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RESEARCH ARTICLE OPEN ACCESS

Thermal Analysis of a Car Air Conditioning System Based On an Absorption Refrigeration Cycle Using Energy from Exhaust Gas of an Internal Combustion Engine

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ABSTRACT
An absorption refrigerator is a refrigerator that uses a heat source (e.g., solar, kerosene-fueled flame, waste heat from factories or district heating systems) to provide the energy needed to drive the cooling system.In this thesis, energy from the exhaust gas of an internal combustion engine is used to power an absorption refrigeration system to air-condition an ordinary passenger car. All the required parts for the absorption refrigeration system is designed and modeled in 3D modeling software Pro/Engineer. Thermal analysis is done on the main parts of the refrigeration system to determine the thermal behavior of the system. Modeling is done in Pro/Engineer and analysis is done in Ansys.
***Keywords* –** Kerosene-fueled flame, district heating systems

I. Introduction

Air conditioning is the process of altering the properties of air (primarily temperature and humidity) to more favorable conditions. More generally air conditioning can refer to any form of technological cooling, heating, ventilation, or disinfection that modifies the condition of air.A company in New York City in the United States, first offered installation of air conditioning for cars in 1933.Most of their customers operated limousines and luxury cars.The innovation was adopted quickly, and by 1960 about 20% of all cars in the U.S. had air-conditioning, with the percentage increasing to 80% in the warm areas of the Southwest. American motors made air conditioning standard equipment on all AMC ambassadors starting with the 1968 model year, a first in the mass market with a base price starting at $2,671. By 1969, 54% of the domestic automobiles were equipped with air conditioning, with the feature needed not only for passenger comfort, but also to increase the car's resale value.It is claimed that a new type of air-conditioning for automobiles called TIFFE (Thermal systems Integration for Fuel Economy) will come into production in 2015. It is said to reduce gasoline consumption by 15%.It is a well-known fact that a large amount of heat energy associated with the exhaust gases from an engine is wasted.radiator and one third is wasted as heat at the exhaust system. Even for a relative small car-engine, 15 kW of heat energy can be utilized from the exhaust gas. This heat is enough to power an absorption refrigeration system to produce a refrigeration capacity of 5 kWDue to the international attempt to find alternative energies,absorption refrigeration has become a prime system for many cooling applications. Where thermal energy is available the absorption refrigerator can very well substitute than the vapour compression system.

Automobile air conditioning systems cool the occupants of a vehicle in hot weather, and have come into wide use from the late twentieth century. Air conditioners use significant power; on the other hand the drag of a car with closed windows is less than if the windows are open to cool the occupants evaporatively. There has been much debate on the effect of air conditioning on the fuel efficiency of a vehicle. Factors such as wind resistance, aerodynamics and engine power and weight have to be factored into finding the true variance between using the air conditioning system and not using it when estimating the actual fuel mileage.Other factors on the impact on the engine and an overall engine heat increase can have an impact on the cooling system of the vehicle.

