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Performance analysis of an active on-board refrigeration system using propane for improved fish preservation in small fishing boats

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ABSTRACT

With a seafood production of 16.25 million metric tonnes in fiscal year 2022-23, India secures third rank globally in seafood production. To ensure the nation's food security and improve export earnings, it is critical to prioritize the preservation of seafood quality, and refrigeration plays an important role. This paper investigates the potential of an on-board refrigeration system powered by a diesel engine and utilizing propane to enhance seafood preservation in small fishing boats prevalent in the Indian seafood industry. The study analyses the economic, environmental, energy, and societal impacts of adopting this refrigeration system compared to conventional preservation methods. The hypothesis is that the refrigeration system will reduce losses and waste of fish/seafood harvest caused by inefficient cooling in traditional preservation methods. The study focuses on the small 60 feet trawlers, operated in the coastal area of Gujarat, India, and the field data are collected to carry out the study.

Keywords: On-board Refrigeration, Propane, Fishing Vessel, Food Security.

1 INTRODUCTION

It is estimated that about 15% to 50% of seafood is wasted or lost at various stages of handling, that indicates the food that is produced is never consumed by people (Nordtvedt and Widell, 2020). Apart from lost opportunity, the food production itself is generally a carbon-intensive process. Further, food waste can give rise to methane emissions, contributing prominently to global warming. Reduction of food loss and wastage are connected with multiple SDG targets, including SDG 12 (responsible consumption and production), SDG 2 (zero hunger), SDG 7 (efficient energy use), SDG 8 (economic growth), SDG 9 (infrastructure), and SDG 13 (climate action). According to Kumar et al., (2019), about 40% of food loss takes place during post-harvest processing, which can properly be taken care of with suitable preservation. India holds the third rank worldwide in seafood production with an estimated production of 16.25 million metric tonnes (MMT) in the fiscal year of 2022-23, (Government of India, 2023). During the fiscal year 2021-22, 1.37 MMT of seafood were exported, valued at $7.76 billion USD. To ensure the nation's food security and improve export earnings, it is essential to prioritise the preservation of seafood and its quality. Refrigeration plays an important role in accomplishing this goal. Refrigeration process, also have a high direct and indirect greenhouse gas emissions (Söylemez et al., 2022). As a result, it is an obvious target for decreasing the environmental impact of refrigeration. In India, land-based seafood industries are well-established and developed, whereas there are very few on-board refrigeration systems for small fishing boats. According to the MPEDA, out of the total registered fishing boats in India, 78% are small motorised or motorised and mechanical vessel which can be modified with on-board refrigeration system.

The layout of a typical motorised and mechanical boat in Indian western coastal region of Gujarat is shown in Fig.1. These fishing vessels mostly carry crushed or block ice from the shore for the entire trip for preservation of harvest based on some estimate. The amount of fish catch varies with the season and amount of ice carried may be insufficient or surplus depending upon the catch. The loss associated with the extra ice carried or the depreciation of quality of the fish due to the insufficiency of ice is proposed to be mitigated with a small on-board refrigeration system operable with the boat engine.

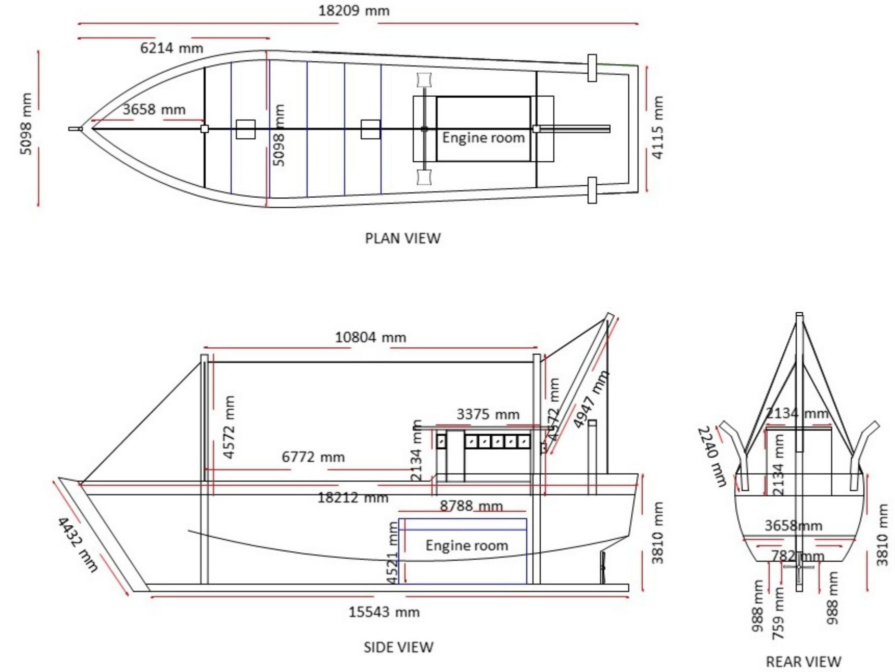

Figure 1: Layout of small motorised and mechanical fishing boats (Source: Boat Manufacturer)

