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EFFECT OF SUCTION AND DISCHARGE TUBE GEOMETRY ON THE COEFFICIENT OF PERFORMANCE OF R-290 BASED AIR CONDITIONING SYSTEM

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Abstract
The need for environmentally friendly substitutes for conventional air conditioning systems is growing as worries about climate change and environmental sustainability rise. The technological and financial feasibility of R-290-based air conditioning systems is examined in this study. The findings highlight the most promising layout, which consists of spiral finned tubes in the suction and discharge line. This configuration exhibits an enhanced coefficient of performance (COP) have been found 4.6 that signifying increased energy efficiency. On the other hand, the opposite structure performs the least well, highlighting how important tube layout is in determining system effectiveness. This work supports the urgent transition to ecologically friendly cooling technologies by providing insightful information about improving the viability of R-290 air conditioning systems.
Keywords: Air-conditioning, R-290, Tube geometry, COP

1. Introduction

The air-conditioning industry is a significant contributor to global greenhouse gas emissions and environmental degradation [1-5]. The air conditioning (AC) system stands out as a significant source of concern due to its reliance on refrigerants with high global warming potential (GWP) [6-13]. There is a need to look for relatively more sustainable alternatives. One such alternative is propane (R-290), a hydrocarbon-based refrigerant that has gained attention for its low GWP and favorable thermodynamic properties [7, 10].

Several studies have investigated the use of R-290 in various air conditioning applications. These studies have focused on evaluating the performance, efficiency, safety, and environmental impact of R-290-based air conditioning systems [13, 15-19]. Smith et al. (2021) studied how to minimize AC induced fuel consumption through optimal application of model based control strategies. The study indicates that R-290 exhibits comparable or superior cooling capacity, energy efficiency, and overall performance when compared to traditional refrigerants. However, safety considerations, particularly its flammability characteristics, require careful attention during system design, installation, and operation [10]. Similar outcomes have been reported in several other works [5-19]. However, relevant literature rarely reports the effect of suction and discharge tube geometries on the refrigerating performance of R-290 based air-conditioning units [5-13].

This work conducts a preliminary thermal feasibility of customized air conditioning systems that utilizes refrigerant R-290. The experimental aim is to assess the effect of suction and discharge tubes geometry and spatial arrangement on the coefficient of performance.

2. Materials and method

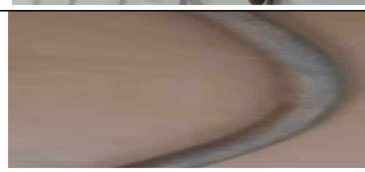
In this experiment, we used R-290 refrigerant, also referred to as propane, as the main refrigeration medium. R-290 was chosen because of its positive environmental attributes, which include its remarkably lack of Ozone Depletion potential (ODP) and low Global Warming Potential (GWP) When R-290 is compared to conventional refrigerants, its GWP is significantly lower, suggesting that it has less of an effect on global warming. Moreover, R-290 does not contribute to the loss of ozone molecules because it is a non-ODP material. It is important to remember that R-290 has a high degree of flammability and is categorized as a pure hydrocarbon under the ASHRAE A3 safety category. Extra care was used when handling R-290 to make sure the experiment was safe. According to sustainable research practices, these characteristics present R-290 as a viable and environmentally responsible option for refrigeration applications, as depicted in figure 1.

Figure 1. The refrigerant utilized in experiment

2.1 Configurations of tubes for experimental conditions.

The set of suction and discharge lines that has been used in this work are: (a) Suction (Straight tubes) with Discharge (Straight tubes), (b) Suction (Spiral tubes) with Discharge (Spiral tubes) lines, (c) Suction (Bent tubes) with Discharge (Bent tubes), (d) Suction (Finned spiral) with Discharge (Finned spiral). Table 1 shown the different configuration of tubes used in experiments.

Table 1 Shown the different types of tubes

Types of tubes	Photographic view of tubes	Configuration of tubes		
		Tube length (ft)	Tube diameter (mm)	No. of bends
Bend tubes		4.5	3/8	5
Spiral tubes		5	3/8	5
Straight tubes		5	3/8	
Finned spiral tubes		5	3/8	5

3. Experimental setup and procedure

Refrigeration set-up based on vapor compression refrigeration cycle (VCRC) used in this work has been shown in Figure 2 and 3. The experiment has been conducted number of times, taking into consideration a set of suction and discharge lines.