II. Working Of Automotive Air Conditioning

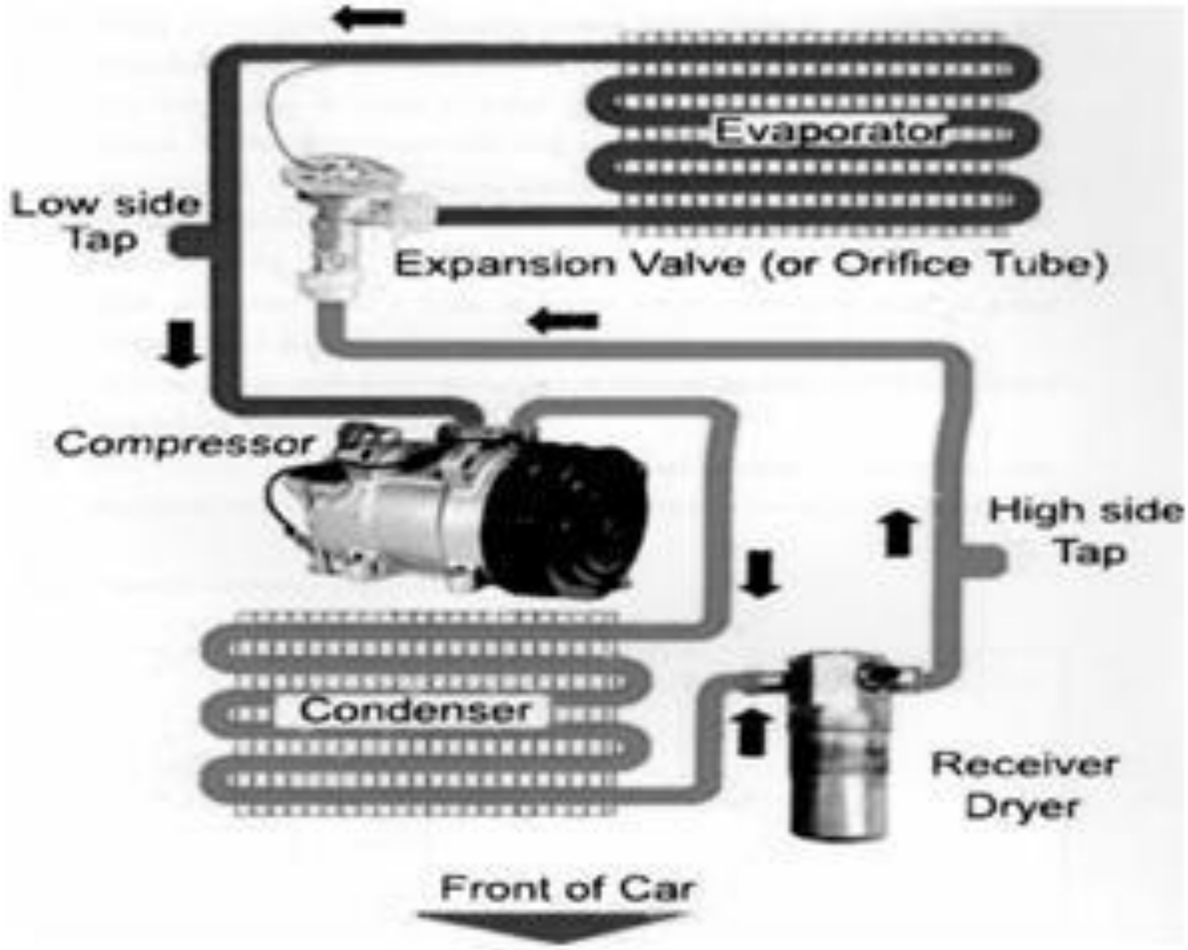
A rough energy balance of the available energy in the **The high-pressure side**combustion of fuel in a motor car engine shows that one **Compressor:** The compressor is a pump driven by a belt third is converted into shaft work, one third is lost at the attached to the engine's crankshaft. When the refrigerant is drawn into the compressor, it is in a low-pressure gaseous form. Once the gas is inside the pump,the compressor lives up to its name. The belt drives the pump, which puts the gas under pressure and forces it out to the condenser. Compressors cannot compress liquids, only gasses. You'll see as we go through the system that there are other parts whose job it is to capture any water that accidentally makes into the AC loop.

Condenser: The condenser is basically a radiator, and it serves the same purpose as the one in your car: to radiate heat out of the system. The refrigerant enters the condenser as a pressurized gas from the compressor. The process of pressurizing the gas and moving it to the condenser creates heat, but air flowing around the twisting tubes of the condenser cool the refrigerant down until it forms a liquid again. Imagine steam cooling down and condensing back into water, and you've got the idea. The liquid refrigerant is now a high-pressure liquid and nearly ready to cool the car. **Receiver-Dryer:** But first, the refrigerant needs to be prepared for the evaporator. As it moves out of the condenser, the liquid goes through a little reservoir installed in the line. This receiver-dryer contains **desiccants**, small granules that attract water. You've seen packets of desiccants in shoeboxes, where they do the same thing: attract water from the air to keep new shoes fresh and ready for your feet. (They're usually labeled "Do not eat.") In the receiver-dryer, they remove any water that has entered the system. If the water is allowed to remain and possibly form ice crystals, it can damage the air conditioning system.**The low-pressure side Thermal Expansion Valve (TXV):** Here, the system changes from the high-pressure side to the low-pressure side. If you were to touch this part of the system, you'd feel it change from hot to cold.The high-pressure liquid refrigerant flows from the receiver-dryer through the expansion valve, where it is allowed to expand. This expansion reduces the pressure on the refrigerant, so it can move into the evaporator. The valve senses pressure and regulates the flow of refrigerant, which allows the system to operate steadily, but the moving parts of the valve can wear out and sometimes require replacement .Some vehicles have an **orifice tube** rather than an expansion valve, but it serves the same purpose in allowing the refrigerant to expand and the pressure to be lowered before the liquid enters the evaporator. The orifice tube allows refrigerant to flow at a constant rate and has no moving parts, but it can become clogged with debris over time. Systems with an orifice tube automatically turn the AC system on and off to regulate the flow of refrigerant to the evaporator

Evaporator: This is where the magic happens. While all the other parts of the system are located in the engine compartment, this one is in the cabin, usually above the foot well on the passenger side. It also looks like a radiator, with its coil of tubes and fins, but its job is to absorb heat rather than dissipate it.

