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Performance Analysis of Vapour Compression Refrigeration System Using Mixture of R290 (Propane) and R600a (Isobutane) with Spiral Condenser and Series Arrangement of Evaporators

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Abstract-
The vapour compression refrigeration system (VCRS) is an important type in refrigeration systems due to its advantageous features like high COP (Coefficient of Performance). In this research performance analysis of Vapour Compression Refrigeration System (VCRS) employing eco-friendly refrigerants R290 (Propane) and R600a (Isobutane) implemented with innovative design modifications like a spiral condenser and a series arrangement of evaporators carried out. The objective of this research work is to evaluate overall performance of system, improvement in COP and energy effectiveness with lesser energy consumption for environmental sustainability conditions. From experimental results various operational parameters were examined giving insight to system behaviour. To achieve environmental sustainability goals there is need to find alternatives for R134a and with the use of Propane-Isobutane blend along with incorporation of series arrangement of evaporators and spiral condenser showed remarkable improvement in performance. Results have contributed base for optimum design, increased efficiency and reduced environmental impact in refrigeration field.
Keywords: VCRS, Spiral Condenser, Series Arrangement, COP, Payback Period.

1. Introduction

Nowadays energy saving is of prime importance and considering that refrigeration system should be efficient and supportable in operation. The vapor compression refrigeration system (VCRS) is type of refrigeration system which is having important role in creating necessary working environment and preserving perishable goods. VCRS system is employing basic thermodynamic principles for transferring heat from Low temperature space to High temperature space resulting into efficient cooling process. VCRS system incorporates components viz. compressor, condenser, expansion valve, and evaporator which are working in sequence to circulate refrigerant in continuous cycle with process compression, condensation, expansion and evaporation. Properties of different refrigerant can be taken into account for enablement of efficient heat transfer ultimately resulting into preferred method for refrigeration, air-condition and industrial applications.

Hydrofluorocarbon (HFC) Refrigerant R134a is used mostly in refrigeration systems. But due to high GWP value there is need to find alternative refrigerant. Selection of refrigerants has very important role in finding impact of refrigeration system on overall efficiency and environment impact. There are many refrigerants that can be used as an alternative to R134a but R290 (Propane) and R600a (Isobutane) found to be promising one because of low GWP and ODP along with good thermodynamic properties. This research focuses not only on thermal performance but also environmental impact. To enhance system performance series arrangement of evaporators along with spiral condenser arrangement is implemented. This has contributed to feasibility and ease to adopt this configuration for sustainable refrigeration field applications.

Most of research work is carried out to find alternative refrigerant to R134a. Due to environmental concerns there is need to move towards low GWP value refrigerant as an alternative to HCFC's and HFC's. [1] focuses on evaluating the potential of alternative refrigerants in current refrigeration systems through exergy assessment for enhancing the thermal efficiency of these systems. Exergy assessment study of multistage multi-evaporator vapor compression refrigeration system is carried out using Simulink model multistage multi-evaporator vapor compression refrigeration system. For this study eighteen refrigerants were examined considering environmental and safety factors. For two evaporators and condenser temperature variations are examined and from result found that compressor is primary contributor for exergy fall followed by condenser, evaporators, expansion devices. Also, environmentally friendly refrigerant like R1234ze(E) and R1234yf performed similar to traditional refrigerant. Extensive Literature Review on performance analysis for different refrigerant blends and nanofluids in VCRS carried out [2] Vapour Compression Refrigeration System (VCRS) has been widely incorporated from many years into different applications because of features like increased COP and RE. These systems are found to be used in domestic as well as industrial applications. HFC's like R134a have been utilised in VCRS systems from due to commendable thermodynamic properties but due to environmental concern raised by Kyoto Protocol HFC's are major contributor to GWP having value nearly 1300. To address these protocols and increasing need to find alternate eco-friendly solution there is need to go for alternate refrigerant. The ideal selected substitute should have characteristics like efficient heat transfer, increased COP and low GWP, ODP value. From research it has been found that Mixed Refrigeration Systems or blends adding various types of nanofluids with R134a showed potential to improve the thermal efficiency and overall performance of refrigeration systems

Thermal analysis of VCRS system using R134a in primary circuit and Al_2O_3 nanofluid in secondary circuit is carried out. This study has also explored performance parameters of VCRS system using eco-friendly refrigerants, impact on heat transfer coefficient employing nanoparticles in secondary circuit whereas R134a in primary circuit, compressor power consumption etc. Thermal performance analysis is carried out using engineering equation solver software (EES). The study highlighted the impact of using different nano-particles with R134a as a refrigerant to enhance heat transfer characteristics in refrigeration systems. [3]. Exergy analysis of VCRS system for constant cooling load under AHRI standard condition carried out and also different refrigerants like R12, R134a, R1234yf (low GWP) and R600a (Natural refrigerants) were studied. To evaluate thermodynamic variables developed mathematical model and explored for different refrigerants. From results it has been observed that R600a performance was superior followed by R152a and R1234yf considering factors like COP. Total equivalent warming impact (TEWI) for each system also identified with R600a having the low and R12 the highest value for TEWI. CO_2 identified as promising alternative due to affordability, non-toxicity etc features.[4]

