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ABSTRACT

The main objective of the proposed project is to design an air-conditioning system for a hybrid-powered car under various conditions surrounding the car during operation or when it is stationary. Hybrid energy here combines two types of energy, one is kinetic energy generated from exhaust gas recycling, and the other is solar energy generated from the photovoltaic system. Both types of hybrid energy can be converted into electrical energy sufficient to operate the electric compressor of the refrigeration system. When the car is running, the kinetic energy of the waste exhaust gases generated by the combustion of diesel fuel inside the engine is converted into electrical energy by passing it to a turbine connected to the dynamo. On the other hand, when the car is in stop mode, solar energy is invested to operate the cooling system by connecting photovoltaic cells to the battery, where it is stored and converted into electrical energy to operate the compressor. As a result, the hybrid cooling system significantly reduces engine load and fuel consumption, thus increasing engine efficiency.

The results of the current study showed that it is possible to operate the air conditioning system in the vehicle during operation and when the engine is off. The study also showed an improvement in the efficiency of the engine as a result of removing the load placed on the engine as well as the coefficient of performance for the proposed cooling system increased by about 5.18% when compared to the conventional cooling system. These findings led to the discovery of a solution to the energy waste problems of the air conditioning system in a vehicle that operates in the vapor compression cycle.

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1. INTRODUCTION

As mentioned earlier in chapter one, the project about Design of a cooling system for a hybrid-powered vehicle. Energy waste and heat pollution have resulted from the extensive release of waste heat from industrial plants and other processes into the environment. Therefore, from the perspective of energy saving and environmental preservation, waste heat recovery and the utilization of clean energy are extremely important. Numerous engineering applications essentially acknowledge the utilization of waste heat technology. A conventional (vapor compression cycle) refrigeration system is not only an alternative to conventional refrigeration units, but it can also be run at relatively low temperatures by a variety of heat sources (such as heat that recovered from heat engine and manufacturing operations), which considers as a perfect option for the application of energy recovery (ER).

A conventional (vapor compression cycle) refrigeration system is the best choice for ER applications because it can operate at relatively low temperatures using a variety of heat sources, including heat from manufacturing processes or a heat engine. This makes it an alternative to conventional refrigeration units. For a typical and representative drive cycle, it is projected that the average values of the heating power available from waste heat will be around 23 kW, as opposed to the 0.8–3.9 kW cooling capacity provided by ordinary passenger car systems. Another disadvantage of the car VCR system is that it reduces the vehicle's overall efficiency because to the compressor's heavy use of the engine's power. The absorption cycle was discovered to be the best option because CFC leakage from these air conditioners has a negative impact on the environment. In 1954, Keating patented his invention of the transportable absorption refrigeration system. Large trucks, boats, and railroad cars can all use this system [1]. Refrigerants that are favorable to the environment are used in the absorption refrigeration system. The most typical mixtures are lithium bromide and water or ammonia. A steam-driven diesel engine or turbine-driven absorption machine was created by McNamara [2]. Three liquid ammonia and helium systems were combined in this system. Solar energy is used to create electrical energy, which is then utilized in the cooling system of automobiles [3]. On top of the car's interior, solar and thermoelectric cells were positioned. Solar energy can be converted into electrical energy using solar cells that are exposed to direct sunlight all day long (during the measuring period from morning to dusk). The findings demonstrated that the circumstances in the cooling room were as follows: the cold room's coefficient of performance (COP) was 0.042, and the lowest temperature that could be attained was 25.6 C. Wei Pang et al. [4] created a complete DC air conditioning system using R134a as the refrigerant and solar energy as the source of electricity. A solar photovoltaic (PV) powered DC air conditioning system has been developed as a solution to the issue of rising temperature inside a car during hot, humid summers. The results showed that the DC air conditioning system significantly improved the vehicle's ambient conditions and complied with requirements of the human body. The experiment's minimum cooling capability should be approximately 1500 W to keep a thermal balance inside when it pauses without anyone inside and the sun is scorching. Nikolay et al. investigated the forced convection conditioning of photovoltaic modules installed on the surface of a moving solar car. [5]. It is demonstrated that the design of the car should be improved in order to increase electricity produced by photovoltaic modules while also improving heat removal and lowering aerodynamic drag. The numerical findings for the solar car in two distinct shapes show that PV modules located in flow separation regions should be handled as independent blocks in order to avoid limiting the system's performance. Additionally, a linear study of the solar array's power loss as a result of shade or partial overheating is carried out.