Some previous studies explored various on-board refrigeration options including vapor compression refrigeration system (VCRS) (Norne WIDELL et al., 2023), Vapor adsorption refrigeration system (VADRS) (Palomba et al., 2017), Vapor absorption refrigeration system (VARS) (Wang and Wang, 2005) etc. Wang and Wang, (2005) explored the VADRS for on-board refrigeration in a fishing vessel where the heat from the exhaust gas is utilised to run the refrigeration system and found a COP of 0.18, which can produce ice at a rate of 18 to 20 kg/hr at -7°C. Authors also claimed that this systems can be adopted with boats with engine power more than 150 HP. Poku and Ogbonnaya, (2018) explored the possibility of implementing aqua-ammonia based VADRS and found that about 90% of heat that available from the exhaust gas, can run the generator. Other studies have reported that the COP of VADRS varies 0.1 to 0.6 (Liu et al., 2005; Núñez et al., 2007; Wang and Oliveira, 2006; Xu et al., 2017). Salmi et al. (2017) proposed a thermodynamic model of VARS and claimed 70% energy saving using VARS running with waste heat from the engine. Further, authors claimed to support 61% of cooling demand of the ship. Baheramsyah et al. (2017) designed a slurry ice system with 32 kW cooling capacity and found that the boat engine capacity needs to increase about 81.7 kW and the fuel carried needs to be increase about 1000 litres. Saini et al. (2019) conducted a theoretical study and proposed a compensatory on-board VARS system running with the exhaust heat of the boat engine to compensate for the melted ice. A double ejector-based VARS driven by exhaust gas was studied by Liang et al. (2019), who found a COP of 0.64. Du (2021) proposed an ejector-based VARS with a cooling capacity varied from 10-50 kW and found a COP of 0.4. The authors study very few VADRS systems. Ezgi (2021) did a theoretical study on adsorption-based cooling and heating systems with a zeolite-water pair. The authors found that the COP varies from 0.11 to 0.38. Baiju et al. (2022) developed a Simulink based two-bed VADRS system for 13.5 kW cooling capacity and found a COP of 0.57. From the study, it is found that the performance of VARS and VADRS systems are low and depends on the engine exhaust temperature, which changes the cooling capacity of the system. Due to the said drawbacks, some recent studies are exploring the on-board VCRS system. Bodys et al. (2018) studied R744-based on-board refrigeration systems employing performance improvement strategies such as flash gas bypass, parallel compression, and ejector, where ejector-based systems achieved a maximum COP improvement of around 10%. Nasution et al. (2020) carried out a numerical simulation on VCRS with two different refrigerants namely R134a and R600a. The evaporator temperature kept at -10 °C while the condensing temperature varied from 34 - 44 °C. The authors found a variation in COP from 3.71 to 4.88 for the R600a system, resulting in higher compared to the R134a system. Propane is a natural refrigerant for its suitable thermo-physical properties and benign presence in the environment. It has zero ozone depletion potential and negligible GWP (≈3), which makes it a preferable future refrigerant. Choudhari and Sapali (2017) compared the performance of the vapour compression cycle with refrigerants R22 and propane and concluded that propane can be a good alternative due to its comparable thermodynamic performance and lower discharge temperature. Nawaz et al. (2017) performed simulation-based study to evaluate the performance of R134a, propane, and R600a. The authors concluded that propane and R600a are suitable alternatives to R134a, and propane is favored for compact systems because of its greater volumetric heating capacity over R600a. Zhou and Zhang (2010) examined the system performance of a split-type air conditioner with R22 and propane under different operating situations and observed that the mass flow rate required for propane was approximately 50% lower, and the energy efficiency ratio of propane was almost 10% greater than that of R22. In general, HC systems appear to offer various advantages over conventional refrigerant systems, including greater cooling capacity, compact system design, and higher energy efficiency. These features make HCs stand out as viable future options. However, there is still a dearth of research and development to fulfil the rising needs of the markets, which require such systems that comprise of environmental and health friendly refrigerants, mostly driven by recent regulatory changes and worldwide activities about global warming concern.

From the prior literature, very few studies have found where VCRS is implemented to preserve fish on fishing vessels, especially in the Indian context. Further, most of the prior studies are thermodynamically evaluated without considering real compressor performance. Economic analysis includes the selection of components and their availability. The additional power source required to run the refrigerant system, the economic viability, and the environmental analysis of the system context to the Indian scenario are yet to be explored. The present study explored the same gap present in the prior art. The current study explores the possibility of implementing the on-board refrigeration system and the corresponding improvement in food quality and reduction of carbon footprint (CFP) with the same.