The readings in this set of experimentation provide the data of the total cooling performance as well as the total power consumption during the experiment. A combination of discharge and suction lines has been developed and worked on in order to evaluate the coefficient of performance.

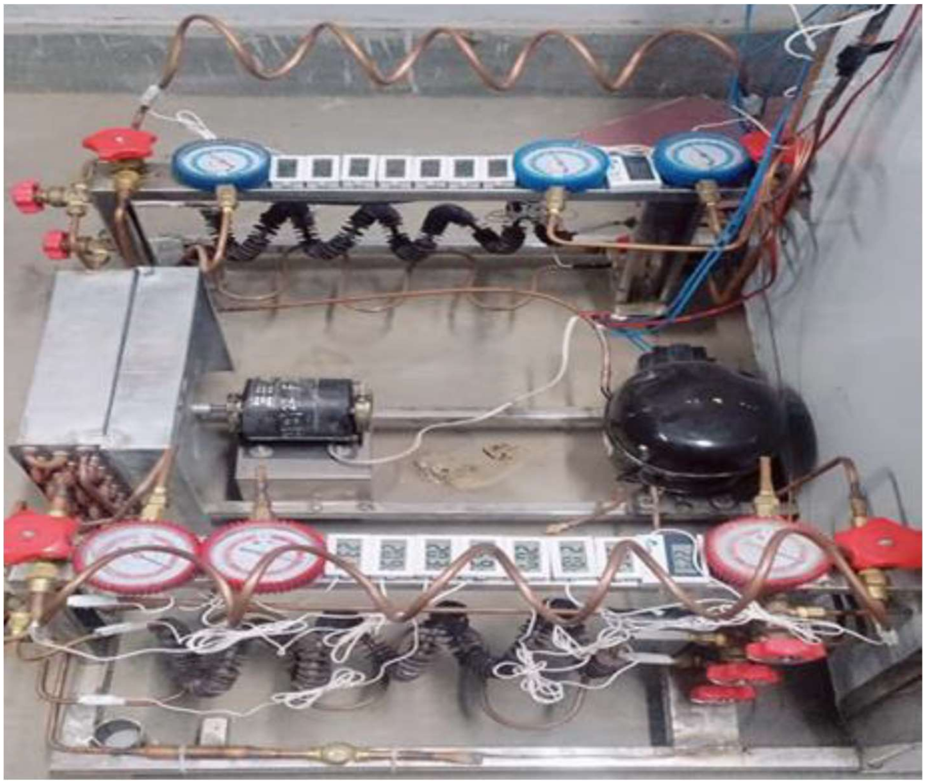


Fig. 2 Experimental set up of VCRS

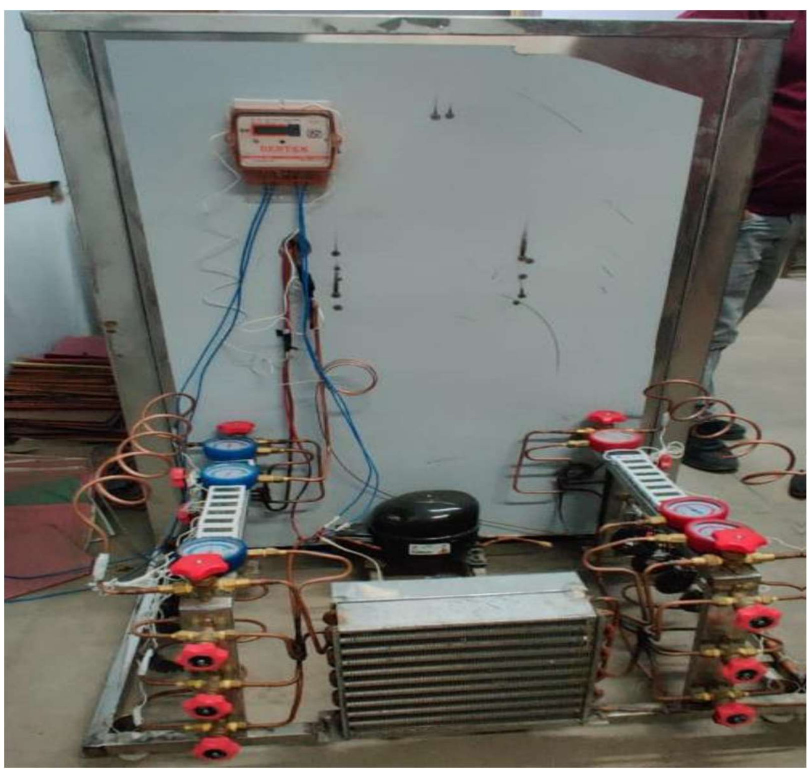


Fig. 3 Front View of Experimental Setup

The experimental procedure has been carried out at every 5 minutes, for a total duration of 15 minutes and the readings are noted down for evaluation. The combinations of suction and discharge lines are as follows: (a) Discharge (Straight tubes) with Suction (Finned Spiral tubes), (b) Discharge (Straight tubes) with Suction (Spiral tubes), (c) Discharge (Straight tubes) with Suction (Bent tubes), (d) Discharge (Bent tubes) with Suction (Straight tubes), (e) Discharge (Bent tubes) with Suction (Finned spiral), (f) Discharge (Finned spiral tubes) with Suction (Straight tubes), (g) Discharge (Spiral tubes) with Suction (Straight tubes), and (h) Discharge (spiral tubes) with suction (finned spiral tubes).