As an alternative to the vapor compression refrigeration cycle (VCR), which uses costly and environmentally unfriendly compounds, the vapor absorption refrigeration cycle (VAR) was the subject of numerous studies and research projects in the past. Economically, it harms the environment by generating noise, wasting thermal energy, and consuming more fuel. the 1960s of the previous century. The ammonia-absorption refrigeration system for use in cars was first introduced by Ghassemi [6]. The results illustrated that the (COP = 0.29) of the system had decreased. Salim [7], who theoretically modeled a single-stage lithium bromide water absorption refrigeration system for autos that absorbs heat from internal combustion engine exhaust gases (EG), is one person who has employed waste heat refrigeration systems for internal combustion engine EG. This technique is beneficial for both water-cooled and air-cooled devices and uses the ABSIM program for calculations. The exhaust fumes from a four-cylinder diesel engine were investigated by the researchers Sohail and Tiwari [8] as a potential source for heating the generator's solution in an intake air conditioning system. The two different working ingredients employed in the system were lithium bromide and water and ammonia. Lithium bromide and water cooling systems have a crystallization problem, whereas ammonia and water cooling systems need an additional source of heat to be added to the exhaust source of energy. Shah Alam [9] introduced three liquid vapor absorbing cooling systems, each driven by a 4-cylinder, 4-stroke passenger car. One ton is the capacity of the car air conditioner. It illustrates that the air conditioner requires over two times as much heat as the engine exhaust does.

One of the hopeful alternatives for the vapor compression cycle is a recently developed method utilizing the Stirling cycle because of its use of non-CFC materials, simplicity, and excellent thermal efficiency. A Stirling cycle system that runs in a linear pistonless motor was researched by Kim et al. [10]. The complete unit can be continuously modified, retain excellent efficiency at low loads because it is sealed off. The Stirling refrigeration system is unreasonable for different applications, including automobiles, because its unavailable qualities. There are further methods, such as using the Desiccant cycle, for cooling and refrigeration in automobiles. Large amounts of water or water vapor are absorbed by this cycle [11, 12]. The blower circulates the cooled air through the drying layers after removing it from the air-conditioned space. By eliminating the water in the air, this constant enthalpy process dries and warms it. The air is subsequently cooled to near-ambient temperatures by the heat exchanger. The airway is then sprayed with a little amount of water. The air is humidified and cooled as a result of this process, and the air then comes into the passenger cabin. The discovery of innovative dryers and dryer/air exchangers that can lower overall system size will determine the future of the dryer cycle in vehicle AC system. The drying apparatus is simply too large to fit in a car, as is the case with present technology.

Wang et al. created an adsorption-operated air conditioner for the locomotive driver's cabin [13]. The cooling power and COP of this system, which is powered by 450°C EG, are 5 kW and 0.25, respectively. With exhaust temperature (ET) of 450°C, cooling air temperature of 40°C, and coolant water temperature of 10°C, the cycle time is 1060 seconds. From 164 W/kg to 200 W/kg, the specific cooling power was attained. Harish and Parishwad [14], a chemical absorption method, have developed a new way for cooling the truck air compartment (adsorption). A number of portable experimental results suggest that adsorption devices are feasible. The combination of NH3 and activated carbon was proposed as a refrigerant and adsorbent, respectively.

