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DESIGN OF A CAR AC SYSTEM BASED ON ABSORPTION REFRIGERATION CYCLE USING ENERGY FROM EXHAUST GAS OF AN IC ENGINE

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ABSTRACT

The most widely used type of air conditioning system in automobiles is Vapour Compression Refrigeration Systems (VCRS), which are mechanical and powered by the engine. This extra power use translates to more fuel being used and lower overall engine efficiency. The present project is an innovative automobile air conditioning system which uses waste heat from the exhaust gas of an Internal Combustion (IC) engine in a Vapour Absorption Refrigeration System (VARS). This thermal energy can be effectively recovered and used to drive the refrigeration cycle, as a big part of the fuel energy is dissipated in exhaust emissions, without having to provide any extra mechanical energy. The proposed system comprises of the four main parts as generator, condenser, evaporator and absorber. The engine's exhaust gases provide heat to the generator, thus starting the refrigeration process. All components are modeled in CATIA software and simulated in thermal and Computational Fluid Dynamics (CFD) in ANSYS software to check heat transfer and temperature distribution, system performance. Thermal behavior and application of materials including steel, aluminum alloy, copper and titanium alloy are investigated to determine its suitability for refrigeration applications. The simulation indicated the possibility to use the exhaust heat from the engine to cool the cabin and decrease the engine loading and fuel consumption for the proposed absorption refrigeration system. The system provides a sustainable, energy-efficient and environmentally friendly solution for the typical air conditioning systems in the automotive industry.

Keywords: Vapour Absorption Refrigeration System (VARS), Internal Combustion Engine, Waste Heat Recovery, Automobile Air Conditioning, Exhaust Gas Energy, Thermal Analysis, CFD Analysis, CATIA Design, ANSYS Simulation, Energy Efficiency.

I. INTRODUCTION

Today, air conditioning is almost a standard feature in automobiles, contributing to their comfort and overall driving experience. The typical cooling system of conventional vehicles is based on Vapour Compression Refrigeration Systems (VCRS) that use the mechanical drive compressor that is powered directly by the engine. These systems work well, but add to the load on the engine and fuel consumption, therefore reducing the overall efficiency of the vehicle [1]. Internal combustion engines utilise only part of the energy available in the fuel for useful work, and there is a large amount of waste heat which is lost to the exhaust gases and cooling systems [2]. It has been found that about 30-40% of total fuel energy is dissipated in the exhaust gases of the engine, and this is a good source of recoverable thermal energy [3]. Utilization of this waste heat can be very efficient for an overall better use of energy and less impact on the environment. Vapour Absorption Refrigeration Systems (VARS) are an attractive alternative as thermal energy is used to produce refrigeration effects instead of mechanical energy [4]. Absorption refrigeration systems use exhaust gas heat as the energy source and thus can cool the cabins without adding to the mechanical burden on the engine. Thus, the combination of waste heat recovery and absorption refrigeration systems offers a potential solution to enhance the energy efficiency and sustainability of vehicles [5].

Paragraph 2

The project aims to design and analyze a car air conditioning system based on Vapour Absorption Refrigeration Cycle utilizing the exhaust gases of an Internal Combustion (IC) engine [6]. In this system, the exhaust heat is utilized for the generation part of the absorption refrigeration machine, and thus the cooling cycle is started. The absorption system, unlike traditional refrigeration systems, which are driven by compressors, is based on the use of heat energy to create the necessary pressure difference between the evaporator and condenser [7]. The system consists of the four main components; generator, condenser, evaporator, absorber and solution heat exchanger. All the components are designed with a high degree of optimization to maximize heat transfer efficiency while at the same time keeping the dimensions as compact as possible for the automotive application [8]. The condenser is designed as an air-cooled heat exchanger to avoid the need for extra water supply and the evaporator is designed to maximize the cooling in the vehicle cab. Moreover, having finned surfaces of the absorber is favourable for the heat dissipation and absorption performance. This integrated design allows for efficient utilization of the waste heat, fuel saving and overall system efficiency [9].