Table 1. Data collected from the field study

Parameter	Details
Boat engine specification	
Boat engine rating	450 BHP
Boat engine variable RPM	500 – 1700 RPM
Power	330 kW
Fuel	Diesel
Avg. Fuel Consumption	10-11 litres/hour
Avg. Speed	15 km/hr
Top Speed	19 km/hr
Speed while Trawling	7-8 km/hr
Diesel carried	3000 – 4000 litres
Overhaul Life	12000 hrs

The study focuses on the small 60 feet boat, which is operated in the coastal area of Gujarat, India. For the current study, it is considered that the fishermen will carry 50% of the ice from shore, and the rest will be generated onboard while the vessel has reached the fishing destination. Only the mechanical winch system is operated with the boat engine and the rest of the engine power can be devoted to ice making. The following data from the field study are collected and shown in Table 1.

2 SYSTEM DESCRIPTION

A 30 kW propane-based flake ice system is explored in the study for producing ice on-board, and the schematic of the same is shown in Fig. 2 (a) (DX system), and the corresponding p-H diagram is shown in Fig.

2 (b). The evaporator is replaced with an evaporative drum to produce flake ice. An IHX is used to subcool the condenser exit and superheat the compressor suction. Suction line accumulator is used at the compressor suction for variable load operation. It is important to select a simple design for the drive mechanism to enhance maintainability within the restrictions of a boat in sea. Accordingly, an open-type screw compressor is proposed to operate the refrigeration system that is directly connected to the boat engine via belt drive. The auxiliary components, such as the reducer motor, evaporator, and condenser pumps, are operated by a typical 24 V truck battery, which is powered by an alternator arrangement. Although heat recovery from on-board refrigeration is not a common practice, however any possible heat recovery potential from each configuration is also evaluated for use in the CIP process. The heat rejected by the condenser can be used to produce hot water at 65 °C. The design parameters of the system are listed in Table 2.

Table 2. Design conditions of refrigeration system

Parameter	Value
Evaporator temperature (°C)	-25
Condensing temperature (°C)	40
Cooling load (kW)	30

The compressors for all the refrigerants evaluated are screw type compressors and the condenser is water-cooled. The performance of propane system is compared with R404A and R407A systems which are mostly used in Indian seafood industries (Vaishak et al., 2023) with similar system configuration. A commercial software (Frascold v1.22) is used to analyse the propane, R404A, and R407A screw compressors in this work. In Table 3, the compressor models for respective refrigerants are tabulated.

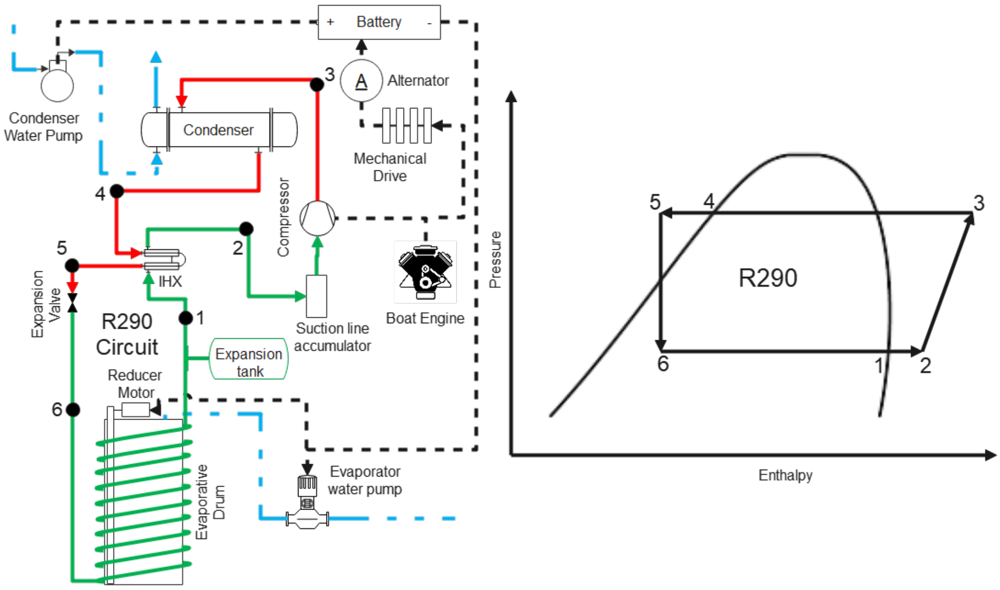

Figure 2: Schematic of (a) proposed DX system and (b) corresponding pressure-enthalpy plot

Table 3. Compressor models for R404A, R407A, and propane

Refrigerant	Compressor model	Type	Nominal speed (RPM)	Displacement at nominal speed (m^3/hr)
R404A	FVR-L-30-120	Open type screw compressor	2900	120
R407A	FVR-L-30-120	Open type screw compressor	2900	120
Propane	FVR-L-30-120AX	Open type screw compressor	2900	120

3 MATHEMATICAL MODEL

Mathematical model of the systems is developed considering the following assumptions.