Slow Market development issue of VCRS refrigerant's with very low target temperature less than -50 ^{o} C because of no GWP limitations. [5] Though many options available as a mixture for refrigeration applications only some exists such as R-469A below -80 ◦C refrigeration. This study explored combination of pure fluids for very low temperature refrigeration. Various parameters considered for theoretical assessment like COP, GWP etc including different refrigerants with steps of 5%. Authors suggested to give low priority to environmental concern during trade off to overcome hurdle of flammability concern. Performance investigation of five new refrigerant (R440A, R441A, R444A, R445A, and R451A) in refrigerator having GWP less than 150 studied. Result indicated that all refrigerants have less pressure ratio compared to R134a. Refrigerant R451A and R440A shown similar thermal characteristics to R134a and superior COP whereas R441A and R445A performance was poor. In spite of flammability issue R451A and R440A are eco-friendly substitutes for R134a in domestic refrigerators.[6]

Implementation of European gas regulation has forced phase out of high GWP Refrigerants. This has especially affected standalone systems with low

GWP refrigerant to replace R134a. Alternative options like R290, R600a and Organic fluid CO2 have been studied and performance of commercial beverage cooler examined with six alternative refrigerants. From results found that notable energy reductions are achieved from these identified refrigerants compared to R134a except R1234yf. [7] Nowadays Global warming is concern to environment which necessitate measure to reduce greenhouse gas and fossil fuel consumption. Heat pump is promising method for waste heat recovery and less power consumption but conventional refrigerants still having high GWP. This has moved towards implementation of low GWP refrigerants. Authors have identified lack of performance analysis study of low GWP refrigerants in heat pump and no application guidelines hence analysed 17 different pure low GWP refrigerants with categorization for the study. Authors also have provided guidelines to utilize the refrigerants in heat pumps. [8]

Experimental investigation conducted on household refrigerator by varying refrigerant charge and capillary tube length. Motive of research was to find alternative refrigerant in last decades observed shift from CFC's to HFC's and mixture of HFC's. This research focused on experimental investigation using two HC Mixture R50/50 (R290/R600a) and R436A which involved changing charge of refrigerant and length of capillary tube. Result showed that R436A refrigerant, using 70g and L=4.5M, achieved a design temperature of -15°C making it a substitute for R134a in domestic refrigerators[9]. As mandated by Kyoto protocol R134a need to phase out so experimental study has been carried out using R290 and R600a mixtures as a substitute for R134a with specific mass ratio. Various tests were performed under different operating conditions and result showed that this HC mixture has low energy consumption and higher COP hence can be considered as promising alternative to R134a. [10]

Mathematical model was prepared for small capacity VCRS system for energy efficient design considering refrigerant viz. R290, R600a, and R1234yf. Environmental and thermos economic analysis involving parameters like COP, exergy efficiency is carried out. From results observed that R290 system identified as most suitable replacement for R134a. From cost analysis found that operational cost accounts for near 75 % of value. [11]. Experimental investigation focusing impact of propane-isobutane mixture for variable speed hermetically sealed compressor in refrigerator was done. Four different compositions with mass weight were studied. Outcome of results were compared considering R600 a as baseline and its impact on coefficient of performance was studied. COP increased with evaporation temperature and almost 20% enhancement compared to R600a alone based on compositions used. [12].

As mandated by Kyoto protocol for phase out of R134a to find alternative mixture of R134a and LPG was explored with 28:72 weight ratio in VCRS System. Various performance tests were conducted and results exhibited that Mixture performance was far better than that of R134a alone achieving higher COP with low compressor discharge temperature. Compatibility test for mixture with mineral oil lubricant gave satisfactory results. Authors concluded that R134a-LPG mixture as a promising alternative for R134a along with offering better performance and suitable environment properties. [13] Performance analysis of different refrigerant mixtures especially three identified pairs in cascade refrigeration system were carried out. For investigation taken superheating and subcooling temperature as 10^{o}c and 5^{o}c whereas HT region evaporator temperature varies from 30^{o}c to 50 ^{o}c while LT region evaporator temperature varies from -70°C to -50°C. Experimental results showed that there is improvement in COP and flow rate with increase in evaporator temperature. Finding indicate that R134a/ R170 shows higher COP and low mass flow rate.[14]

To examine losses occurring during various stages of process and cycle exergy analysis of VCRS system was carried out. Different refrigerants including R-134a, R-12, and R-22 and their impact on evaporator temperature was major consideration for this study. Parameters like exergetic efficiency and irreversibility were evaluated with the help of RefProp software. Result showed that with increase in evaporator temperature exergy loss and second law efficiency decreases and apart from these refrigerants R134a shows maximum whereas R22 medium and R12 minimum exergy loss.[15] Use of