Paragraph 3

Advanced design and simulation tools are used all throughout the project to assess feasibility and performance of the proposed refrigeration system. The geometric models of the generator, condenser, evaporator and absorber are created by CATIA software that allows the accurate generation of the 3D model of the components in the construction of the system [10]. Thermal and Computational Fluid Dynamics (CFD) analysis of the system components is carried out with the software ANSYS to study the temperature pattern, heat transfer characteristics, thermal performance and flow behavior of the fluids in the system components [11]. Various engineering materials including steel, aluminum alloy, copper, and titanium alloy are studied and their suitability for refrigeration applications is determined based on the thermal conductivity, and heat transfer efficiency [12]. The results of the simulation can be used to gain insight into the performance of the components and to optimize the design for maximum cooling effect. The results show that the absorption refrigeration system is feasible for generating refrigeration effect using engine exhaust waste heat and can also cut down the dependence on compressor based refrigeration system. Thus, the project helps in the development of environment-friendly, energy efficient and sustainable automotive air conditioning technologies for future applications in transportation [13].

II SURVEY OF RESEARCH

1. A Vapour Absorption Refrigeration System (VARS) using waste Heat of Exhaust Gases (HEG) of the Engines for refrigeration was proposed by researchers [1]. The objective of the study was to overcome the drawback of conventional Vapour Compression Refrigeration Systems (VCRS) in which fuel consumption is increased due to the operation of the compressor. The system proposed here used the waste heat of the exhaust gases to run the refrigeration cycle. In laboratory tests it was found that a large portion of the heat generated in the exhaust could be efficiently transformed into cooling energy. The system lowered the load on the engines, increased fuel efficiency and increased overall energy efficiency. In addition, the mechanical-driven compressor was eliminated, thus lowering the maintenance needs and noise level during operation. The researchers found that the waste heat recovery based refrigeration systems are energy efficient and environmentally friendly solution for automotive air conditioning applications. The results of the study provided a basis for further research on automotive thermal management and sustainable refrigeration technologies, and for efficient utilization of rejected engine energy [1].

2. Advanced absorption refrigeration systems for cars have received considerable interest for many reasons, including the growing fuel efficiency demands [2]. The feasibility of replacing the conventional compressor driven AC systems with thermally driven absorption refrigeration systems was studied. The planned design used exhaust gas heat for main energy source for the refrigeration cycle. A number of refrigerant-absorbent pairs were explored to enhance the cooling performance and thermal efficiency. It has been shown experimentally and theoretically that enough cooling capacity can be obtained from waste heat of IC engines. This system caused a substantial decrease in mechanical power requirement of the engine and enhanced the fuel economy. Furthermore, the small size allowed it to be easily embedded in vehicle structures. Reduced use of fuel and greenhouse gas emissions were also recognised as benefits to the environment in the study. The researchers found that absorption refrigeration technology is a viable, environmentally friendly solution in comparison with the conventional automotive air conditioning system, and could also enhance the overall energy efficiency and thermal performance of the vehicles [2].

3. The innovative exhaust heat recovery system was developed for using exhaust gas waste heat for cooling the vehicle cabin [3]. The study is aimed at the collection of the exhaust heat in a heat exchanger and its transfer to the generator compartment of an absorption refrigeration system. Experimental analyses were conducted with different operating conditions of the engine in order to assess cooling performance and the utilization of energy. Exhaust gas analysis showed that the exhaust gases had enough heat to keep the refrigerator running and to keep the passengers comfortable in the train. The suggested system proved to be very effective in reducing the consumption of fuel due to elimination of compressor-driven cooling. Plus, energy savings helped

minimise the environmental footprint and helped to boost vehicles' efficiency. The researchers also investigated the effect of the engine speed and load on the refrigeration performance and its refrigeration output remained stable under the wide range of operating conditions. It was concluded that exhaust heat recovery technologies are an efficient solution for automotive cooling system and can be used to be helpful and play an important role in future applications to sustainable transportation and exhaust heat utilization [3].