3. Results and discussion

Figure 4 displays the data obtained after the experiment, showcasing the variation in evaporator temperature across different types of tubes (straight tube, bend tube, spiral tube, and spiral finned tube) and time intervals. Upon careful examination of the graph, it becomes evident that the spiral- finned tube is proving to be highly effective in achieving lower evaporator temperatures. This efficiency is particularly beneficial in enhancing the coefficient of performance (COP) of the refrigerator.

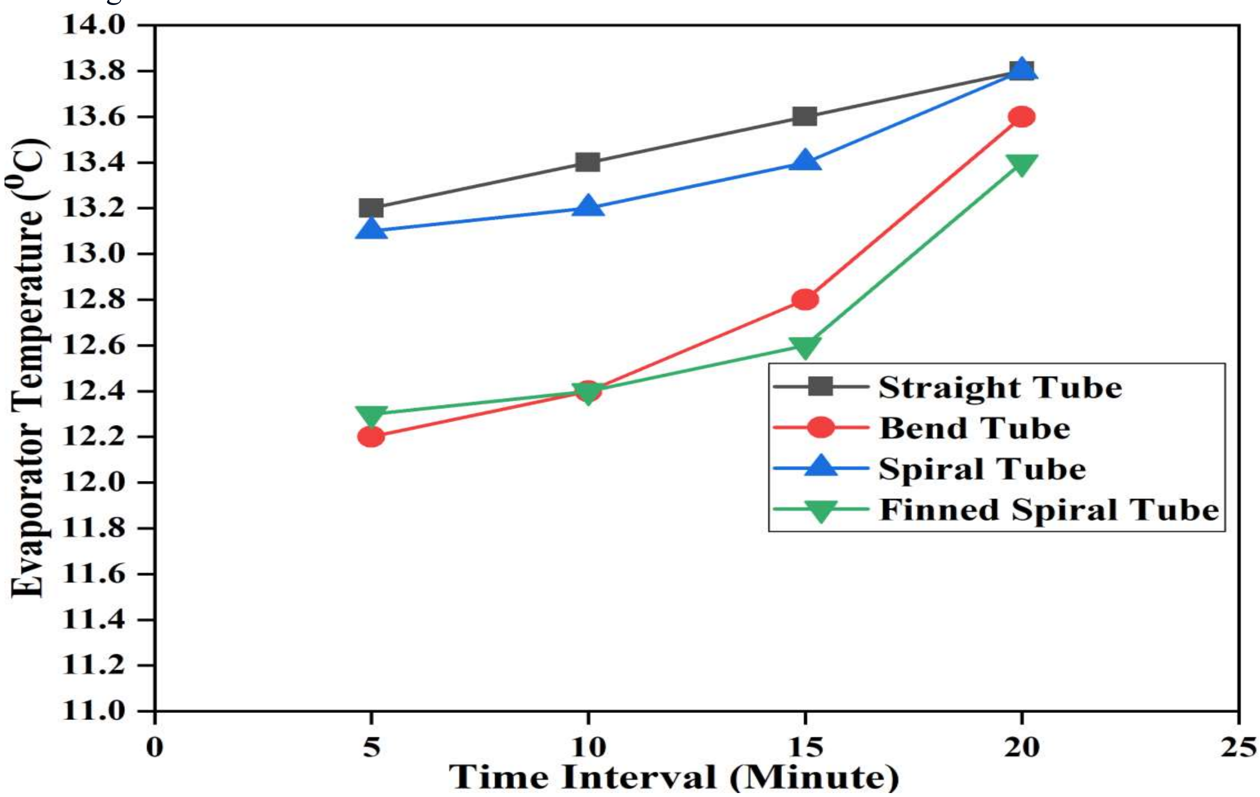


Fig. 4 Shown evaporator temperature and time interval

Figure 5 illustrates the relationship between the coefficient of performance (COP) and time intervals for all the tubes (straight tube, bend tube, spiral tube, spiral finned tube) after conducting the experiment. The results indicate that the highest COP is achieved with the spiral-finned tube. Post-experiment analysis reveals that the maximum COP, reaching 4.8, is obtained with the spiral-finned tube configuration.