Al_2O_3 nanoparticle in VCRS system was explored in existing VCRS system without retrofit. Performance and energy analysis with AL_2O_3 dispersed nanofluid over conventional working fluid was carried out. From investigation with use of nano refrigerant due to excellent thermophysical properties like high thermal conductivity etc. thermal performance was improved and viscosity test result shown reduction in viscosity ultimately resulting into lower energy consumption. Authors suggested to perform improved material selection for the compressor before using nano refrigerants.[16]

Considering current need of global environmental concern in cooling sector and to enhance energy efficiency in VCRS system. Study focuses on subcooling impact on commercial refrigeration system using R449A with two parts in first using EES analysis for subcooling system and in second simulations using low global warming potential refrigerants. Different mixture of binary and tertiary refrigerant using Refprop software was carried out. Base safety refrigerant was assessed for supermarket operation and environmental assessment was also carried out. From result R290 stands for achieving highest reduction in Greenhouse gas [17]To enhance heat transfer efficiency with innovative method of addition of nano refrigerants and nano lubricants research was carried out. These refrigerants with nanoparticles dispersed have potential application in refrigeration and air conditioning. Various thermodynamic parameters are examined in this research like thermal conductivity, viscosity, pressure drop, COP etc. Authors have covered existing research along with challenges related to application of nano-refrigerants and nano lubricants. Nanofluids are supposed to be effective solutions for increasing COP and reducing energy consumption. [18]

Modification in system components of VCRS system has shown improved COP, for regulating mass flow rate of refrigerant along with lowering temperature and pressure expansion valve plays important role in VCRS system. Also, proper selection of expansion valve is necessary for controlling superheat and different researchers in past conducted different approaches like experimental analytical etc and authors have provided insight for using various type of expansion devices for different refrigerants. [19]

Performance of VCRS system was studied using R134a refrigerant, SiO_2 nanoparticle when mixed with POE oil nano lubricant along with the change in condenser design. COP can be enhanced by increasing refrigeration effect which can be achieved by use of spiral condenser which is having more surface area compared to conventional. For study copper tube with 6.35 mm diameter and 5 mm length was used. Different concentration of nanoparticles was used for this research work and observed that COP increases with increase in concentration when compared over conventional as well. [20]

Assessed performance of two evaporator VCRS system varying their arrangement from series to parallel when both evaporators were of same cooling capacity. Performance of system for both arrangements studied separately under same environmental condition and COP range of series system found to be more compared to parallel arrangement. Considering unequal refrigerant mass distribution with parallel evaporator arrangement in series arrangement as cooling in evaporator occur one after another optimum cooling achieved with refrigerant R134a. [21]Design of Evaporator which is crucial part of VCRS system modified through installation of fins. Comparative analysis of using HC Refrigerant and R134a was done and compatibility assessment carried out showing advantageous features like low GWP and power consumption with increased heat transfer rate. From finding observed that integration of HC-R134a is advantageous due to many reasons including time reduction to achieve same refrigeration effect, increased COP and reduced power consumption. [22]

From previous reported research interaction of change in design parameters and implication of use of different refrigerant blends on VCRS performance was studied independently. Also, practical insight and advantages of suggested modifications for guiding future advances in refrigeration field along with economical sustainability is needed. To address this research, gap this research focus on performance of VCRS combining all above parameters.

2. Materials and Methods

This section describes selection of different parameters, specification of used components and experimental setup. Performance of Vapour compression refrigeration system is measured in terms of Coefficient of Performance (COP) calculated by

$$COP_R = \frac{Refrigerating\ Effect}{Work\ Done} = \frac{h1-h4}{h2-h1} \quad (1)$$

2.1 Mathematical Modelling and Selection of compressor

Mathematical modelling of compressor includes measuring thermodynamic process and energy interactions occurring around this component. Fundamental equation for compressor involves Wc (Work done by compressor) or power consumption during compression process.

Work done by compressor Wc = h2 − h1 kJ/kg (2)

Where, h2 represent Enthalpy at compressor outlet and h1 Enthalpy at compressor inlet.

Along with that isentropic efficiency (ηc) of the compressor is expressed as the ratio of actual work input to the ideal isentropic work. These equations provide basis to model compressor considering different parameters including type of refrigerant, operating conditions etc.

For this research work compressor used was 0.32 HP Hermetically sealed compressor with Model Number KCN415LAG-BXX with voltage 230V-50HZ manufactured by Emerson.

2.2 Mathematical Modelling and Selection of Condenser

Mathematical modelling condenser includes heat rejection and energy interaction occurring with this component. Fundamental equation for condenser involves Qc (Heat rejected by condenser) during condensation process.

Heat rejected in condenser Qc = m. (h2 − h3) kJ/kg (3)

Where, m represents the mass flow rate of the refrigerant and $h2$ is the enthalpy at the condenser inlet, and $h3$ is the enthalpy at the condenser outlet. Additionally, the effectiveness (ε) of the condenser calculated as the ratio of actual heat transfer to the maximum possible heat transfer.