4. The use of absorption refrigeration technology in an automobile air conditioning system using engine exhaust heat was studied [4]. The study emphasized minimization of the dependence from the conventional Vapour Compression Refrigeration Systems (VCRS) which use mechanically driven compressors and have higher fuel consumption. The proposed system involves using waste heat energy of exhaust gases and extracting it via a generator-absorber system to drive the refrigeration cycle. The various combinations of refrigerant and absorbent were studied such as ammonia-water and lithium bromide-water solutions to assess their cooling performance and thermal efficiency. Thermodynamic analysis showed that the exhaust gas temperature was suitable for operating refrigeration continuously under normal operating modes of the vehicle. Experimental results showed the system to be effective in reducing the engine load and improve overall fuel economy whilst also cooling the cabin. The absorption refrigeration system also reduced the mechanical complexity by eliminating compressor parts, which reduced the maintenance requirement and operating noise. The study has come to the conclusion that exhaust-gas driven absorption refrigeration systems are a sustainable alternative to the conventional automotive air conditioning systems [4].

5. An automotive Vapour Absorption Refrigeration System using R134a as refrigerant and Dimethylformamide (DMF) as absorbent was experimentally studied [5]. The goal of the project was to test some new refrigerant-absorbent pairs for waste heat-driven refrigeration systems. The system was tested with various thermal conditions and refrigeration capacity, thermal efficiency and coefficient of performance were evaluated. Experimental results showed stable operation and the good cooling performance appropriate for automotive application. The system used the waste heat of engine exhaust gases, which led to a reduction in the mechanical compressor work requirements and hence fuel consumption and engine load. The team also noticed that there was a decrease in vibration and noise from the operation of compressor driven parts. The performance analysis was conducted under different operating conditions and it was observed that energy utilization has improved and refrigeration output is effective. The study found that R134a-DMF working pairs have a high potential to improve the performance of absorption refrigeration systems, and can be used to realize sustainable automotive cooling technologies [5].

6. The optimization of the thermal performance of the components of the absorption refrigeration system is crucial to enhance the efficiency and reliability of the system [6]. The Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA) were used to conduct a detailed research on generators, condensers, evaporators and absorbers. Steel, aluminum alloy, copper and titanium alloy were selected as the engineering materials and various tests were conducted to evaluate their thermal properties and applications for refrigeration. The simulation results showed that the copper and aluminum had the best thermal conductivity and heat transfer performance among other materials. The optimal configurations of components were determined by using temperature distribution and heat flux analyses so that the refrigeration efficiency is maximized. The study showed the feasibility of using advanced simulation tools to effectively describe the thermal behavior and optimize the design of the components prior to physical implementation. The researchers found that the choice of material, optimization of geometry and thermal analysis are all key factors in improving the performance of absorption refrigeration systems. The results can be used significantly to enhance development of efficient automotive refrigeration systems utilizing waste heat reutilization technologies [6].

II. WORKING METHODOLOGY

The proposed system is based on the idea to use the waste heat of the exhaust gases of an Internal Combustion (IC) engine to drive a Vapour Absorption Refrigeration System (VARS) for automobile air conditioning. The absorption refrigeration system is a system driven by thermal energy as opposed to a mechanically driven compressor in conventional Vapour Compression Refrigeration Systems (VCRS). While running, the exhaust gases from the engine are expelled at temperatures between 450 °C and 600 °C. This thermal energy is extracted by a heat exchanger and fed into the refrigeration generator portion of the refrigeration system. The exhaust gas's heat content can be determined as follows:

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$$Q = \dot{m}C_p(T_{in} - T_{out})$$

where Q is the heat recovered, m is the amount of exhaust gas per unit time.C: amount of exhaust gas per unit time.p is the mean temperature.is the specific heat and is the mean temperature.When the supplied thermal energy causes the refrigerant to separate from the absorbent solution, the high-pressure refrigerant vapor is produced. This process is used to start the refrigeration cycle without using any further mechanical power from the engine. The use of waste heat energy in the system also enhances the overall fuel efficiency and minimises losses due to conventional air conditioning systems. The proposed concept therefore provides an efficient use of the vehicle while ensuring the coolness of the vehicle for the passenger's comfort.