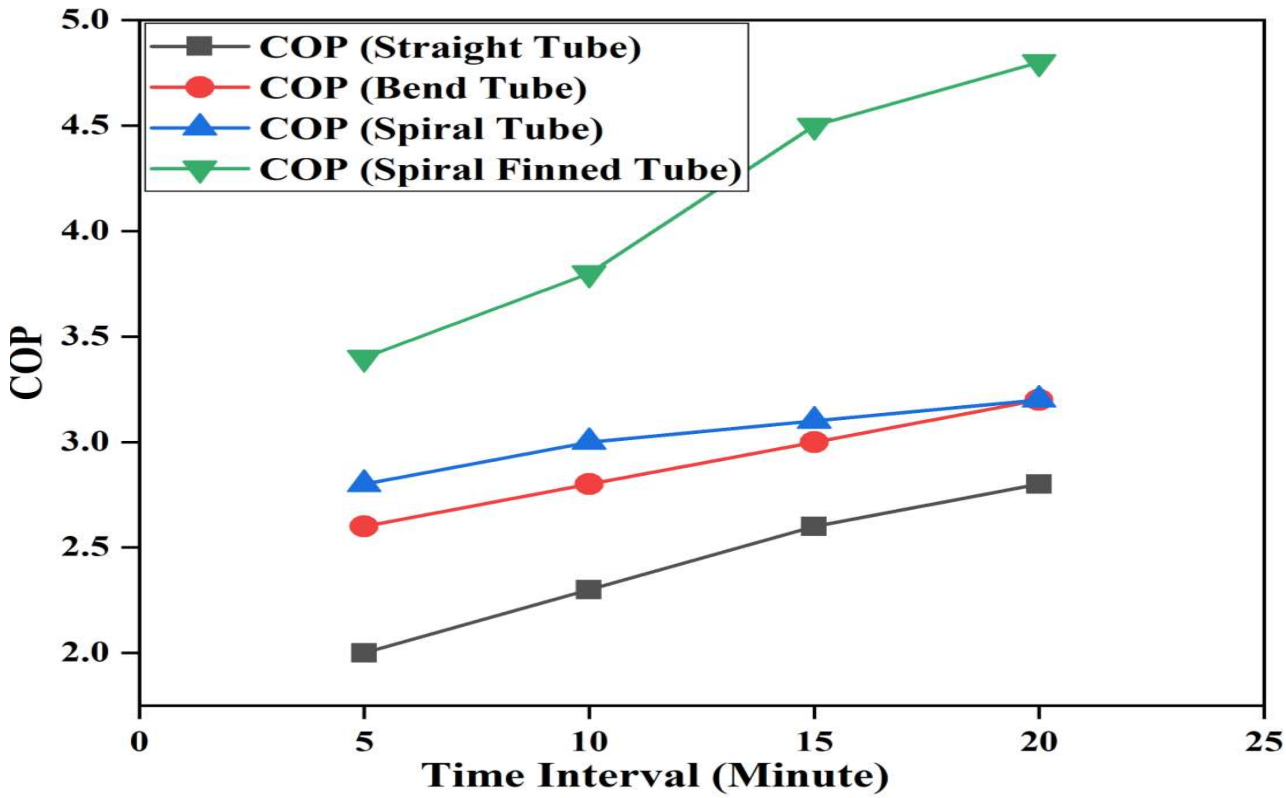


Fig. 5 Shown COP of VCRS cycle with time interval

Figure 6 depicts the plot between time intervals (5, 10, 15, and 20 minutes) and the inlet temperature of the evaporator with all different tubes (straight tube, bend tube, spiral tube, and spiral finned tube). Showcasing the results obtained after the experiment, it becomes evident that the minimum evaporator temperature is notably effective in the spiral finned tube configuration.
This effectiveness proves to be beneficial in enhancing the coefficient of performance (COP) of the refrigerator.