- Steady state operation
- Negligible heat loss and pressure drop
- Throttling process is isenthalpic

Compressor-specific equations are used to build a mathematical model of the proposed configurations incorporating various losses and hence leading to a more realistic outcome. Other similar tools available for compressors, such as Bock, Bitzer, Dorin, etc., may be used for simulation if relevant data is available. A polynomial function is shown in Eq. (1), which is available in the compressor selection software (v1.22) by Frascold® and is used to calculate the mass flow rate (m_{ref}) and compressor power consumption (W_{comp}), where the evaporator and condensing temperature is denoted by T_e and T_c respectively; values of the polynomial coefficients (C_1, C_2, C_3 ....) are listed in the Appendix. The compressor power consumption and cooling COP ($COP_{cooling}$) is estimated through Eq. (1). In Eq. (2), the Cooling COP of the system is expressed where Q_e is the cooling capacity of the system.

$$\text{Parameter} = C_1 + C_2T_e + C_3T_c + C_4T_e^2 + C_5T_eT_c + C_6T_c^2 + C_7T_e^3 + C_8T_cT_e^2 + C_9T_eT_c^2 + C_{10}T_c^3 \quad \text{Eq. (1)}$$

$$COP_{cooling} = \frac{Q_e}{W_{comp}} \quad \text{Eq. (2)}$$

The heat recovery potential of the system (Q_{hr}) is calculated using Eq. (3) and given as

$$Q_{hr} = m_{ref}\Delta h \quad \text{Eq. (3)}$$

Where the m_{ref} represents the refrigerant mass flow rate and Δh is the enthalpy difference across the component.

The overall COP ($COP_{overall}$) includes both the cooling and heating capacity of the system and defined as Eq. (4)

$$COP_{overall} = \frac{(Q_e + Q_{hr})}{W_{comp}} \quad \text{Eq. (4)}$$

The Return on Investment (ROI) of the system is calculated as Eq. (5)

$$ROI = \frac{Initial\ investment}{Net\ saving\ per\ trip} \quad \text{Eq. (5)}$$

where Q_e is the cooling capacity and W_{comp} is the total work input to the system which is the same as the work input to the screw compressor with respective refrigerants., The parameters used in the simulation are listed in Table 4.

Table 4. Parameters used for simulation

Parameters	Values
Evaporator load (kW)	30
Evaporator temperature (°C)	-25
Condensing temperature (°C)	40
Approach temperature (°C)	5
Water inlet temperature (°C)	30
Water outlet temperature (°C)	65
IHX effectiveness	0.3

4 ECONOMIC AND ENVIRONMENTAL MODEL

The economic viability of the on-board refrigeration system is carried out and the payback period is calculated. From the field data, it is found that the fishermen typically carry around 10 metric tonnes (MT) of ice from shore. While evaluating the economic and environmental feasibility, it is considered that 50% of the ice will be taken from the shore and 50% ice will be made on-board. The economic benefits obtained due to the reduction in ice carried, savings in fuel due to reduction in boat weight and the better fish quality. While, there are some added costs due to increase in weight due to machine installation, running cost of the machine and one time cost of the machine.

The cost of the various components of the refrigeration system is collected from the different vendors (Bock®, Alfa Laval®, Danfoss®, etc.) and listed in Table 5. For the environmental analysis, the following assumptions are considered and tabulated in Table 6.

Table 5. Component cost of the refrigeration system

Components	Cost (INR)
Propane compressor (Bock®)	40,000
Sea water-cooled condenser (Local manufacturer)	2,50,000
Evaporative drum (Local manufacturer)	5,50,000
Expansion valve (Danfoss®)	5,000
Plate type IHX (Alfa laval®)	15,000
Piping and fittings	15% of the component cost

Table 6. Parameters for environmental and economic analysis (Tan and Culaba, 2009)

Parameters	Values
Carbon footprint (CFP)	0.25 – 0.3 kg/kg of perished fish
Increment in diesel consumption	0.6 litre/kg of boat weight
CO_2 emission due to burning of diesel	3.1 kg/kg of diesel
Typical fish catch in one trip	7 metric tonnes
Ice carried from shore	10 metric tonnes
Perished fish due to improper refrigeration	15% of the catch
Cost of diesel	92 INR/lit
Cost of ice	160 INR/100 kg

5 RESULTS AND DISCUSSION

5.1 Performance analysis

In the present study, the performance of propane based on-board refrigeration system is evaluated for 40 °C condensing temperature while the evaporator is at -25 °C with a cooling capacity of 30 kW. This condensation and evaporation temperatures are essential to obtain the real compressor equations. The Economic and environmental impact are also studied and presented. The proposed system is compared with traditional R404A and R407A system from the energetic point of view in terms of cooling COP and overall COP. The environmental impact assessment of installing an onboard refrigeration system is carried out in terms of Carbon Footprint (CFP), while the economic viability of the system is explored in terms of 'Return on Investment (ROI)'.