High-pressure refrigerant vapor moves out of the generator to the condenser where the heat is removed to the surrounding air. An air-cooled condenser is used which reduces the installation work and does not require other cooling water systems. The refrigerant releases heat, and becomes a high-pressure liquid. Heat being rejected in the condenser is expressed as:

$$Q_c = \dot{m}(h_2 - h_3)$$

where Qc is the temperature of the condenser.is condenser heat rejection and h is condenser temperature.This liquid refrigerant is then sent to a pressure and temperature reducing valve called an expansion valve, and finally to the evaporator. The refrigerant takes heat from the interior of the vehicle in the evaporator and turns into a gas to cause the cooling effect. A refrigeration capacity is dependent on:

$$Q_e = \dot{m}(h_1 - h_4)$$

The evaporator is configured into a spiral tubular shape to get the maximum heat transfer area in minimal space inside the vehicle. The refrigerant vapor that has left the evaporator goes into the absorber where it is absorbed by the absorbent solution. The finned surfaces furnished on the absorber dissipate the heat released during the absorption process. The strong solution will then be returned to the generator, and the cycle will repeat. The overall performance of the absorption refrigeration system is judged by the coefficient of performance (COP):

$$COP = \frac{Q_e}{Q_g}$$

where Qe is the cooling sensation.is cooling sensation and Q is refrigeration effect. Qg is the amount of heat sent to the generator. CATIA is employed for three dimensional modeling and ANSYS is used for thermal and CFD analysis of the proposed refrigeration system for its evaluation and optimization. Thermal behaviour of different materials like steel, aluminium alloy, copper, titanium alloy etc. is analyzed. The refrigeration components can transfer heat according to the following:

$$Q = UA\Delta T$$

The overall heat transfer coefficient, U, the heat transfer area, A, and the temperature difference, ΔT. The effectiveness of the suggested absorption refrigeration system in efficient cooling of the vehicle cabin with reduction of fuel consumption, engine loading, and environmental impact has been confirmed by simulation results. Therefore, the system is an environmentally friendly and energy-efficient solution to the conventional automotive air conditioning system.

IV RESULTS EXPLANATIONS

Condenser:

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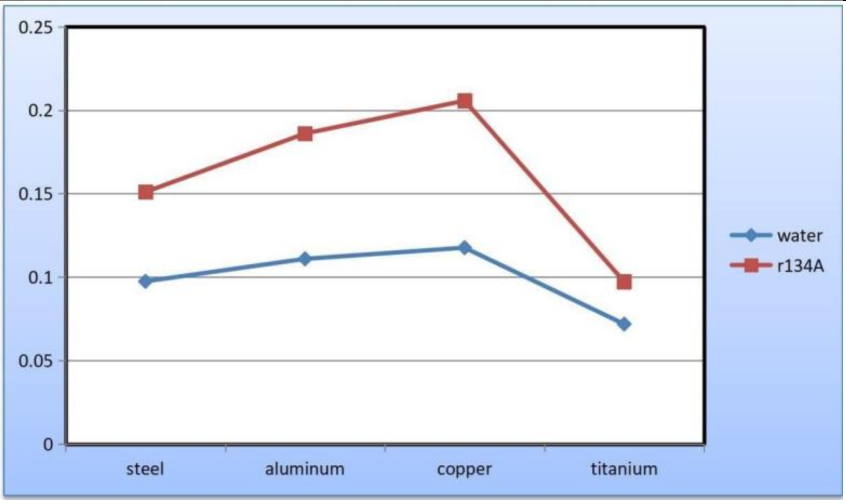
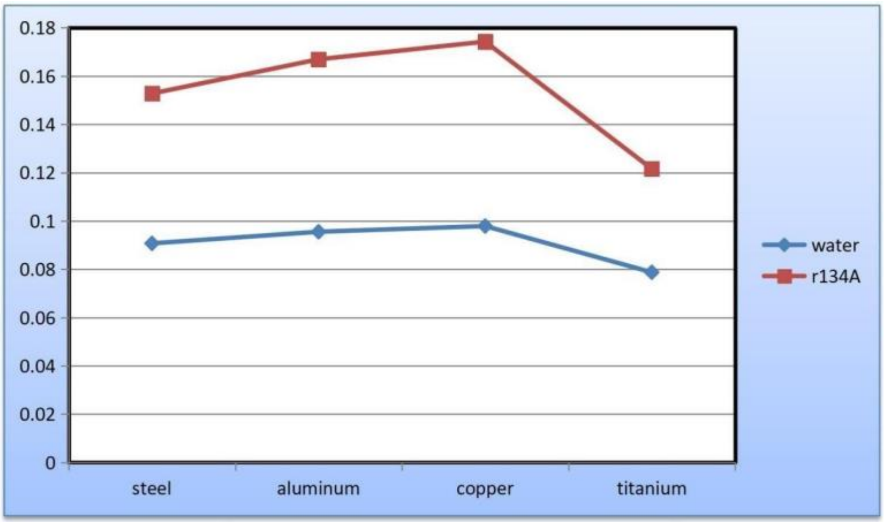