These equations provide basis to model condenser considering different parameters including type of refrigerant, mass flow rate etc and also help to provide insight for system analysis and optimisation.

Table 1 gives information about parameters of condensers selected for this research work setup.

Table 1 Selection of condenser parameters

Parameter / Value	Fins Type (Air cooled)	Spiral condenser (Air cooled)
Diameter	0.005 m	0.007m
Length	9 m	7 m
Material	MS	Copper
No. of Turns	10	5

2.3 Mathematical Modelling and Selection of Expansion Device

Mathematical modelling of expansion device includes measuring changes in pressure and enthalpy during expansion. Fundamental equation for expansion involves isenthalpic expansion process.

$$h3=h4 \quad (4)$$

where $h3$ is the enthalpy at the inlet of the expansion device, and $h4$ is the enthalpy at the outlet. Also, the isentropic efficiency (ηexp) of the expansion device, which measures its effectiveness in achieving the isentropic expansion. With the help of this equation performance of expansion device can be calculated affecting factors are refrigerant, operating condition and efficiency.

For this research work capillary tube used as an expansion device Capillary tube is of copper tube of small internal diameter and varying length depending upon application. Diameter of capillary tube used for this setup is 2 mm.

2.4 Mathematical Modelling and Selection of Evaporator

Mathematical modelling of evaporator includes study of heat absorption process and energy interactions around this component. A fundamental equation governing the behavior of the evaporator based on the first law of thermodynamics given as,

Heat Absorbed in evaporator, Qe = m. (h1 − h4) kJ/Kg (5)

Where, m is the mass flow rate of the refrigerant and $h1$, $h4$ represents the enthalpy at the evaporator outlet and inlet resp. Also, the effectiveness (εevap) of the evaporator shows the ratio of actual heat transfer to the maximum possible heat transfer.

These equations are needed for modelling the evaporator's performance, considering factors such as refrigerant properties, mass flow rate, and heat transfer efficiency. For this experimental work evaporator is made up of wooden and coiling was made inside with tube diameter of 7 mm. To prevent heat loss to surrounding insulation is provided inside. Evaporators are arranged in series and cooling capacity is identical for both.

2.5 Selection of other components

WIKA pressure gauges are used of max 150 psi to -30 psi to note down suction pressure and pressure gauge of max 300 psi and 0 psi was used to note down discharge pressure. Two heaters of 500 W each was used. Rotameter is a device used to measure flow rate of fluid or gas and for this setup rotameter used is of glass tube of 0.50 to 50 LPH. For safety overload cutoff for compressor was provided. RTD temperature sensors are used to measure temperature at different locations. Refrigerant mixture/blend of R290 propane- R600a isobutane was used. Low Boiling/Freezing point and High critical temperature are desirable characteristics for any refrigerant. For R134a, -26^{o}C and 101^{o}C are values of Boiling point and critical temperature respectively whereas for Propane these are -42.1 ^{o}C and 96.7^{o}C and for Isobutane R600 these are -11.7 °C and 134.98^{o}C resp. From these values we can say propane and isobutane have desirable Boiling point and critical temperature characteristic.

Molecular weight of R134a is 102.03 g/mol whereas for R290 44.1 g/mol and R600a it is 58.12 g/mo. In reciprocating compressor less molecular weight is advantageous as compressor size is reduced, we can see Propane and Isobutane have less molecular weight hence preferred over R134a. As per international safety standard (IEC and EN 60335-2-24) For household appliances maximum refrigerant charge limit is 150 gm which corresponds to approx. 360 g of usual refrigerants.

Following four cases were identified for experimentation purpose which were achieved with the help of valves-

1] Conventional VCRS (Compressor, Condenser, Expansion Device and Evaporator I)

2]Conventional VCRS with series arrangement of evaporators (Compressor, Condenser, Expansion Device, Evaporator I and Evaporator II)

3] VCRS using Spiral condenser (Compressor, Spiral Condenser, Expansion Device and Evaporator I)

4] VCRS using Spiral condenser with series arrangement of VCRS (Compressor, Spiral Condenser, Expansion Device, Evaporator I and Evaporator II). These arrangements were achieved with help of valves.

Figure 1 and 2 shows spiral and fins type condenser arrangement used for experimental work.

Figure 1 Spiral Condenser Arrangement **Figure 2 Fins type condenser arrangement**

3. Results and Discussion

With the modification of Vapour compression refrigeration system by including spiral condenser and series evaporator arrangement along with the use of R290 (Propane) and R600a (isobutane) as a refrigerant both COP enhancement and environment sustainability can be achieved. Spiral condenser has advantages features like compact design, enhanced heat rejection in condenser and series arrangement gives efficiently managed cooling during evaporation. Use of R290 and R600a has become significant because of its favourable thermodynamic and environment friendly properties. These are natural refrigerants having reduced greenhouse gas emissions and considered as environment friendly solution. Combined effect of Spiral condenser, series arrangement and use of propane-isobutane eco-friendly refrigerant improves system efficiency and make a promising alternative for conventional refrigeration system.