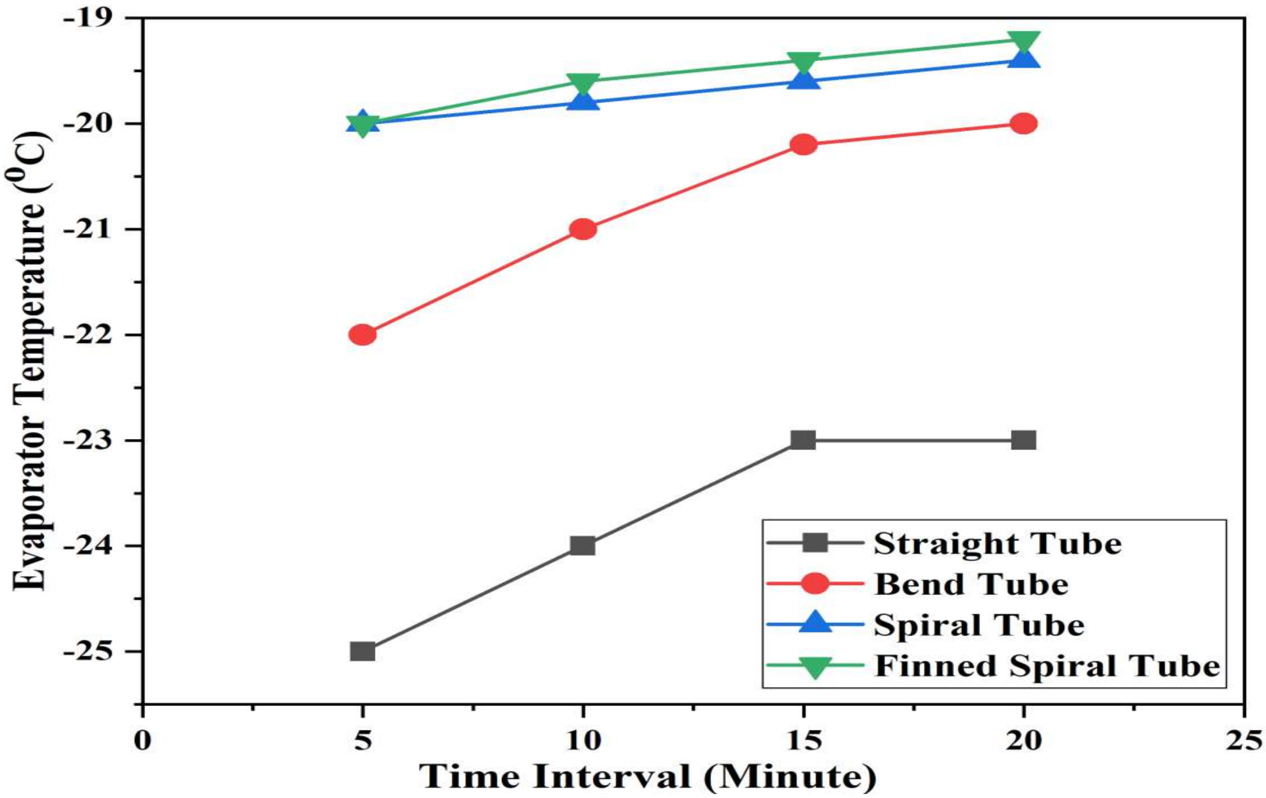


Fig. 6 Shown evaporator inlet temperature with time interval

Figure 7 illustrates the relationship between the compressor inlet temperature and time intervals (5, 10, 15, and 20 minutes) derived from the experimental results. Following experiments with all tubes (straight tube, bend tube, spiral tube, and spiral-finned tube), it is evident that the compressor inlet temperature is higher in the case of the spiral-finned tube. A higher compressor inlet temperature typically leads to a reduction in compressor work, thereby providing a more substantial contribution to increasing the coefficient of performance (COP). This outcome emphasizes the potential for enhanced COP when the compressor operates at a higher inlet temperature, particularly in the case of the spiral-finned tube.