The key of this project is to invest solar energy as a clean energy to produce electric energy, and at the same time recover waste heat from car EG and use it to drive a conventional cooling system that works with an electric compressor. In other words, the EG kinetic energy has been converted into electrical energy by using the gas turbine connected to the dynamo, which in turn is connected to the compressor of the cooling system, as well as the use of solar energy as a basic reserve for clean energy.

2. EXPERIMENTAL TEST RIG

The experimental side of the project can be divided into two parts, depending on the energy sources feeding the cooling system, which are solar energy and kinetic energy of the EG. Therefore, the first part will be about the parts and components of the solar photovoltaic system and how to convert it into electric energy. On the other hand, it will be about the components and design of the system for recovering the kinetic and thermal energy of the EG of a diesel vehicle engine and converting it into electrical energy. And both systems can be linked with each other through a control system that produces electrical energy that makes the cooling system work day and night. The diagram of the proposed system is illustrated in figure [1].

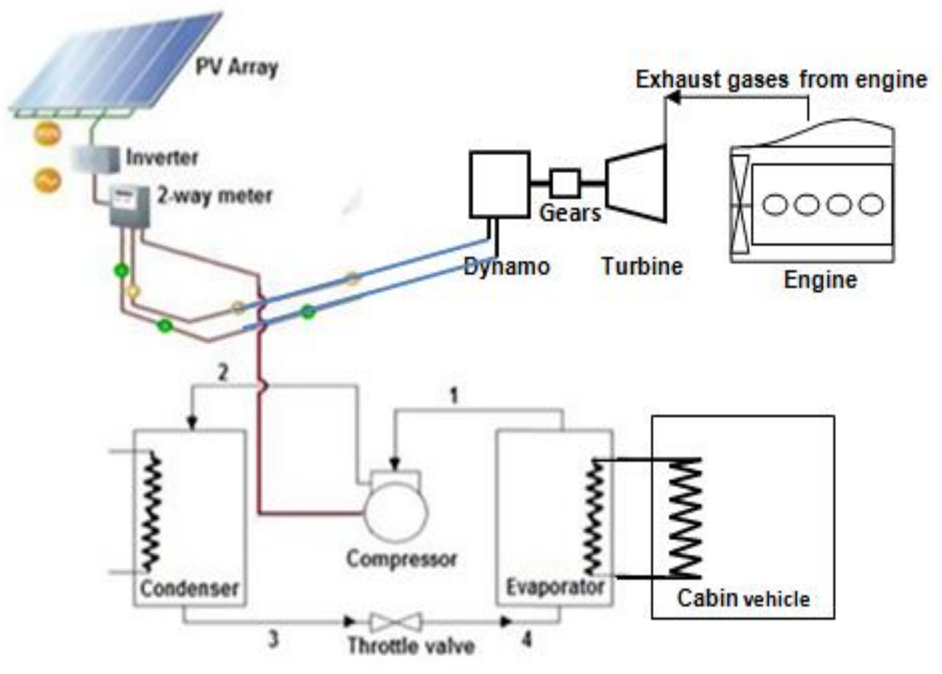

Figure [1]: Diagram of the proposed system

The design section consists of four basic components, which are the vehicle cabin room, the vapor compression system, the diesel engine and its accessories, and the photovoltaic cell. These components come together to form the proposed system. The photographs of the experimental device and components is shown in Figure [2].

