/irwns.v14i1.5368

[5] Republik Indonesia. *Peraturan Pemerintah Republik Indonesia Nomor 11 Tahun 2023 tentang Penangkapan Ikan Terukur*. Indonesia: Lembaran Negara Tahun 2023 Nomor 36; JDIH BPK, 2023.

[6] Budiarto, Untung, Kiryanto Kiryanto, and Heru Firmansyah. "Rancang bangun sistem Refrigerated Sea Water (RSW) untuk kapal nelayan tradisional." *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan* 10, no. 1 (2013): 48-57.

[7] Gunawan, Terry, Harto Tanujaya, and Asrul Aziz. "Uji eksperimental mesin pendingin berpendingin air dengan menggunakan refrigeran R22 dan refrigeran R407c." *Poros: Jurnal Ilmiah Teknik Mesin UNTAR* 12, no. 2 (2014): 165-172. https://doi.org/10.24912/poros.v12i2.570

[8] Razali, Razali, and Stephan Stephan. "Perencanaan sistem pendingin palka ikan menggunakan tenaga surya." *Inovtek Polbeng* 4, no. 2 (2014): 98-105.

[9] Sungadiyanto. *Studi eksperimental performa mesin pengkondisian udara (AC) mc quay dengan refrigeran R-22 pada laboratorium teknik mesin Universitas Negeri Semarang.* Universitas Negeri Semarang, 2007.

[10] Makatita, Matheis Everdin. *Mesin pendingin minuman dengan dua evaporator rangkaian seri.* Yogyakarta: Universitas Sanata Dahrma, 2007.

[11] Ng, Fei Chong, Lun Hao Tung and Mohamad Aizat Abas, "Analytical analysis on the capillary pressure of underfill flow meniscus during the flip-chip encapsulation process," *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 94, no. 2 (2022): 174-183. https://doi.org/10.37934/arfmts.94.2.174183

[12] Sukamta, Sukamta. "Computational fluid dynamics (CFD) and experimental study of two-phase flow patterns gas-liquid with low viscosity in a horizontal capillary pipe." *CFD Letters* 11, no. 8 (2021): 16-23.

[13] Sukamta, Noviyanto. "Void fraction features using image processing on a clear capillary pipe with a 45° slope to the horizontal line of two-phase air-liquid flow with high viscosity." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 83, no. 2 (2021): 164-172. https://doi.org/10.37934/arfmts.83.2.164172

[14] Sukamta, Sukamta, Endradi Roziantho, and Sudarja Sudarja. "Experimental study on two-phase flow of gas-liquid with high viscosity in capillary with the slope of 5o against horizontal position." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 69, no. 2 (2020): 120-129. https://doi.org/10.37934/arfmts.69.2.120129

[15] Sukamta, Sukamta, and Sudarja Sudarja. "Pressure gradient on gas-liquid two-phase flow with high viscosity in capillary pipe with the slope of 5 degrees of horizontal pipe." *Journal of Advance Research in Fluid Mechanics and Thermal Sciences* 63, no. 2 (2021): 210-217. https://doi.org/10.37934/arfmts.69.2.120129

[16] Widodo, Sapto, and Syamsuri Hasan. *Refrigerasi dan tata udara*. Jakarta: Departemen Pendidikan Nasional, 2008).

[17] Azhar, Ahmad. *Studi karakteristik variasi panjang pipa kapiler pada blast freezeruntuk mengawetkan nugget ikan sebagai sarana pemberdayaan masyarakat kepulauan seribu.* PhD diss., Universitas Negeri Jakarta, 2017.

[18] Fakhrudin, Anas, Slamet Supriyadi, and Aan Burhanudin. "Sistem kerja mesin pendingin sebagai media pembelajaran praktikum teknik refrigerasi." *Jurnal Pendidikan Teknik Mesin* 21, no. 1 (2021).

[19] Stoecker, Wilbert F, and Jerold W. Jones. *Refrigeration and Air Conditioning*. New York: McGraw Hill, Inc., 1982.