Refrigerant enters the evaporator coil as a cold, low-pressure liquid, ideally at 32 degree s Fahrenheit (0 degrees Celsius), which is why you don't want an y water in the system. The refrigerant doesn't freeze at this temperature, but it does have a very low boiling point. The heat in the cabin of the car is enough to make the R-134a in the evaporator boil and become a gas again, just like water turning back to steam . In its gaseous form , refrigerant can absorb a lot of heat .The gas moves out of the evaporator -- and out of the passenger compartment of the car, taking the heat with it. A fan blowing over the outside of the evaporator coil blows cool air into the passenger compartment.

The refrigerant in gas form then enters the compressor, where it is pressurized and the whole process starts all over again. by a generator, an absorber and a small pump. A Vapour Absorption Refrigeration System utilizes two or more than two fluids which has high affinity towards each other, in which one is the refrigerant and the other is the absorbent.The process of working of this refrigeration system is that a mixture of refrigerant and an absorber (i,e. strong solution) is pumped from the absorber using a small pump to the generator. The generator is the main unit of the whole refrigeration system. This is the place where heat is supplied to the strong solution. Due to the supplied heat to the mixture in the generator the refrigerant is separated from the strong solution and forms vapour. The remaining weak solution flows back through a restrictor in to the absorber. The refrigerant is then allowed to pass through a condenser where the heat of the vapour is extracted and the refrigerant temperature is brought to the room temperature. This cooled refrigerant is then passed through an expansion device where during expansion the temperature of the refrigerant falls below the atmospheric temperature. This cold refrigerant is then passed through an evaporator from where the refrigerant absorbs heat and produces refrigerating effect. The refrigerant coming from the evaporator is hot and it is passed to the absorber. The weak solution coming from the generator mixes with the refrigerant coming from the evaporator in the absorber due to high affinity towards each other for the two fluids, hence forming a strong solution. The formed strong solution is again pumped into the generator and the cycle repeats itself.



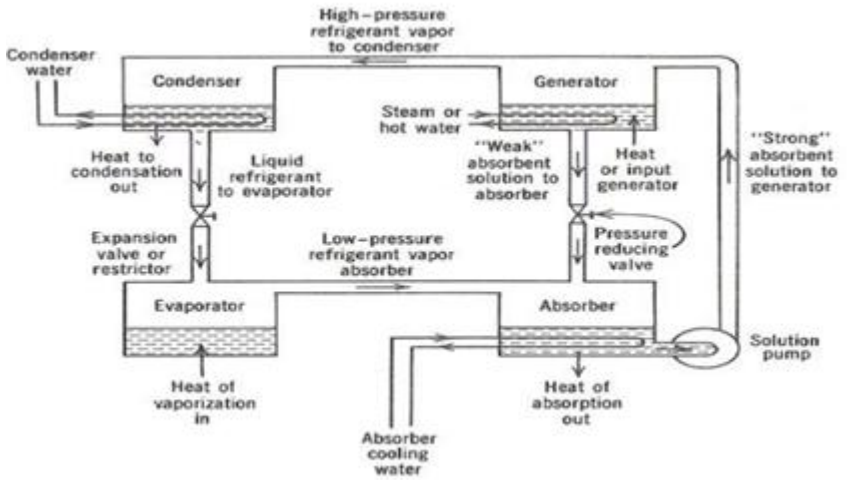


Fig. 20-21 Basic absorption refrigeration cycle.

Methods of implementation of vapour absorption system in an automobile

For a road transport utilizing Vapour Absorption Refrigeration System heat energy can be supplied in two ways:

Using heat of combustion of a separate fuel

by using a separate fuel for working the refrigeration system i,e. a fuel for example natural gas can be used for the working of a vapour absorption refrigeration system. this can be achieved by burning the fuel in a separate combustion chamber and then supplying the generator of a vapour absorption refrigeration system with the products of its combustion to produce the required refrigerating effect. however this prospect is eliminated since it requires a separate fuel and a separate combustion chamber which makes it uneconomical and the system becomes inefficient.

Using waste heat of the IC engine

Another method is by utilizing the heat of combustionwhich is wasted into the atmosphere. by designing a generator capable of extracting the waste heat of an ic engine without any decrease in engine efficiency, a vapour Absorption Refrigeration System can be brought to work. Since this arrangement does not require any extra work expect a small amount of work required for the pump, which can be derived from the battery, this system can be used in automobiles where engine efficiency is the primary consideration.

Design &calculations

Designing involves developing each components of the system that has to be installed on to the automobile to produce the required cooling effect which involves generator, condenser and evaporator.

PRE-HEATER

A pre-heater is employed which extracts heat from cooling water to reduce the amount of heat taken from the engine exhaust and also to reduce the total size of the generator.