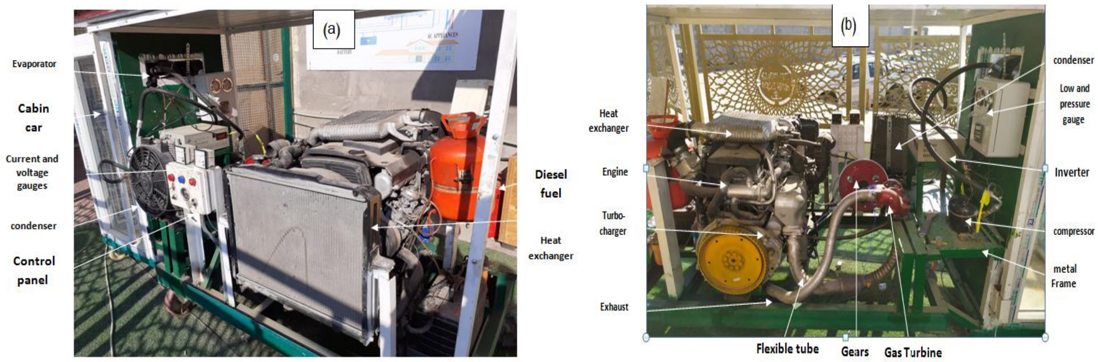

Figure (2). A photograph of the test rig (a) front view and (b) back view.

This study's experimental engine is a Kia Carnival with attachments that runs on four-stroke turbocharged diesel fuel. The engine also has an intercooler that reduces the air temperature entering the engine from the compressor. The choosing a diesel engine compared to a gasoline engine are for several reasons, among which is that diesel fuel has a higher density, which gives it about 15% more power. Furthermore, the temperature of a diesel engine's EG is larger compared with a gasoline engine.

A photovoltaic system typically includes a panel , a charge controller, a battery and interconnection wiring. Solar photovoltaic (PV) technology is one of the technologies for directly converting solar energy into electrical energy. As a result, since the electricity supplied by PV modules is direct current DC, one of two options must be installed in order to power the compressor of vapor compression refrigeration system: either a DC motor driven compressor or an inverter that converts the DC provided by the PV modules into AC. In this project, a DC compressor was used to operate the cooling system. The solar panel specification is described in the Table 1.

Table 1: Solar panel specification

Solar Panel	Specification
Maximum Power ($P_m$ax)	250 W
Maximum Power Voltage (V_{mp})	30±3 V
Maximum Power Current (I_{mp})	16.4 A
Open circuit Voltage (V_{oc})	38 V
Maximum Series Voltage	41.27
Maximum System Voltage	39.5V
Short circuit Current (I_{sc})	8.4 A
Nominal Operating Temperature (NOCT)	25 °C

Charge regulator and charge controller are both acceptable terms. A low voltage disconnect (LDV), a separate circuit that shuts off the load when the batteries are overdischarged (certain battery chemistries are such that over-discharge might harm the battery), is one of the extra features that some charge controllers provide. An electric battery is made up of at least two electrochemical cells, which transform chemical energy that has been stored into electrical energy. A positive terminal, known as the cathode, and a negative terminal, known as the anode, are present in every cell. The anode, which is designated as the negative terminal, has a lower electrical potential energy than the cathode, which is designated as the positive terminal. Electrons from batteries travel to the external gadget when it is attached to the positively labeled terminal, giving it the power it needs. Electrolytes are able to travel as ions inside a battery when it is connected to an external circuit, allowing chemical processes to be performed at the various terminals and supplying energy to the external circuit.

3. DATA REDUCTION

In order to compute design parameters, such as cooling effect, power consumption, and heat rejection, coefficient of performance, and other aspects, the thermodynamic properties of the refrigerant must be determined at specific points along the cooling cycle. The enthalpy of the refrigerant at the intake and outflow of each component is used to determine the experimental results. Enthalpy values are calculated using pressure of refrigerant and the average measured refrigerant temperature at each state point. Between the condenser and the capillary tube, there is a turbine flow meter that monitors the mass flow rate of refrigerant directly. The suggested cycle's energy equations are reduced to data as follows:

The heat absorbed by the evaporator ($\dot{Q}_{evap}$) is calculated from the following equation:

$$\dot{Q}_{evap} = m_{ref}(h_{11} - h_{10}) \tag{1}$$

where h_{10} and h_{11} represent the enthalpy at the inlet and outlet of the evaporator and m_{ref} denotes the refrigerant mass flow rate. The work done by the compressor ($\dot{W}_{comp}$) is:

$$\dot{W}_{comp} = m_{ref}(h_5 - h_{12}) \tag{2}$$

where h_{12}, h_5 represent the enthalpy at the inlet and outlet of the compressor. The heat released by the condenser ($\dot{Q}_{cond}$) is calculated from the following equation:

$$\dot{Q}_{cond} = m_{ref}(h_7 - h_6) \tag{3}$$

where h6 and h7 signify the enthalpy at the condenser's inlet and outlet. The expansion device's process is an isenthalpic process ($h_8 = h_9$). The first law of thermodynamics is applied to flow processes to calculate the internal work of gas turbine ($\dot{W}_T$) as follows:
Energy Input - Energy Output = Increased Energy in the System

$$\dot{Q}_{rej} - \dot{W}_T = \dot{m}_{ex}\, c_{p_{ex}}(T_4 - T_3) \tag{4}$$

where T_4, T_3 represent the temperatures of the EG at the inlet and outlet of the gas turbine, respectively. And $c_{p_{ex}}$, $\dot{m}_{ex}$ represent the flow mass and the adiabatic heat capacity of the EG, respectively. We calculate wasted heat from the engine, assuming that 30% of the engine's power is removed from the outside, as follows:

$$\dot{Q}_{rej} = 0.3\, \dot{m}_{fuel}.L.C.V \tag{5}$$

Where $\dot{m}_{fuel}$ represents the average running mass of diesel fuel and L.C.V is the diesel low calorific value of diesel fuel which is equal to 45.83 MJ/kg. Substituting eq. (6) into Eq. (5), we get the power of the gas turbine:

$$\dot{W}_T = 0.3\, \dot{m}_{fuel}.L.c.V - \dot{m}_{ex}\, c_{p_{ex}}(T_4 - T_3) \tag{6}$$

Than the actual cycle efficiency becomes:

$$\eta_{cycle} = 1 - \frac{\dot{m}_{ex}\, c_{p_{ex}}(T_4 - T_3)}{0.3\, \dot{m}_{fuel}.L.C.V} \tag{7}$$

The energy required to operate the dynamo can also be calculated from the law of energy conservation., where the electric compressor power is equal to the energy generated by the dynamo:

$$\dot{W}_{dynmo} = \dot{W}_{comp} = V.I.cos\ cos\ \theta \tag{8}$$

Where *V* is voltage (volt), *I* is electric current (Amp.) and $cos\ cos\ \theta$ is power factor which is taken as 0.98 in the calculation.

The performance coefficient (COP) of the cooling system in the car can be determined from the ratio of the amount of heat absorbed in the evaporator to the capacity of the compressor, as follows:

$$COP_R = \frac{\dot{Q}_{evap}}{\dot{W}_{comp}} = \frac{\dot{m}_{ref}(h_{11}-h_{10})}{V.I.coscos\,\theta} \qquad (9)$$

At maximum power circumstances for the PV array, the photovoltaic solar panels' efficiency, referred to as the ratio of electrical power generated to incident radiation, ranges between 10 and 15%. The voltage applied to the PV array must be roughly equivalent to the voltage that presents the greatest power if the PV refrigeration system is to work with high efficiency.

The following formula was used to calculate the photovoltaic efficiency under both no load and full load conditions.

$$\eta_{pv} = \frac{P_{max}}{S \times A_{pv}} \qquad (10)$$

Where, η_{pv}= photovoltaic system efficiency, P_{max}= Maximum power provided by the photovoltaic system (W), S = Solar irradiance measured by (W/m^2) and A_{pv}= Area of the photovoltaic system measured by (m^2).

In order to better understand the proposed system with all measurement devices, a diagram of the proposed test rig has been developed as shown in Figure [3].