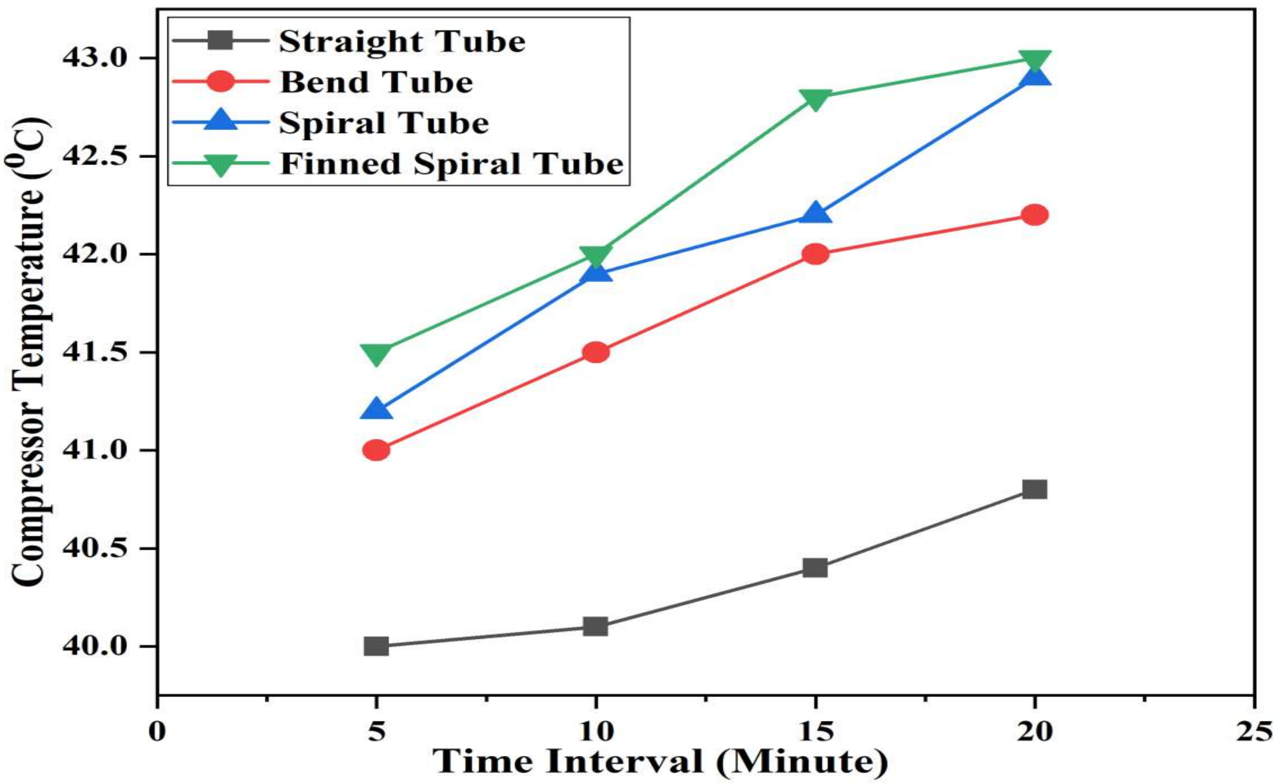


Fig. 7 Shown compressor inlet temperature and time interval

The experimental analysis demonstrates that the arrangement comprising straight tubes at the suction line and finned spiral tubes at the discharge line yields the optimal coefficient of performance, while the inverse configuration exhibits the lowest performance. The incorporation of fins in the suction line significantly enhances the efficiency and overall efficacy of the air conditioning unit. Enhanced COP resulted into the reduced cabin cooling time, facilitating the earlier disengagement of the cooling unit by the thermostat and subsequently reducing energy consumption. Figure 8 summarizes the effect of change in geometry of the suction and discharge tubes on the COP of refrigeration set-up. In summary, change in geometry of the suction and discharge tubes impacts the COP of refrigerating set-up significantly.