Design of pre-heater

Mass flow rate of Ammonia-H_2O solution, m = 8.804 g/s Inlet temperature of the Ammonia-H_2O solution, t_i = 35 °C Outlet temperature of the Ammonia-H_2O solution,t_0= 75 °C Surface temperature of the tube or cooling water temperature, t_s = 80 °C
Mean temperature, t_m = (t_i + t_o)/2
= (35+80)/ t_m
= 57.5 °C
Properties of water at t_m = 57.5°C
Density ρ = 983 kg/m^3

Thermal Conductivity, K = 0.649 W/m °C Prandtl Number, Pr = 2.96
Dynamic Viscosity, μ = 0.462x10'^{3} Kg/ms
Tube through which Ammonia-H_2O solution passes
- Taking outside Diameter of the tube, D_0 = 0.012 m

- And taking inside Diameter of the tube, Dj = 0.01 m Velocity of Ammonia-H_2O solution through the tube, V =

m/Aρ

= 0.008804 /(7.85xl0"^{5}x983) = 0.114m/s Reynolds Number,

Re = ρVd/μ
= (983x0.114x0.01) / (0.462xl0"^{3}) = 2426.32

For forced convection through circular tubes Nusselt Number,
Nu = $0.023Re^{0.8}Pr^{0.3}$
= $0.023 (2426.32)^{0.8}(2.96)^{0.3}$
= 16.26

Also,

Nu = hDi/K

Therefore, heat transfer co-efficient, h = NuK/Di

= (16.26x0.649)/0.01

= 1055.16 W/mK

Log Mean Temperature Difference,
LMTD = [(t_s - t_i) - (t_s –t_o)] / In [(ts – t_i)/(t_s – t_o)]
= [(80 - 35) - (80 - 75)] / In [45/5]
= 18.2 °C Heat Transfer Rate,
Q = UA(LMTD)

Overall heat transfer co-efficient U = h

Also, amount heat to be transferred Q = mCpT = 0.008804x4.18x40

= 1.472 kW

Area of flow through tubes, A =7tD_0L = 7tx0.012xL

Where, L is the length of the tube. L = Q / [hx7tx0.012 (LMTD)]
t = 1.02mm

= 1.472xl0^3 / [1055.16x7tx0.012xl8.2] **L** = 2.033 **m**

Final dimensions
Dimensions of the designed pre-heater
Outside Diameter of the tube, **D_0 = 0.012 m** Inside Diameter of the tube, **Dj = 0.01 m** Length of the tube, **L =2m**

By using similar calculations also findout the dimensions Of the following Generator

It is the place where the exhaust gas tube is passed through the container and the tube temperature is assumed to be a constant.

Dimensions of the designed generator

Outside Diameter of the exhaust gas tube,
D_0 = 0.04 **m**
Taking inside diameter of the exhaust gas tube, D_i = 0.038 **m**
Length of the tube required for the required heat transfer, **L**
= **1 m Condenser:**
Assume circular cross section of the condenser coil of thickness, a = 5 mm &Diameter d = 18 mm.

Dimensions of the designed condenser

Diameter of the tube, **d = 0.018 m** Thickness of the tube, **a**
= **0.005 m** Length of the tube, L = 7**.45 m**

Evaporator

The evaporator is of circular cross section and should be made of copper tubes to have maximum heat transfer from the atmosphere to the refrigerant. The tube is coiled to accommodate it inside the automobile.

Dimensions of the designed evaporator

Outside Diameter of the tube, D_0 = 0.01 **m** Inside Diameter of the tube, **Dj** - 0.008 **m** Length of the tube, L = **6.26 m**

Absorber

It is a container in the system which absorbs the refrigerant coming from the evaporator using the solution coming from the generator. Proper cooling should be provided as heat is liberated during the absorption process which should be done using air.

Dimensions of the designed absorber

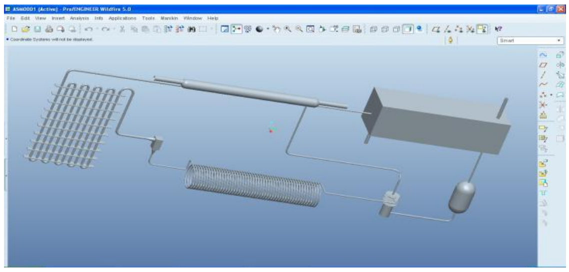
Outside diameter of the absorber, D_0 = 76 mm Total length of the absorber, L = 205 mm Outer diameter of the fins, Df = 109 mm No. of fins, n=7

Pro/engineer

pro/engineer wildfire is the standard in 3d product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with your industry and company standards.