Validation

To ensure accuracy of results data validation is important. Use of cool pack software provided confidence in accuracy along with strengthening finding from study.[23] In this section experimental results are validated with cool pack software and are in good agreement with difference less than 10%.

3.1 Effect of modification on Coefficient of Performance:

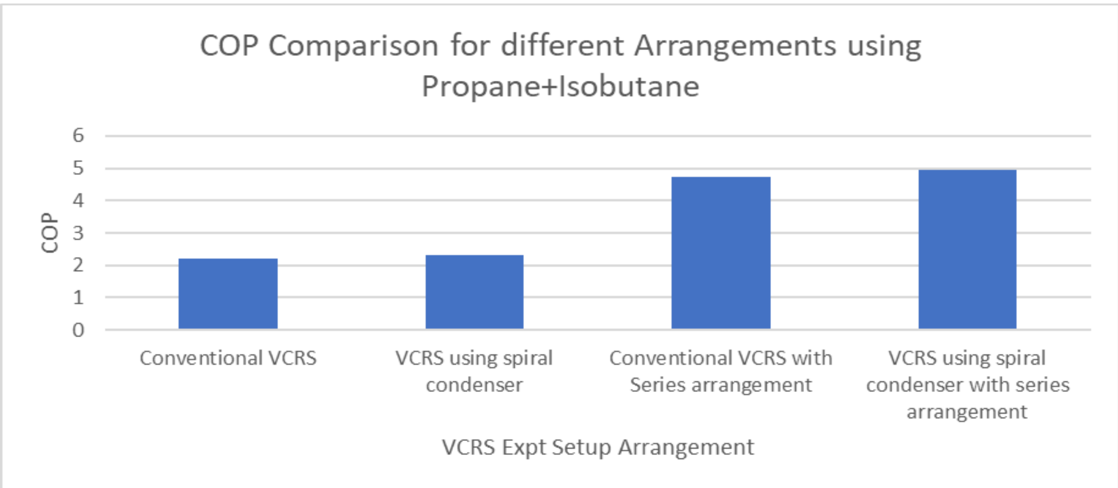

Figure 3 COP Comparison for different Arrangements using R-290 and R600a

Utilisation of spiral condenser, series arrangement of evaporators when incorporated along with mixture of R290(Propane) and R600a(Isobutane) as a refrigerant having notable impact on coefficient of performance. Efficient heat transfer in condenser is possible with Spiral condenser design and optimum effective cooling in evaporator is achieved with the help of series arrangement. R290 and R600a enhance COP by providing more efficient heat transfer. With combination of these parameters COP is increased.

From Figure 3 it can be seen that with use of spiral condenser and use of R290 and R600a mixture 5% COP enhancement is achieved and when COP of VCRS using spiral condenser with series arrangement is compared with conventional refrigeration with series arrangement 4% COP enhancement is achieved.

3.2 Effect of modification on Power Consumption (Wc):

Spiral condenser, series arrangement of evaporators and propane isobutane refrigerant mixture influences net refrigeration effect. Spiral condenser is known for heat rejection properties, series arrangement for effective cooling and improving efficiency. Propane-Isobutane exhibit improved refrigeration performance. Cumulative effect of optimised system design resulted into increased refrigeration effect and positive impact on overall performance of system.

From Figure 4 it can be seen that with use of spiral condenser over conventional with use of propane and isobutane resulted in 24% decrement in power consumption. Also, there is 43% reduction in power consumption when spial condenser-series arrangement is compared with conventional-series arrangement.