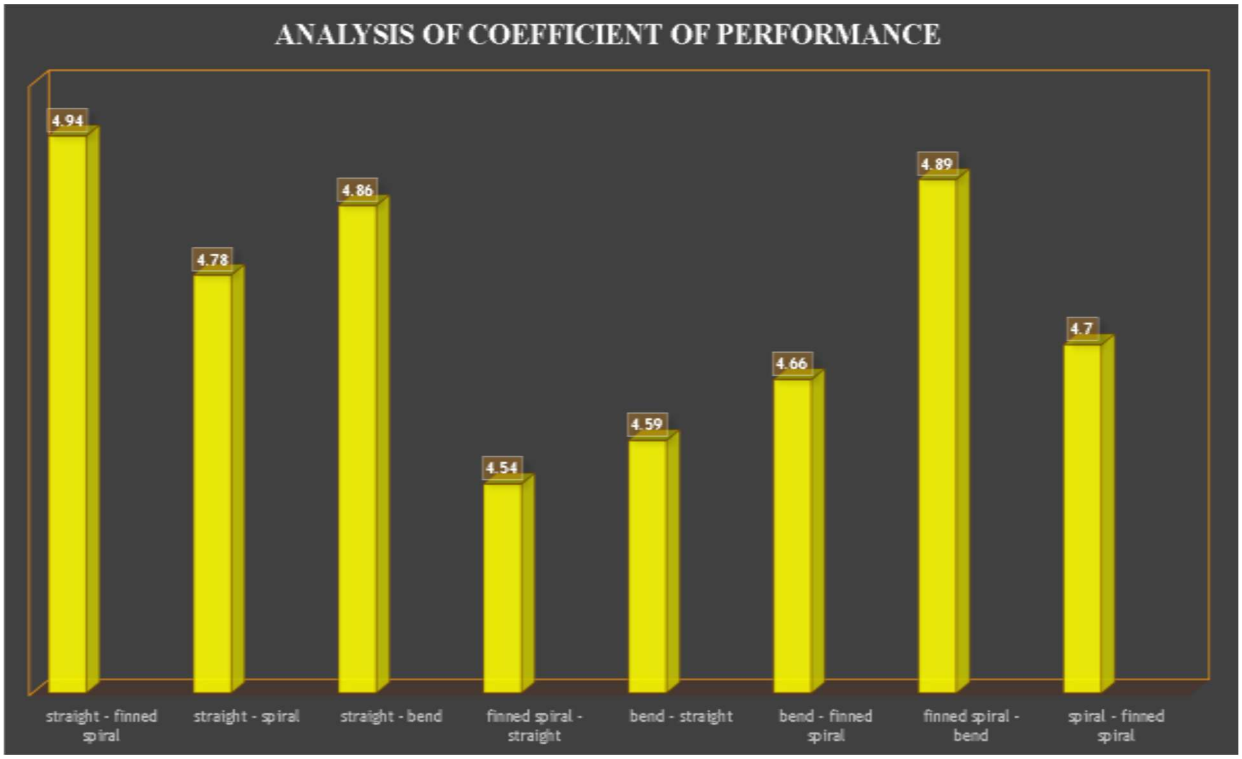
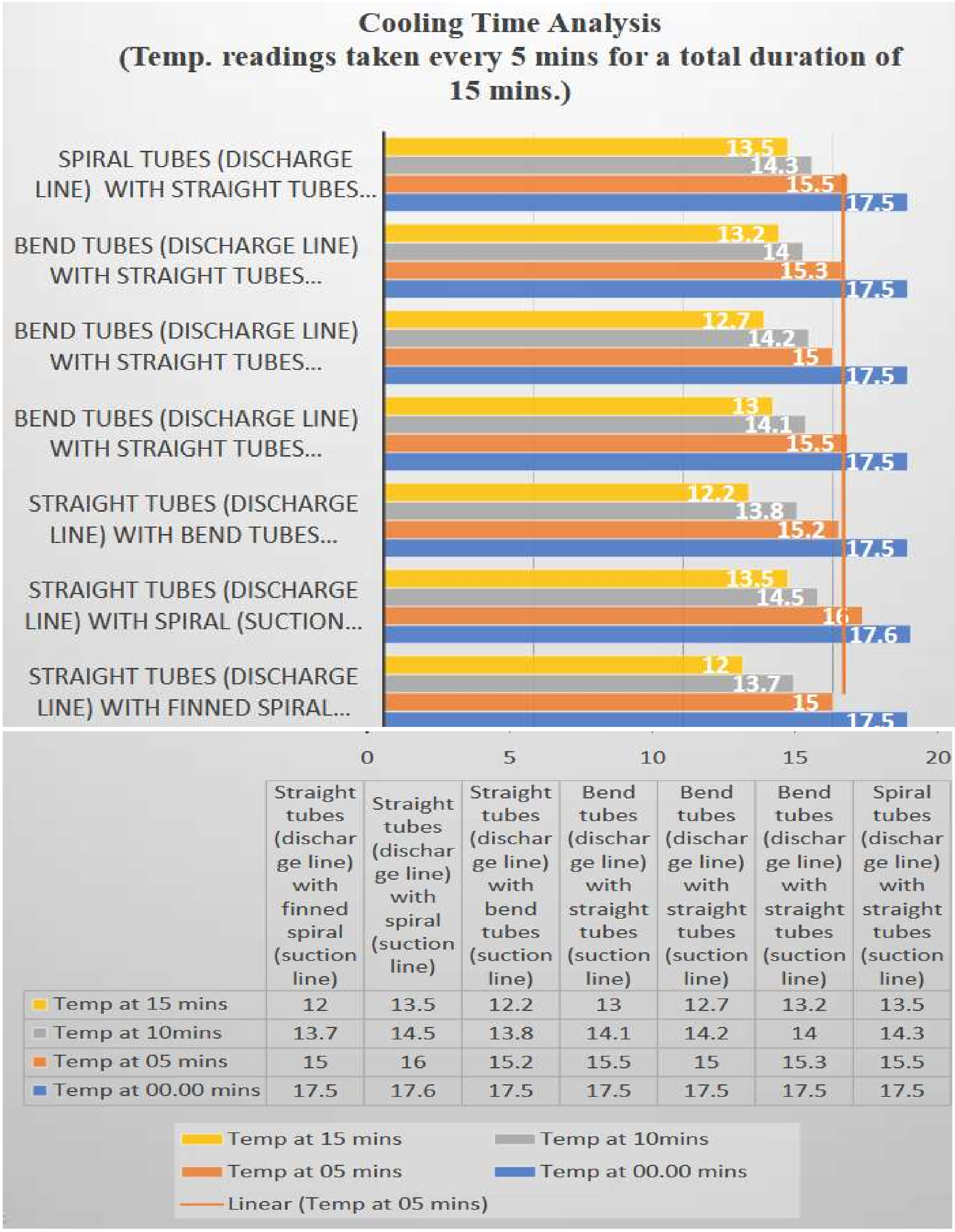