The first graph compares the thermal performance of four different materials (Steel, Aluminum, Copper and Titanium) with two different working fluids (Water and R134A). It is clear that in both fluids, the performance in terms of amount of heat transferred in the order of Steel to Copper decreases significantly when it is used with Titanium. In the case of Water, the thermal performance becomes 0.118 for Copper and 0.098 for Steel, respectively, which shows that the Copper has a higher value of the thermal performance since it has a higher thermal conductivity value. R134A also shows an improvement in overall performance, from about 0.151 to 0.206, when tested in Copper. Copper is the most thermally-performing material among all the tested materials, and is the most appropriate material for use in the refrigeration system components, such as condenser and evaporator. Due to the good performance of thermal conductivity and lightweight, Aluminum is the second most preferred metal after Copper. Although Steel offers moderate heat transfer performance, Titanium has the lowest values of Water and R134A, showing that Titanium has a poor heat dissipation capability compared to other materials. A second noteworthy aspect is that for all material types, R134A produces higher heat transfer results than does Water; this indicates that R134A has superior refrigerating properties and gives it better ability to transfer thermal energy. The results clearly indicate that material selection plays a crucial role in determining the efficiency of refrigeration systems. Thus, the use of Copper and R134A yields the highest thermal performance and is suggested for attaining the maximum cooling efficiency, heat transfer efficiency and overall effectiveness of the system in automotive absorption refrigeration systems.

Evaporator



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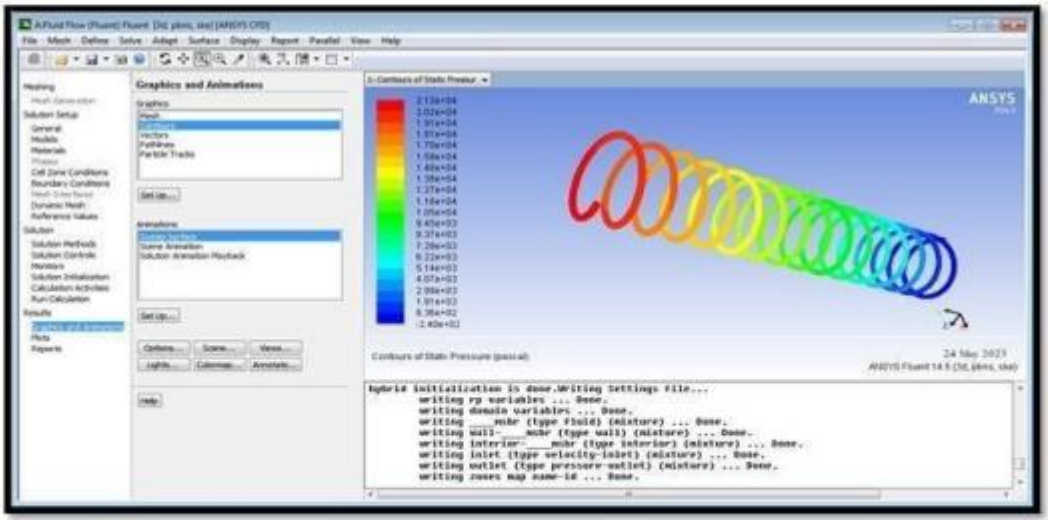
The second graph shows the difference in thermal performance obtained with Steel, Aluminium, Copper and Titanium materials for the water and R134A working fluids. The trend of the graph is similar to the first analysis with the thermal performance gradually increasing from Steel to Copper and decreasing significantly for Titanium. For Water the values are enhanced from almost 0.091 (Steel) to 0.098 (Copper) which shows improved heat transfer properties because of the improvement of thermal conductivity. Similarly, R134A has much higher values, ranging from about 0.153 for Steel up to 0.175 for Copper, the highest thermal performance of the analysis. The results show that the heat transfer capability of Copper is higher than all the materials considered and it can be used as the best material to construct the refrigeration system. Aluminum has also satisfactory thermal performance, and is a suitable alternative due to its low weight and relatively high conductivity. The performance level of Titanium is the lowest with values dropping to around 0.079 for Water and 0.121 for R134A. This reduction mainly due to lower thermal conductivity of it than Copper and Aluminium. Additionally, it is obvious that R134A has a superior refrigerant ability and its heat-absorptive and heat-transmissible abilities are better than those of Water in all material types, as revealed in the graph. The analysis shows that the type of refrigerant and the type of material used are very important factors affecting the thermal efficiency of the refrigeration system. Considering the observed results, it is concluded that the combination of Copper + R134A is the most suitable configuration for automotive absorption refrigeration system and waste heat recovery system.