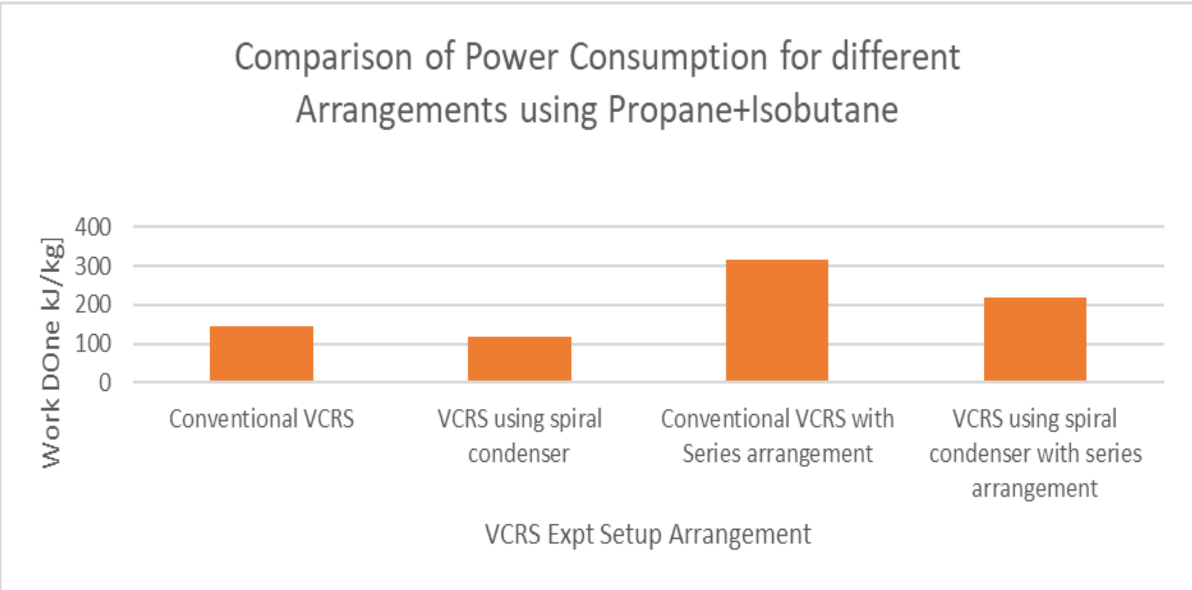

Figure 4 Comparison of Power Consumption for different Arrangements using Propane along with Isobutane

3.3 Effect of modification on Net Refrigeration Effect (RE):

The Spiral Condenser and Series Evaporator arrangement combined with the use of a refrigerant mixture comprising R-290 (Propane) and R600a (isobutane) significantly influences the net refrigeration effect in a cooling system. The Spiral Condenser and Series Evaporator arrangement, ensuring controlled and effective cooling. R-290 and R600a, as constituents of the refrigerant mixture, exhibit favourable thermodynamic properties, resulting in improved heat transfer capabilities and overall refrigeration performance. This optimized system design, coupled with the benefits of the refrigerant mixture, leads to an increased net refrigeration effect.

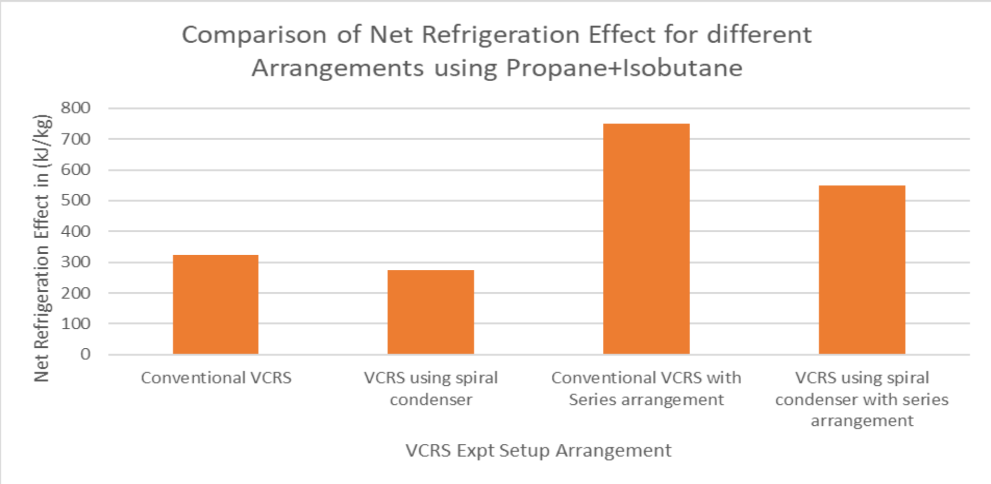

Figure 5 - Comparison of Net Refrigeration Effect for different Arrangements using Propane along with Isobutane.

From Figure 5 it is visible that there is 18% decrement in Net refrigeration effect when spiral condenser performance compared with conventional. Also, there is 70% increment in refrigeration effect when spiral condenser with series arrangement of evaporators was compared over conventional VCRS.

3.4 Economic analysis of modified VCRS system (Payback Period):

The payback period is the time it takes for the cumulative cash flows to equal the initial investment. It's the point at which the project has "paid back" its initial cost.

Payback Period=Initial Investment/Annual Net Cash Inflow The result is the number of years it takes for the investment to be recovered. [24]

Price of R134a per 150 gm is 260 Rs approx. whereas for R600a price is increases up to 275 Rs. per 200 gm and R 290 is 379 Rs. for 150 gm. Due to Better Thermodynamic properties R290 charge is 0.8 compared to R134a and R600a charge is 0.7 compared to R134a.

Table 2 gives information about Comparison of cost parameters between modified and conventional system

Table 2 Comparison of cost parameters between modified and conventional system

Sr.No.	**Conventional System Component**	**Modified System Component**	**Increase in Modification cost.**
1	Fins type Condenser	Spiral Condenser	1000
2	Refrigerant R134a	Refrigerant R290 + Refrigerant R600a	0
3	Evaporator 1	Evaporator I and II	4000
4	Air Heater I	Air Heater I and II	1000

A] Initial Investment-

Initial Investment for this case will be additional 6000 Rs.