Assembly of vapour absorption system ANSYS

 ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated, or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

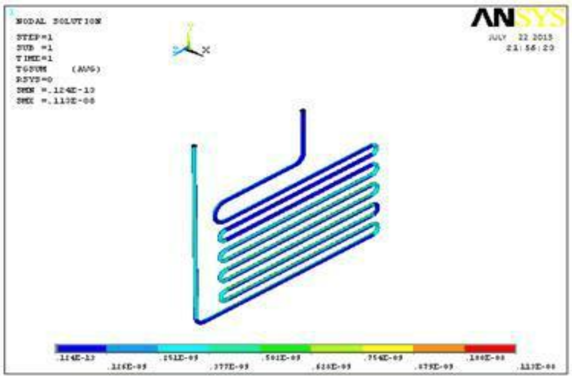


ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges. ANSYS is also used in Civil and Electrical Engineering, as well as the Physics and Chemistry departments.

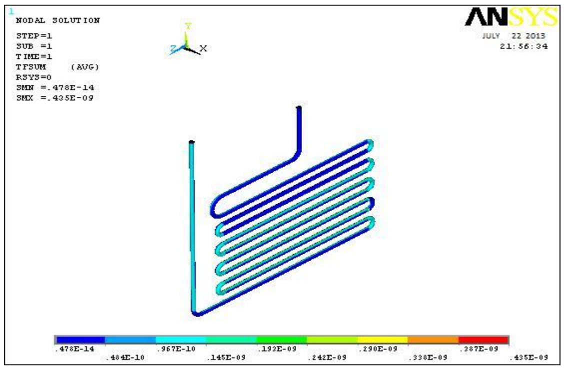
Thermal analysis

Condenser Here we use two materials for comparison

COPPER

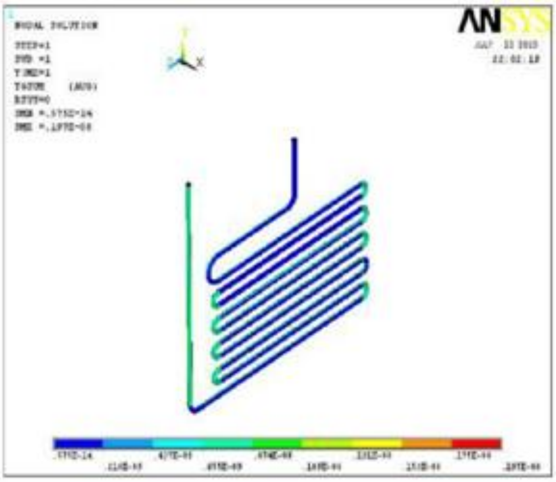


General Post Processor – Plot Results – Contour Plot - Nodal Solution – THERMAL GRADIENT Vector sum As shown in below fig :i

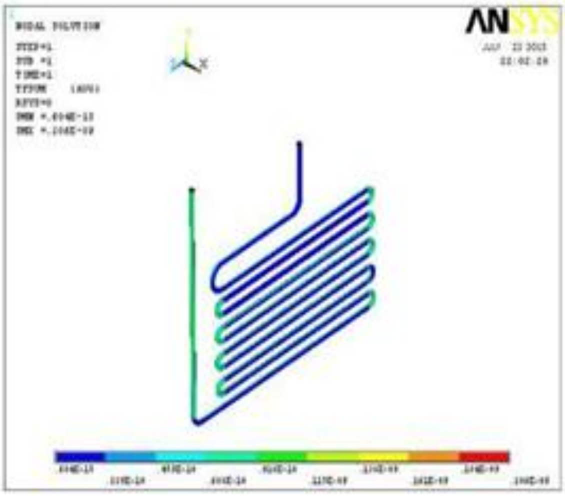


General Post Processor – Plot Results – Contour Plot - Nodal Solution – THERMAL FLUX As shown in below fig :ii

ALUMINUM ALLOY 204

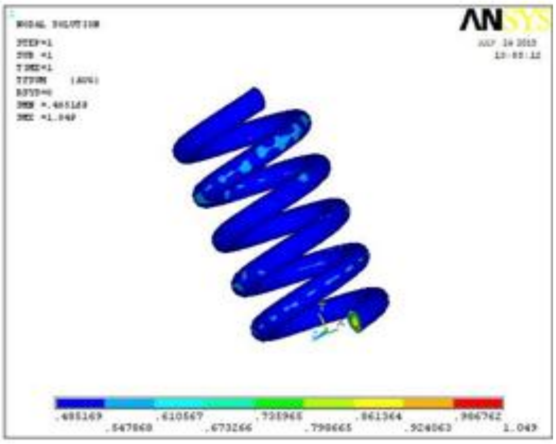


General Post Processor – Plot Results – Contour Plot - Nodal Solution – THERMAL GRADIENT as shown in below fig:iii