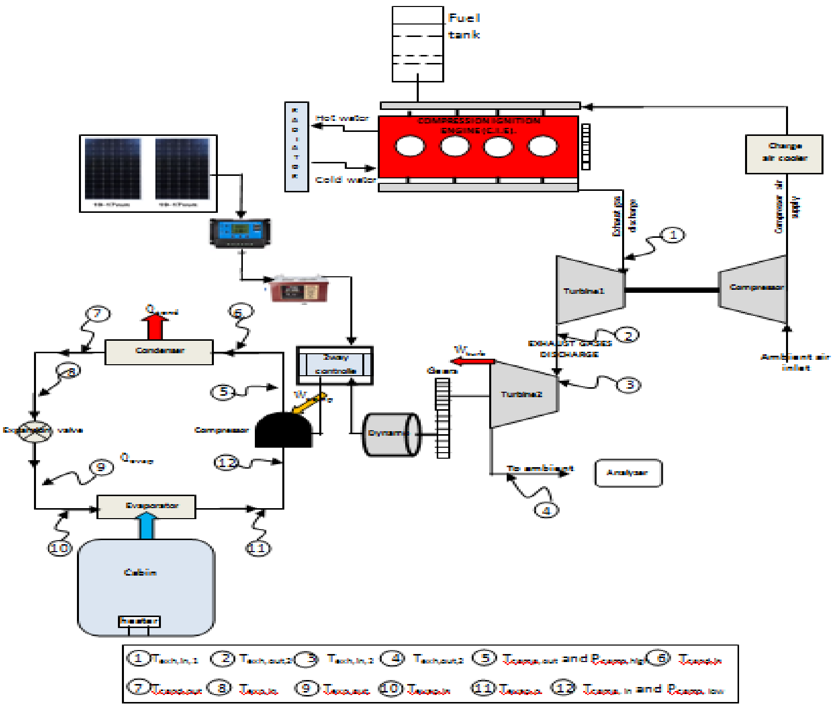

Figure [3]: A schematic diagram of the test rig.

4. RESULTS AND DISCUSSION

The cooling level in the cabin room of the vehicle is influenced by several factors, such as humidity, outdoor temperature, air leakage, occupants number, sun load, and fresh air quantity taken in and sun load.

Exhaust gas from a 4.4-liter, 4-cylinder IC engine with a turbocharger was used to power a 2-ton vapor compression cycle air conditioning system by expanding the EG to rotate the turbine fan, which in turn is connected to the dynamo to produce enough electrical work to power the compressor refrigeration cycle. Increasing engine speed will increase the consumption of fuel and heat emitted from the engine, and the temperature of the EG leaving the engine, as was already stated in [15]. All results presented in this manuscript show a evaluation for both the usual system and the new proposed system. Figure [4] depicted the relationship between cooling load and time where it noticed that the cooling load vary directly with time. Besides, the increase in the heat rejection of the engine with engine speed, as shown in Figure [5].

Figure [6] shows the COP as function of engine speed and figure [7] shows the P-H diagram of new cooling system.

Based on these findings, solutions have been found to the problem of energy loss resulting from burning diesel fuel in internal combustion engines and using it to operate the air conditioning system in the automobile that works with the vapor compression cycle..