The performance parameters such as refrigerant mass flow rate, compressor work, cooling COP, discharge temperature, heat recovery potential and overall COP of the proposed system are evaluated and compared. Fig. 3 (a) exhibits the comparison of refrigerant mass flow rate of propane-based system compared to R404A and R407A system. The least refrigerant mass flow rate is found for propane-based system while the same found highest for R404A system. This attributed to the fact that higher enthalpy of vaporisation of propane at -25 °C ($h_{fg} \approx 406.8\ kJ/kg$) leads to lower refrigerant mass flow rate for the similar cooling capacity when compared to compared to R404A ($h \approx 185.9$ /) and R407A ($h \approx 219.3$ /) systems. Further, the lower refrigerant mass flow rate leads to smaller pipe diameters and compact system. The mass flow rate of propane is decreased about 58.7% and 45.2% respectively when compared with R404A and R407A systems. The reduced refrigerant mass flow rate leads to lower compressor work, that results in higher COP. The higher COP indicates towards the more energy efficient system, leading to lower CFP. The requirement of smaller heat exchangers and piping due to the higher h_{fg} results in reduced component cost.

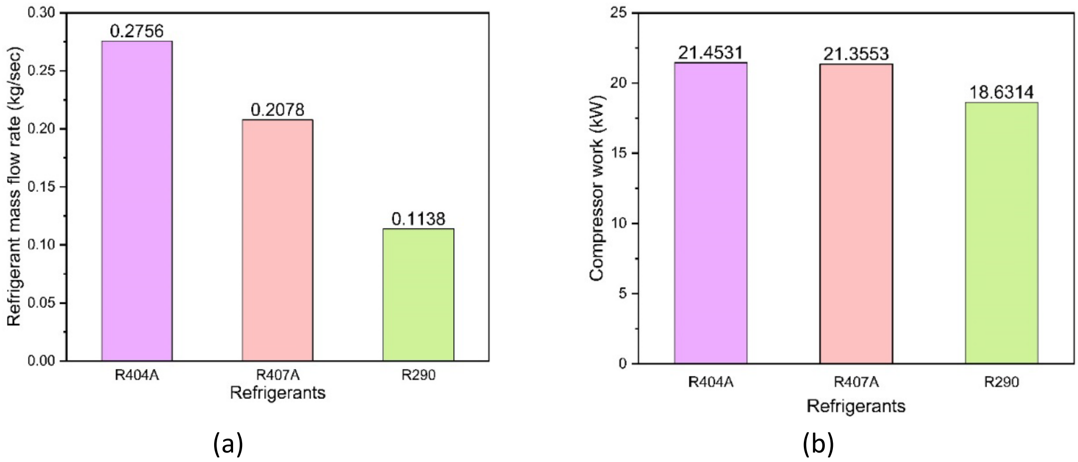

Figure 3: (a) Refrigerant mass flow rate and (b) Compressor work all the systems

The variation in compressor work is shown in Fig. 3(b). The compressor work is found least for propane system when compared R404A and R407A systems due to lower refrigerant mass flow rate and lower condensing pressure. The compressor work of propane is found 13.1% and 12.74% lower compared to R404A and R407A respectively. It is worth noting that this study is explored considering that the power required to run the compressor is extracted from the boat engine. So, the reduced compressor power consumption will not only improve the COP of the system but also decrease the diesel consumption by the engine, which leads to reduced CFP compared to R404A and R407A.

The variation in cooling COP due to reduced compressor work is shown in Fig. 4(a). The cooling COP is found highest for propane system when compared with R404A and R407A due to lower compressor work. The Cooling COP of propane is found to be 1.61, 15.13% higher compared to R404A, and 14.6% higher compared to R407A, respectively.

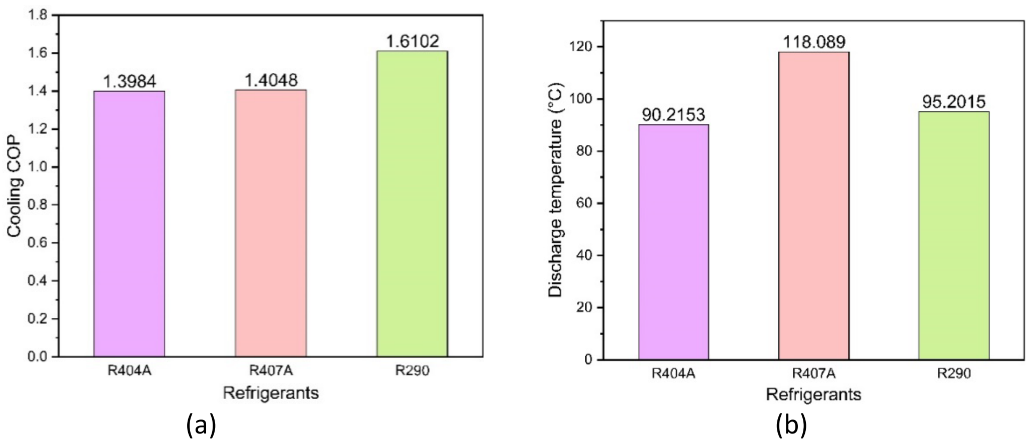

Figure 4: (a) Cooling COP and (b) Compressor discharge temperature all the systems