The Computational Fluid Dynamics (CFD) pressure analysis of the spiral tube of the absorption refrigeration system has been shown above, using ANSYS Fluent software. The contour plot is a representation of the variation of static pressure at length of the helical tube. The colour of the pressure areas are different, red is the highest pressure area, blue is the lowest pressure area. One can see that the pressure is highest at the entry part of the spiral tube and falls towards the exit part of the tube. This pressure drop is caused by the frictional losses, resistance of the working fluid, and change in direction of flow of the working fluid as it passes through the helical path. The gradual color changes from red, orange, yellow, green to blue suggest that the pressure difference is consistent along the entire length of the tube, indicating stable flow conditions in the fluid. This is because there are no sudden changes in the pressure which further supports the fact that the spiral tube design is effective in minimizing turbulence and flow separation. This pressure distribution is desired as it allows for continuous flow of refrigerant and maximises heat transfer efficiency in the refrigeration system. Effective flow path is increased in helical configuration with better interaction between refrigerant and the tube walls which creates better thermal efficiency. The CFD results also show that the pressure drops are within acceptable limits, which is important for the efficient operation without excessive pressure drops and in need of pumps. So, the analysis confirms the appropriateness of the spiral evaporator design for automotive absorption refrigeration system. The stepped reduction in pressure along with the steady flow characteristics help to achieve better cooling efficiency, effectiveness of heat transfer, and stable system operation. The results provide the validation of the proposed design that it can carry out the efficient refrigeration by utilizing the waste heat from the engine exhaust gases.

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Fluids	Materials	Temperature (^{0}C)		Heat flux (w/mm^2)
		Max.	Min.	
Water	steel	38	34.714	0.097461
	Aluminum alloy	38	36.529	0.11095
	copper	38	37.41	0.11765
	Titanium alloy	38	31.109	0.071858
R134A	steel	38	32.828	0.15101
	Aluminum alloy	38	35.312	0.186044
	copper	38	36.969	0.20571
	Titanium alloy	38	28.473	0.097288

Fluids	Materials	Temperature (^{0}C)		Heat flux (w/mm^2)
		Max.	Min.	
Water	steel	8.3241	7	0.090738
	Aluminum alloy	7.5802	7	0.095554
	copper	7.2158	7	0.097907
	Titanium alloy	10.168	7	0.078762
R134A	steel	9.2272	7	0.15279
	Aluminum alloy	8.0129	7	0.16696
	copper	7.3841	7	0.17428
	Titanium alloy	11.882	7	0.12163