Fig. 8 Variation of coefficient of performance (COP) of the refrigerating set-up with the change in geometry of the suction and discharge tubes

Switching from conventional refrigerants (e.g., R134A, R22) to R-290 presents an environmentally sustainable choice, offering a greener alternative with a meager global warming potential (GWP) of 3 and a negligible Ozone Depletion Potential (ODP) [2-7]. Due to reliable corrosion, shocks, and impact resistance, the application of copper tubes in the devised AAC system ensures an extended lifespan and superior performance. Preliminary investigations into the arrangement of suction and discharge lines have shown that finned spiral tubes at both ends yield exceptional cooling efficiency, surpassing other configurations. Notably, the cross arrangement of straight tubes at the suction line and the finned spiral tubes at the discharge line rapidly achieved the desired temperature conditions. In Figure 9 cooling time analysis was conducted at 5-minute intervals, totaling a 15-minute observation period. Through experimentation, analysis revealed that the coefficient of performance (COP) is enhanced. The lowest temperature was observed within 15 minutes, achieved through the configuration of finned spiral and straight tubes, serving as the suction and discharge components, respectively.



	Straight tubes (discharge line) with finned spiral (suction line)	Straight tubes (discharge line) with spiral (suction line)	Straight tubes (discharge line) with bend tubes (suction line)	Bend tubes (discharge line) with straight tubes (suction line)	Bend tubes (discharge line) with straight tubes (suction line)	Bend tubes (discharge line) with straight tubes (suction line)	Spiral tubes (discharge line) with straight tubes (suction line)
Temp at 15 mins	12	13.5	12.2	13	12.7	13.2	13.5
Temp at 10mins	13.7	14.5	13.8	14.1	14.2	14	14.3
Temp at 05 mins	15	16	15.2	15.5	15	15.3	15.5
Temp at 00.00 mins	17.5	17.6	17.5	17.5	17.5	17.5	17.5

Fig. 9 Variation of the cooling time of refrigerating space with respect to geometry of suction and discharge tubes

The adoption of copper tubes, renowned for their superior corrosion resistance and shock resilience compared to conventional aluminum tubes, augments the system's economic viability and confers a higher salvage value.

5 Conclusions

The current study looks at how tube geometry affects the performance of refrigeration systems. It finds that a spiral-finned tube with time intervals of 5, 10, 15, and 20 works best for freezing applications. The obtained results and graphical representations, on the other hand, show that spiral-finned tubes are more suitable for cold storage or air conditioning purposes. The R-290-based customized air-conditioning system demonstrates thermal feasibility for air conditioning applications with a focus on environmental sustainability. The system's coefficient of performance can be enhanced as a function of suction and discharge tube geometry and their spatial combination. This comprehensive analysis suggests promising avenues for improving system efficiency in real-world applications.

The fastest cooling performance is observed in a cross arrangement where the suction line (straight tube) is paired with the discharge line (finned spiral tube).

As the future, looking into adding certain nanoparticles to the refrigerant to improve its thermal properties could help make the whole system work better.

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