The heat recovery potential of the system depends upon the refrigerant mass flow rate and the discharge temperature. In this study, the outlet temperature of water from the heat recovery unit is kept at 65 °C. The variation in compressor discharge temperature is shown in Fig. 4(b). The highest discharge temperature from the compressor is found for R407A while the lowest is found for R404A. The discharge temperature from the compressor is high enough to produce 65 °C water in all the cases. However, the quantity of the heat that can be recovered is shown in Fig. 5(a). The heat recovery potential is found highest for R407A system while the same is found lowest for propane system. This attributed to the fact that higher refrigerant mass flow rate and higher discharge temperature of R4047A system leads to higher heat recovery from the system while on the other hand, although the discharge temperature of propane is higher than R404A system, the lower refrigerant mass flow leads to least heat recovery potential of propane system. The heat recovery potential of the propane system is 7.9% and 39.4% lower when compared to the R404A and R407A systems, respectively.

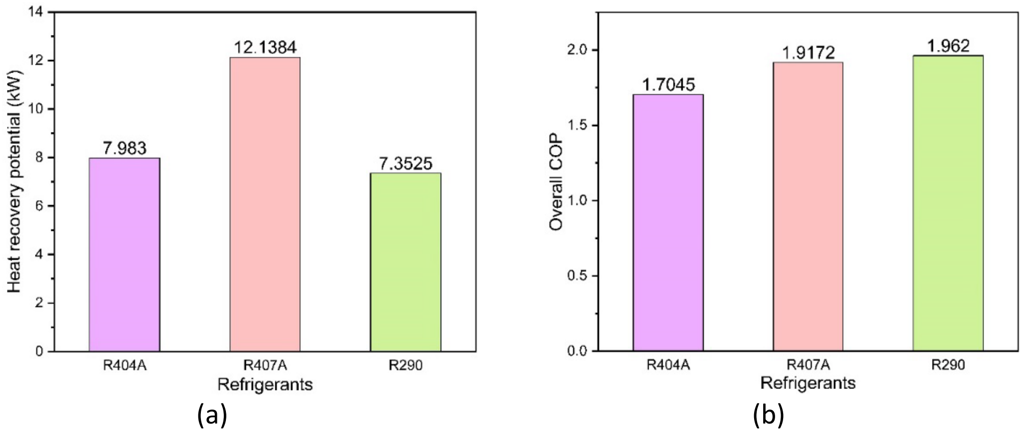

Figure 5: (a) Heat recovery potential and (b) Overall COP all the systems

The combined effect of cooling COP and heat recovery potential of the system are used to evaluate the overall performance of the system and is shown in Fig. 5(b). Although the heat recovery potential is the least for the propane system, the highest overall COP is found for the propane system. This attributed to the fact that the improvement in cooling COP is more dominant than the reduction in heat recovery potential from propane. The overall COP is found to be lowest for the R404A system due to the lower cooling COP and heat recovery potential. The overall COP of the propane system is found to be 1.96, while the same was found to be 1.70 and 1.92 for R404A and R407A-based systems. The improvement in overall COP for propane is found to be 15.4% and 2.2% higher compared to R404A and R407A-based systems, respectively.

5.2 Environmental analysis

The environmental impact in terms of carbon footprint (CFP) is studies for the on-board refrigeration system. The reduction of CFP is found due to a reduction in fuel consumption due to lesser Ice carried from the shore and an improvement in fish quality, while the CFP increases slightly due to the extra diesel consumption for running the refrigeration system. As given in Table.6, typical fish catch and ice carried from shore are 7 MT and 10 MT, respectively. Due to the on-board refrigeration system, the ice carried from shore is reduced to 50%, and the 15% of fish lost due to improper refrigeration can be avoided.

The reduction in boat weight due to the reduction in ice carried is 5 MT. The increase in weight due to the machine is 0.7 MT (weight of machine). Therefore, the net reduction in boat weight is 4.3 MT. The increase in fish due to on-board refrigeration is 1.05 MT. The reduction in diesel consumption is around 2580 litres (0.6 lit/kg), which results in a reduction in CFP of around 8000 kg of CO_2 emission per trip (3.1 kg of CO_2 per lit diesel burn). Further, the reduction in CFP due to improvement in fish quality is around 315 kg of CO_2 emission per trip (0.3 kg of CO_2 per kg of fish). The excess diesel consumption for running the refrigeration system is found to be around 290 liters, which is equivalent to 900 kg of CO_2 emission. Considering all the effects the total reduction in CFP is found around 7416 kg of CO_2 emission.