B] Operating Cost Saving-

Total Operating cost maybe combination of many parameters

Total Operating Cost=Energy Consumption Cost +Maintenance Cost Repair Cost +Life Cycle Cost +Water Cost +Refrigerant Cost +Environmental Compliance Cost+ Labor Cost+ Monitoring and Control System Cost+ Energy Efficiency Investment Cost

In many industrial and commercial settings, energy costs can represent a significant portion of the total operating costs, especially in systems like refrigeration where continuous operation is necessary. It's not uncommon for energy costs to account for 30% to 50% or more of the total operating costs in these types of systems. As a starting point using typical range as 40%

Cost Savings (%) =Efficiency Improvement (%) ×Percentage of Energy Costs in Total Costs

In this case Efficiency Improvement for Spiral along with series arrangement is 122%.

Cost Savings (%) =122%×40%=48.8%

This means that it could expect a **48.8%** reduction in total operating costs due to the efficiency improvement.

C] Energy Consumption Cost

Considering compressor runs at 12 hours per day then Daily Energy Consumption=0.325 kW **[Taken from Compressor Catalogue Emerson]** ×12 hours =3.9 kWh

Energy Consumption (Monthly) = 3.9 kWh*30 = 117 kwh

Cost of Monthly Energy Consumption= 117*9.64 [**MSEDCL Electricity Rate, 2023**] = 1128 Rs

Cost of Yearly Energy Consumption = 1128*12= 13534

With above modification there is **48.8**% reduction in cost saving hence total energy consumption cost saved per year will be 6605 Rs/-

D] Payback period

Payback Period=Initial Investment/Annual Net Cash Inflow or saving

Payback Period = 6000/6605 = **0.9 Year**

4. Conclusions

The proposed system was designed to accommodate environment friendly refrigerant and to compare performance with conventional system valve arrangement was used. Spiral condenser arrangement was used along with series arrangement of evaporators. Validation results from coolpack software of base case are within permissible limit of 10%.

In conventional VCRS most commonly used refrigerant is HFC-R134a due to its low cost and excellent thermodynamic properties. However, for following best environment practices use of R134a to be prohibited in coming days. There are also some difficulties while using R134a like higher Global Warming Potential value and its immiscibility with natural oil. Hence is need to find long term alternative refrigerant/refrigerant blends which will be meeting standards of international protocols and will increase performance when incorporated in system. Hence, from literature review carried out it has been found that use of HC Mixture, different refrigerant blends will be having low GWP impact as well as improvement in performance. The shift from traditional fin-type condensers to spiral condensers within vapor compression refrigeration systems brings about substantial enhancements in both performance and energy efficiency. The incorporation of a series arrangement of evaporators in vapor compression refrigeration systems has a substantial impact on system performance and efficiency.

Following are major findings pointed out from this research work.

1) Hydrocarbon Mixture of Propane and Isobutane could be considered as an option to R134a in domestic refrigerators.

2) R290 (60%) and R600a (40%) composition is having best performance considering parameters like mass flow rate, COP etc.

3) Modification of system design with use of spiral condenser and series arrangement of evaporators using R290 and R600a resulted into 122%. performance improvement over conventional VCRS along with 0.9-year payback period.

To summaries in short with all combined modifications studied for this research work COP enhancement is achieved with reduction in power consumption and as payback period is almost less than 1 year's initial investment will be returned in terms of energy saving cost.

List of abbreviations

COP	Coefficient of performance
GWP	Global Warming Potential
HFC	Hydrofluorocarbon
HCFC	Hydrochlorofluorocarbon
ODP	Ozone Depletion Potential
VCRS	Vapour compression refrigeration system

Declarations

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

Competing interests

The authors declare that they have no competing interests

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Conflicts of Interest

Authors declare that there is no conflict of interest regarding the publication of this article.

Authors' contributions

Activity	Author Name
Conceptualization, Methodology, Formal analysis, Supervision	Author 1, Author 2, Author4
Software, Validation, Investigation	Author 1, Author 3
Writing - Original Draft, Writing - Review & Editing	Author1, Author2, Author 4

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References

1. Malwe PD, Shaikh J, Gawali BS. Exergy assessment of a multistage multi-evaporator vapor compression refrigeration system using eighteen refrigerants. Energy Reports. 2022; 8:153–62.
2. Kulkarni S, Chavali S, Dikshit S. A review on analysis of Vapour Compression Refrigeration System (VCRS) for its performance using different ecofriendly refrigerants and nanofluids. Mater Today Proc. 2023; 72:878–83.
3. Shankar Prasad U, Mishra RS, Das RK. Experimental studies of vapour compression refrigeration system with eco-Friendly primary refrigerant and brine mixed with nano particles as secondary refrigerant. Mater Today Proc. 2021; 45:3857–9.
4. Islam MdA, Mitra S, Thu K, Saha BB. Study on thermodynamic and environmental effects of vapor compression refrigeration system employing first to next-generation popular refrigerants. International Journal of Refrigeration. 2021; 131:568–80.
5. Mota-Babiloni A, Fernández-Moreno A, Giménez-Prades P, Udroiu C-M, Navarro-Esbrí J. Ternary refrigerant blends for ultra-low temperature refrigeration. International Journal of Refrigeration. 2023; 148:108–16.
6. Bolaji BO. Theoretical assessment of new low global warming potential refrigerant mixtures as eco-friendly alternatives in domestic refrigeration systems. Sci Afr. 2020;10: e00632.
7. Sánchez D, Andreu-Nácher A, Calleja-Anta D, Llopis R, Cabello R. Energy impact evaluation of different low-GWP alternatives to replace R134a in a beverage cooler. Experimental analysis and optimization for the pure refrigerants R152a, R1234yf, R290, R1270,