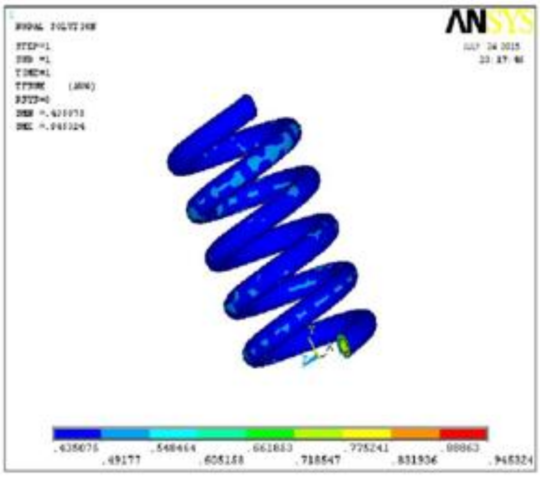


General Post Processor – Plot Results – Contour Plot - Nodal Solution – THERMAL FLUX vector sum. As shown in below fig :iv

Evaporator
ALUMINUM ALLOY 204

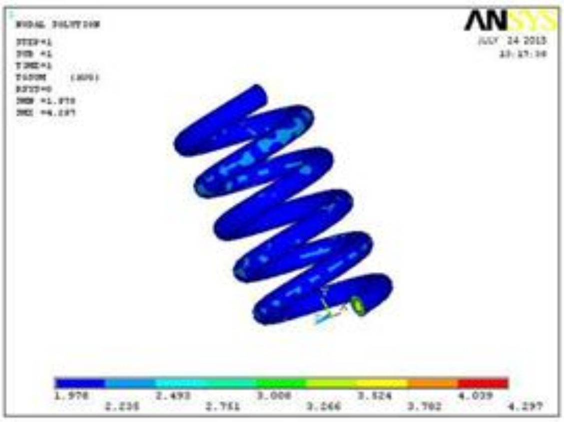


General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal Gradient as shown in below fig:v

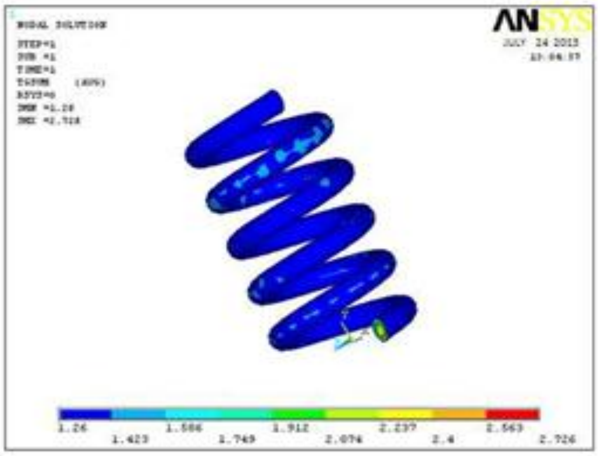


General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal flux vector as shown in below fig:vi

Copper



General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal Gradient Vector sum as shown in below fig:vii