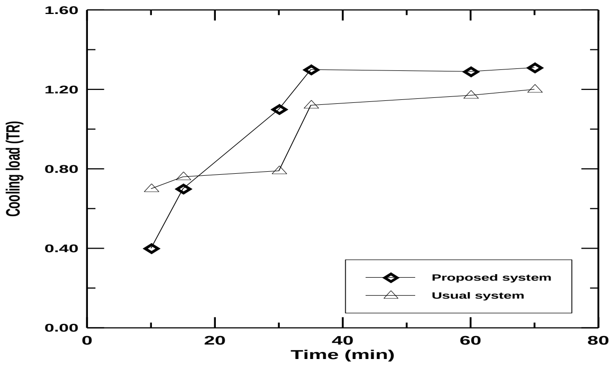

Figure [4]: Cooling effect with time

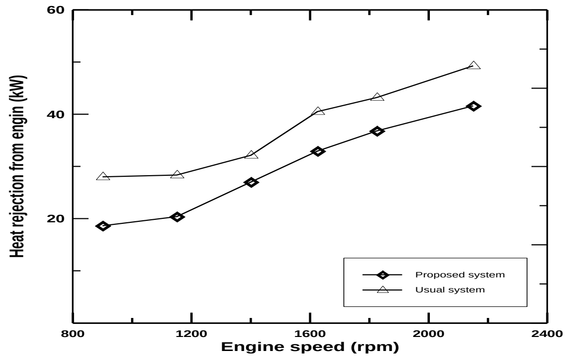

Figure [5]:diesel engine speed versus heat expulsion

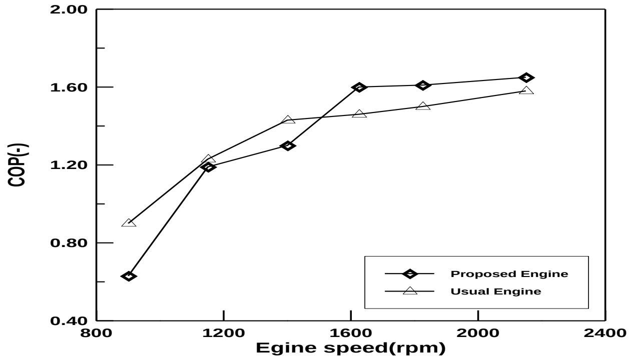

Figure [6]: Diesel engine speed as function for COP

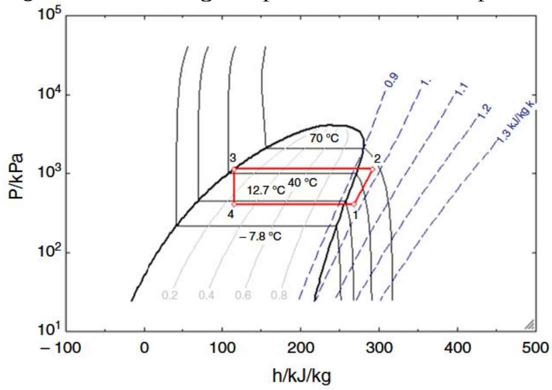

Figure [7]: The P-H diagram of new cooling system

The experiments on the photovoltaic system were conducted on 22/3/ 2023 and the results of the tests are as given in **Table 2**.

Table 2: Results with solar panel

S.No	Time	Voltage (V)	Current (A)	Power (W)
1	11 :00 am	12.71	2.08	26.43
2	11:30 am	15.17	2.31	35.04
3	12:00 pm	17.41	2.41	41.95
4	12:30 pm	15.50	2.75	35.65
5	1:00 pm	12.00	2.10	25.20

5. CONCLUSION

In this study, we exploit the energy of the exhaust gas of diesel engine that was previously wasted to generate enough electrical work to operate the cooling system by converting the kinetic energy of the exhaust gas into electrical energy. This was done by connecting the exhaust of the Kia Carnival engine with the gas turbine on the one hand and connecting the gas turbine with the dynamo on the other side, meaning we converted the kinetic energy into electrical work. The traditional air cooling system has also been operated through the electrical work produced by the dynamo after it is connected to an electric compressor. An inverter is used to change the phase of the current from DC to AC. The conclusions are as follows:

1- Electricity generation and use for various purposes.
2- Improving the thermal efficiency of the engine by reducing the load on the engine.
3- The efficiency of the engine as a result of removing the load placed on the engine as well as the coefficient of performance for the proposed cooling system increased by about 5.18% when compared to the conventional cooling system.

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