5.3 Economic analysis

For economic analysis, the cost of fish at whole sale outlet is considered 30 rupees per kg or $0.36 USD (Saini et al., 2019) (considering $1 USD ≈ 83 INR). Cost saving in terms of diesel is 237360 INR or $2848 USD. The reduced cost of Ice from shore is 8000 INR or $96 USD. Profit due to the better fish quality is 31500 INR or $378 USD. The cost of an On-board refrigeration system is around 989000 INR or $11868 USD (Table 5). The increase in expense due to an increase in diesel consumption for running the refrigeration system is 26680 INR or $320 USD. The ROI for the system is calculated as given in Eq. (5) and found around 4 trips.

6 CONCLUSIONS

The study explores the performance of propane-based on-board refrigeration systems and compares them with R404A and R407A systems. The real compressor equations are used to compare the performance of all the system. Further, the economic and environmental assessments are performed to evaluate the ROI and reduction in CFP, respectively. From the results, the following conclusions can be drawn.

- The higher enthalpy of vaporisation of propane reduces the refrigeration mass flow rate compared to R404A and R407A which leads to 13.14% and 12.74% less compressor work for same cooling load.
- The reduced compressor work leads to less power supply from the boat engine, resulting lesser fuel consumption.
- The cooling COP of propane system is 15.1% and 14.6% higher when compared to R404A and R407A systems.
- In addition of using of natural refrigerant, the on-board refrigeration system can reduce CFP upto 7416 kg of CO_2
- The ROI for installing the on-board refrigeration system is found around four trips

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NOMENCLATURE

Abbreviations			
CFP	Carbon footprint	Q	Cooling load
CIP	Clean in place	ROI	Return on investment
COP	Coefficient of performance	SDG	Sustainable development goal
DX	Direct expansion evaporator	VADRS	Vapor adsorption refrigeration system
EER	Energy efficiency ratio	VARS	Vapor absorption refrigeration system
HP	Horse power	VCRS	Vapor compression refrigeration system
IHX	Internal heat exchanger	W	Compressor work
INR	Indian currency	**Subscript**	
MMT	Million metric ton	e	Evaporator
		hr	heat recovery unit

REFERENCES

Baheramsyah, A., Cahyono, B., Aruan, F.S., 2017. Slurry Ice as a Cooling System on 30 GT Fishing Vessel. Int. J. Mar. Eng. Innov. Res. 1. https://doi.org/10.12962/j25481479.v1i3.2005

Baiju, V., Asif Sha, A., Sajid, N.M., Muhammedali Shafeeque, K., 2022. Simulation and performance study of a two-bed adsorption cooling system operated with activated carbon-ethanol. Proc. Inst. Mech. Eng. Part C J. Mech. Eng. Sci. 236, 3804–3817. https://doi.org/10.1177/09544062211042040

Bodys, J., Hafner, A., Banasiak, K., Smolka, J., Ladam, Y., 2018. Design and simulations of refrigerated sea water chillers with CO2 ejector pumps for marine applications in hot climates. Energy 161, 90–103. https://doi.org/10.1016/J.ENERGY.2018.07.126

Choudhari, C.S., Sapali, S.N., 2017. Performance Investigation of Natural Refrigerant propane as a Substitute to R22 in Refrigeration Systems. Energy Procedia 109, 346–352. https://doi.org/10.1016/J.EGYPRO.2017.03.084

Du, S., 2021. Thermal Analysis of a Forced Flow Diffusion Absorption Refrigeration System for Fishing-Boat Exhaust Waste Heat Utilization. Front. Energy Res. 9, 1–13. https://doi.org/10.3389/fenrg.2021.761135

Ezgi, C., 2021. Design and thermodynamic analysis of waste heat-driven zeolite–water continuous-adsorption refrigeration and heat pump system for ships. Energies 14. https://doi.org/10.3390/en14030699

Government of India, 2023. Annual Report 2022-23 1–23.