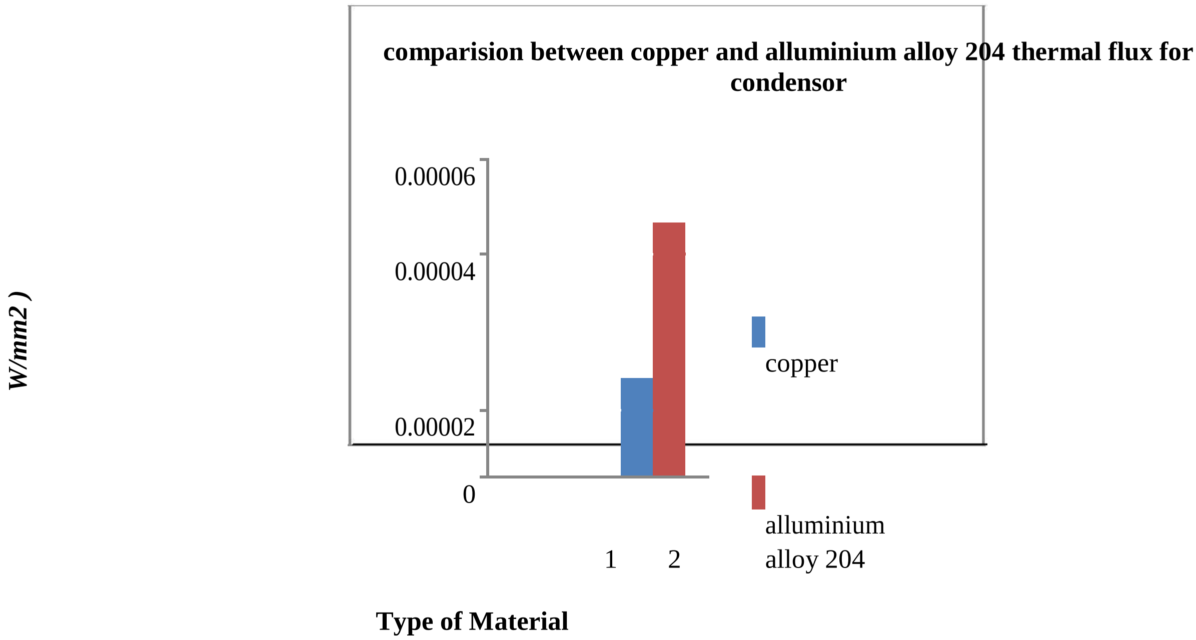


General Post Processor – Plot Results – Contour Plot - Nodal Solution – Thermal flux vector sum as shown in below fig:viii

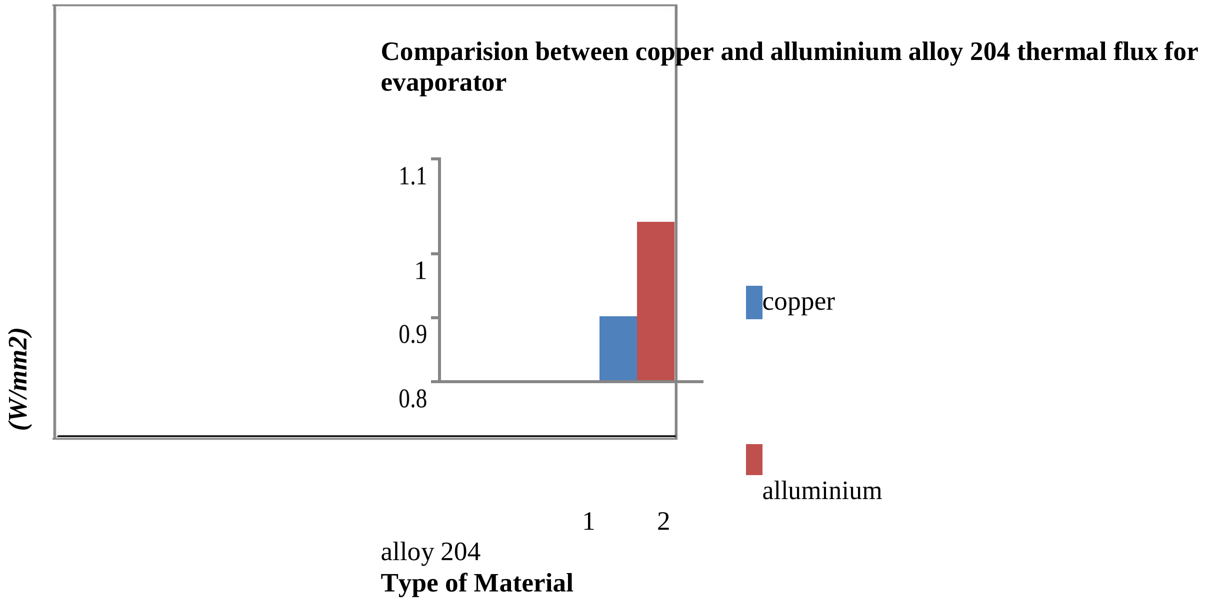
ANALYSIS REPORTS

	COPPER		ALUMINUM ALLOY 204	
	THERMAL GRADIENT (K/mm)	THERMAL FLUX (W/mm^2)		THERMAL GRADIENT (K/mm)
CONDENSER	$0.113e^{-8}$	$0.206e^{-9}$	**CONDENSER**	$0.113e^{-8}$
EVAPORATOR	2.726	0.945324	**EVAPORATOR**	2.726