R600a and R744. Energy Convers Manag. 2022; 256:115388.
8. Wu D, Hu B, Wang RZ. Vapor compression heat pumps with pure Low-GWP refrigerants. Renewable and Sustainable Energy Reviews. 2021; 138:110571.
9. Reddy DVR, Bhramara P, Govindarajulu K. Experimental Evaluation of the Effect of Refrigerant Charge and Capillary Tube Length on the Performance of Household Refrigerator with Different Configurations of R290 and R600a. Mater Today Proc. 2018;5:11845–52.
10. Mohanraj M, Jayaraj S, Muraleedharan C, Chandrasekar P. Experimental investigation of R290/R600a mixture as an alternative to R134a in a domestic refrigerator. International Journal of Thermal Sciences. 2009; 48:1036–42.
11. de Paula CH, Duarte WM, Rocha TTM, de Oliveira RN, Mendes R de P, Maia AAT. Thermo-economic and environmental analysis of a small capacity vapor compression refrigeration system using R290, R1234yf, and R600a. International Journal of Refrigeration. 2020; 118:250–60.
12. Ozsipahi M, Kose HA, Kerpicci H, Gunes H. Experimental study of R290/R600a mixtures in vapor compression refrigeration system. International Journal of Refrigeration. 2022; 133:247–58.
13. Gill J, Singh J. Energy analysis of vapor compression refrigeration system using mixture of R134a and LPG as refrigerant. International Journal of Refrigeration. 2017; 84:287–99.
14. Logesh K, Baskar S, Azeemudeen M, Praveen Reddy B, Venkata Subba Sai Jayanth G. Analysis of Cascade Vapour Refrigeration System with Various Refrigerants. Mater Today Proc. 2019; 18:4659–64.
15. Ozair Arshad M, Azam Q, Twaha Irfan Ahmad S, Khan F, Atif Wahid M. Analysis of vapour compression refrigeration system with R-12, R-134a and R-22: An exergy approach. Mater Today Proc. 2021; 46:6748–52.
16. Ajayi OO, Ukasoanya DE, Ogbonnaya M, Salawu EY, Okokpujie IP, Akinlabi SA, et al. Investigation of the Effect of R134a/Al2O3 –Nanofluid on the Performance of a Domestic Vapour Compression Refrigeration System. Procedia Manuf. 2019; 35:112–7.
17. Giménez-Prades P, Navarro-Esbrí J, Udroiu C-M, Mota-Babiloni A. Influence of subcooling in R-449A supermarket refrigeration system and screening of refrigerant mixtures for its energetic and environmental improvement. Appl Therm Eng. 2024; 236:121787.
18. Said Z, Rahman SMA, Sohail MA, Bahman AM, Alim MA, Shaik S, et al. Nano-refrigerants and nano-lubricants in refrigeration: Synthesis, mechanisms, applications, and challenges. Appl Therm Eng. 2023; 233:121211.
19. Sivaraman N, Muthu Vaidyanathan R, Patel M, Markos M. Performance analysis of refrigerants with various expansion valves in vapour compression refrigeration and air-conditioning system. Mater Today Proc. 2021; 45:2465–9.
20. Kumar S, #1 A, Prasanthi SG. Performance Analysis of Vapour Compression Refrigeration System with Spiral Condenser Using R134a and Sio 2 Nanoparticle with Poe as Refrigerant. The International journal of analytical and experimental modal analysis. 2019.
21. Ishu Garg, Dr. V.K. Bajpai. Experimental Study to Compare the C.O.P. of a Vapor Compression Refrigeration System by using two Evaporators in Series or in Parallel. Journal of Material Science and Mechanical Engineering. 2018; 5:1–4.
22. Subramanian S, Joswa L, Srinivasan S, Sundaresan D, Balakrishnan S. Performance analysis of fin tube evaporator using various refrigerants. Thermal Science. 2020; 24:609–12.
23. CoolPack Tutorial [Internet]. [cited 2023 May 14]. Available from: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.ipu.dk/wp-content/uploads/2018/09/coolpack-tutorial.pdf
24. Gao P, Wang LW, Zhu FQ. Vapor-compression refrigeration system coupled with a thermochemical resorption energy storage unit for a refrigerated truck. Appl Energy. 2021; 290:116756.