Kumar, S., Sankar, M., Widell, K.N., 2019. Thermal and economic analysis of an on-board compensatory refrigeration system for small fishing boats. https://doi.org/10.1615/IHMTC-2019.1690

Liang, X., Zhou, S., Deng, J., He, G., Cai, D., 2019. Thermodynamic analysis of a novel combined double ejector-absorption refrigeration system using ammonia/salt working pairs without mechanical pumps. Energy 185, 895–909. https://doi.org/10.1016/J.ENERGY.2019.07.104

Liu, Y.L., Wang, R.Z., Xia, Z.Z., 2005. Experimental study on a continuous adsorption water chiller with novel design. Int. J. Refrig. 28, 218–230. https://doi.org/10.1016/J.IJREFRIG.2004.09.004

Nasution, D.M., Siregar, A.H., Bukit, F.R.A., 2020. Modelling a simple-vapour compression refrigeration cycle for Fish-Storage boxes. J. Phys. Conf. Ser. 1542. https://doi.org/10.1088/1742-6596/1542/1/012066

Nawaz, K., Shen, B., Elatar, A., Baxter, V., Abdelaziz, O., 2017. propane (propane) and R600a (isobutane) as natural refrigerants for residential heat pump water heaters. Appl. Therm. Eng. 127, 870–883. https://doi.org/10.1016/J.APPLTHERMALENG.2017.08.080

Nordtvedt, T.S., Widell, K.N., 2020. Refrigeration and sustainability in the seafood cold chain. Refrig. Sci. Technol. 2020-Augus, 13–24. https://doi.org/10.18462/iir.iccc.2020.314814

Norne WIDELL, K., Starheim SVENDSEN, E., Ståle NORDTVEDT, T., 2023. Possibilities of ice slurry systems onboard fishing vessels. https://doi.org/10.18462/iir.nh3-co2.2023.XXXX

Núñez, T., Mittelbach, W., Henning, H.M., 2007. Development of an adsorption chiller and heat pump for domestic heating and air-conditioning applications. Appl. Therm. Eng. 27, 2205–2212. https://doi.org/10.1016/J.APPLTHERMALENG.2005.07.024

Palomba, V., Aprile, M., Motta, M., Vasta, S., 2017. Study of sorption systems for application on low-emission fishing vessels. Energy 134, 554–565. https://doi.org/10.1016/J.ENERGY.2017.06.079

Poku, R., Ogbonnaya, E.A., 2018. Thermodynamics analysis of recovering heat for refrigeration system of a fishing vessel. Niger. J. Technol. 37, 936. https://doi.org/10.4314/njt.v37i4.11

S, V., Singha, P., Dasgupta, M.S., Hafner, A., Widell, K., Bhattacharyya, S., Saini, S.K., Arun, B.S., Samuel, M.P., Ninan, G., 2023. Performance analysis of a CO2/NH3 cascade refrigeration system with subcooling for low temperature freezing applications. Int. J. Refrig. 153, 140–154. https://doi.org/10.1016/J.IJREFRIG.2023.05.013

Saini, S.K., Dasgupta, M.S., Widell, K.N., Bhattacharyya, S., 2019. Thermal and economic analysis of an on-board compensatory refrigeration system for small fishing boats. Proc. 25th Natl. 3rd Int. ISHMT-ASTFE Heat Mass Transf. Conf. https://doi.org/10.1615/IHMTC-2019.1690

Saleh, B., Aly, A.A., Alogla, A.F., Aljuaid, A.M., Alharthi, M.M., Ahmed, K.I.E., Hamed, Y.S., 2019. Performance investigation of organic Rankine-vapor compression refrigeration integrated system activated by renewable energy. Mech. Ind. 20, 206. https://doi.org/10.1051/meca/2019023

Salmi, W., Vanttola, J., Elg, M., Kuosa, M., Lahdelma, R., 2017. Using waste heat of ship as energy source for an absorption refrigeration system. Appl. Therm. Eng. 115, 501–516. https://doi.org/10.1016/J.APPLTHERMALENG.2016.12.131

Söylemez, E., Widell, K.N., Gabrielii, C.H., Ladam, Y., Lund, T., Hafner, A., 2022. Overview of the development and status of carbon dioxide (R-744) refrigeration systems onboard fishing vessels. Int. J. Refrig. 140, 198–212. https://doi.org/10.1016/J.IJREFRIG.2022.05.007

Tan, R., Culaba, A., 2009. Estimating the carbon footprint of tuna fisheries. WWF Bin. Item 1–14.

Wang, R.Z., Oliveira, R.G., 2006. Adsorption refrigeration—An efficient way to make good use of waste heat and solar energy. Prog. Energy Combust. Sci. 32, 424–458. https://doi.org/10.1016/J.PECS.2006.01.002

Wang, S.G., Wang, R.Z., 2005. Recent developments of refrigeration technology in fishing vessels. Renew. Energy 30, 589–600. https://doi.org/10.1016/J.RENENE.2004.03.020

Xu, X., Li, Y., Yang, S.Y., Chen, G., 2017. A review of fishing vessel refrigeration systems driven by exhaust heat from engines. Appl. Energy 203, 657–676. https://doi.org/10.1016/J.APENERGY.2017.06.019

Zhou, G., Zhang, Y., 2010. Performance of a split-type air conditioner matched with coiled adiabatic capillary tubes using HCFC22 and HC290. Appl. Energy 87, 1522–1528. https://doi.org/10.1016/J.APENERGY.2009.10.005