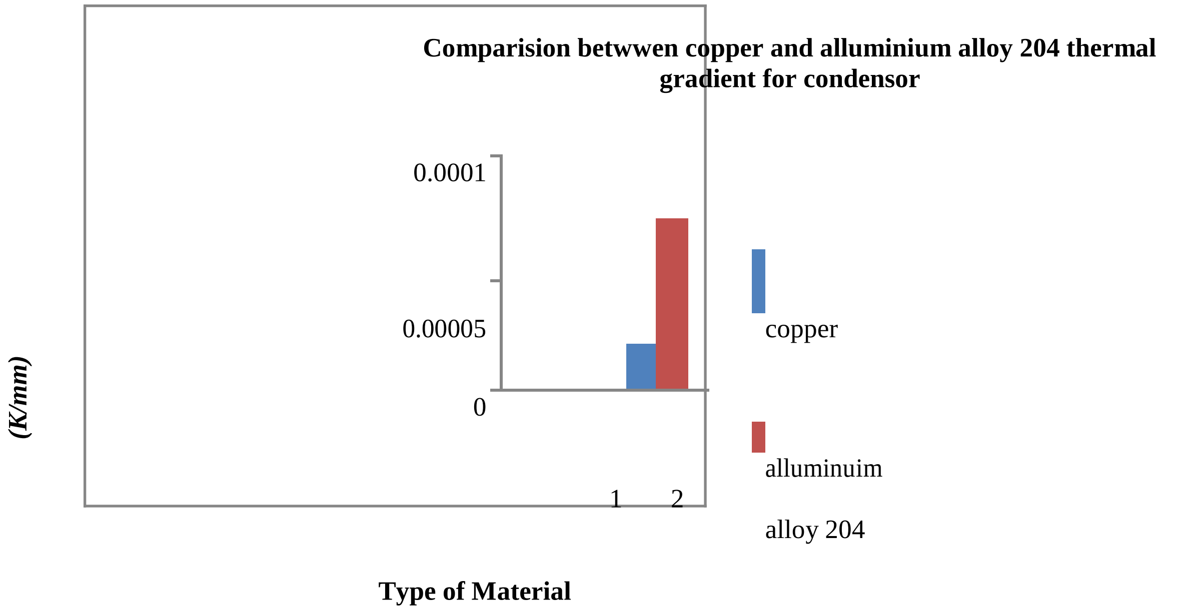
COMPARISION OF THERMAL FLUX FOR CONDENSOR



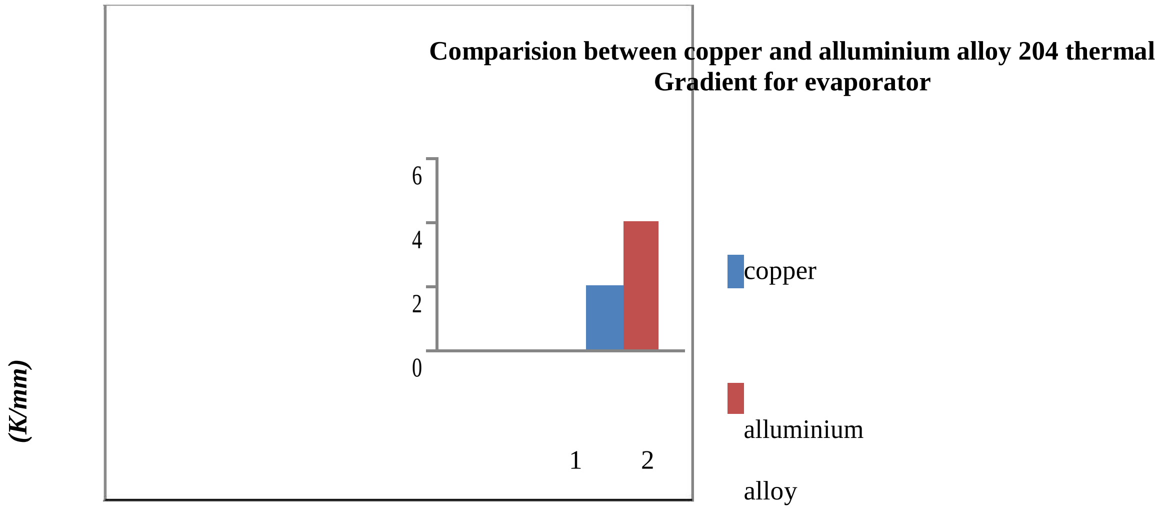
COMPARISION OF THERMAL FLUX FOR EVAPORATOR



COMPARISION OF THERMAL GRADIENT FOR CONDENSOR



COMPARISION OF THERMAL GRADIENT FOR EVAPORATOR



Type of Material

III. CONCLUSION

Thermal analysis was done in two main components i.e condenser & evaporator though the results obtained. This result will have to be improved for further development

It can be concluded that:

i. For the working of vapour absorption refrigeration system generally achieved by burning the fuel in a separate combustion chamber and then supplying the Generator of a Vapour Absorption Refrigeration System with the products of its combustion to produce the required refrigerating effect. However this prospect is eliminated since it requires a separate fuel and a separate combustion chamber which makes it uneconomical and the system becomes inefficient.

ii. The above draws back will eliminated by utilizing the heat of combustion which is wasted into the atmosphere. By designing a generator capable of extracting the waste heat of an IC engine without any decrease in engine efficiency, a Vapour Absorption Refrigeration System can be brought to work. Since this arrangement does not require any extra work expect a small amount of work required for the pump, which can be derived from the battery, this system can be used in automobiles where engine efficiency is the primary consideration.

iii. In this thesis use pro/engineer for the design of components & use ansys for the analysis

iv. By observing the analysis results, thermal flux is more for aluminum alloy 204 than copper for both condenser and evaporator. so using aluminum alloy 204 is better.

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