The results of the thermal analysis for four different materials—Steel, Aluminum Alloy, Copper, and Titanium Alloy—with the working fluids Water and R134A are given above. The parameters that are studied are maximum temperature, minimum temperature and heat flux; which are parameters of great importance in the study of refrigeration system components and their heat transfer. For Water, the temp maximum goes from 8.3241°C to 7.2158°C from Steel to Copper and the heat flux goes from 0.090738 W/mm² to 0.097907 W/mm². This means that because Copper is HIGHLY thermally conducting, it offers better heat transfer than other materials. Aluminum Alloy has a good thermal performance with heat flux of 0.095554 W/mm2 which is appropriate to be used as alternative material. Titanium Alloy has the highest maximum temperature of 10.168°C and the lowest heat flux of 0.078762 W/mm², which means it has poor heat dissipation properties. The same behavior is seen for R134A refrigerant. Copper has the highest heat flux at 0.17428 W/mm², Aluminium Alloy at 0.16696 W/mm² and Steel at 0.15279 W/mm². Titanium Alloy has the lowest heat flux value, 0.12163 W/mm², and the highest Maximum temp, 11.882°C. The data clearly shows that the higher the thermal conductivity of the material, the better the heat transfer and the lower operating temperature. Moreover, the heat flux values obtained with R134A are always and for all materials higher, which means better refrigeration performance. Hence, it is believed that Copper has the best thermal performance when coupled with R134A and is the best material-fluid combination for enhancing the heat transfer efficiency of an automotive absorption refrigeration system.

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Models	Fluids	Pressure drop(Pa)	Velocity (m/s)	Heat transfer coefficient (w/m2-k)	Mass flow rate(kg/s)	Heat transfer rate (W)
Condenser	Water	1.32e+06	2.47e+01	6.78e+04	0.032626152	10214.063
	R134A	5.74e+03	2.49e+01	3.69e+02	0.00012858864	9.7034912
Evaporator	Water	3.68e+06	2.30e+01	7.48e+04	0.01999718	6262.4688
	R134A	2.13e+04	2.20e+01	4.47e+02	0.00014976	11.298492

The results of the Computational Fluid Dynamics (CFD) analysis of the condenser and evaporator components with two different working fluids (Water and R134A refrigerant) are shown in the above table. The evaluated parameters are pressure drop, velocity, heat transfer coefficient, mass flow rate and heat transfer rate. The pressure drop of the condenser for Water is 1.32×10^6 Pa and that of R134A is 5.74×10^3 Pa. The flow velocity of both fluids is almost the same, around 24 m/s, so the flow is deemed to be stable. Compared to R134A, Water has a much larger heat transfer coefficient of 6.78×10^4 W/m²-K versus 3.69×10^2 W/m²-K. Likewise, the mass flow rate and heat transfer rate of Water is much larger (0.0326 kg/s and 10214 W, respectively). Again, Water shows remarkable thermal performance in the evaporator: 7.48×10^4 W/m²-K and 6262 W; R134A: 4.47×10^2 W/m²-K and 11.3 W. Water has a much higher heat transfer value, but also has a higher pressure drop across the system. R134A, however, is utilised at lower pressure drops and lower mass flow rates, thus allowing its use in refrigeration applications that demand efficient phase change cooling. The CFD analyses show that Water has very good heat transfer properties, with R134A having good refrigeration capabilities and lower restriction properties. Thus, both fluids have their own merits based on the thermal and operational needs of an absorption refrigeration system.

V.CONCLUSION

The present work successfully presents the design and analysis of the car air conditioning system using Vapour Absorption Refrigeration System (VARS) with the use of exhaust heat recovery from Internal Combustion (IC) Engine. Traditional car air conditioning systems use Vapour Compression Refrigeration Systems (VCRS) that are mechanical drive systems that need to consume a lot of fuel from the car's engine. To overcome this limitation, the proposed system recovers the wasteful exhaust thermal energy of the vehicle and makes better use of the vehicle's overall energy usage. All major components of the absorption refrigeration system such as generator, condenser, evaporator and absorber were designed using CATIA software and analyzed by the ANSYS thermal and Computational Fluid Dynamics (CFD) simulation software. Different materials like steel, aluminum alloy, copper, and titanium alloy were investigated for their thermal performance and heat transfer properties. The results from the simulation showed that materials with high thermal conductivities such as copper, aluminum, etc. had better heat transfer performance and effective refrigeration. The thermal analysis was conducted to determine if enough waste heat exists in the engine exhaust gas for an effective cabin cooling system using the absorption refrigeration cycle. The system proposed reduces the maintenance needs, the engine load, the environmental footprint, improves fuel consumption and does not require compressor power. Moreover, in automotive applications, the use of waste heat can improve sustainability and energy efficiency.

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