Development of an ac system using waste heat of an ic engine

Science, Physics

DEVELOPMENT OF AN A/C SYSTEM USING WASTE HEAT OF AN IC ENGINE PROJECT REPORT Submitted by ALEX ROY JIJIN JOSEPH RAKESH R SAJI ABRAHAM K S SHAN ABSTRACT The refrigerating units currently used in road transport vehicle are of Vapour Compression Refrigeration system (VCRS). This system utilizes power from the engine shaft as the input power to drive the compressor of the refrigeration system, hence the engine has to produce extra work to run the compressor of the refrigerating unit utilizing extra amount of fuel. This loss of power of the vehicle for refrigeration can be neglected by utilizing another refrigeration system i, e. a Vapour Absorption Refrigeration System (VARS). It is well known that an IC engine has an efficiency of about 35-40%, which means that only one-third of the energy in the fuel is converted into useful work and about 60-65% is wasted to environment. In which about 28-30% is lost by cooling water and lubrication losses, around 30-32% is lost in the form of exhaust gases and remainder by radiation, etc. In a Vapour Absorption Refrigeration System, a physicochemical process replaces the mechanical process of the Vapour Compression Refrigeration System by using energy in the form of heat rather than mechanical work. The heat required for running the Vapour Absorption Refrigeration System can be obtained from that which is wasted into the atmosphere from an IC engine. LIST OF TABLES Table Page 2. 1 Refrigerant - Absorber Pairs 8 7. 1 Properties of refrigerant at each point of the system 23 u LIST OF FIGURES Figure 1. 1 Conventional refrigeration system used in automobiles 2 Pressure enthalpy diagram 1 Block diagram of a vapour absorption refrigeration system 2. 2 A simple absorber 2. 3 A generator 1 Block diagram of the system 1 Vapour absorption system with a pre-heater 1

Isometric view of pre-heater 8. 2 Isometric view of generator 8. 3 Isometric view of absorber NOMENCLATURE Symbol Definition | A | area of flow- | | Cpe | specific heat at constant volume of exhaust gas | | Cpvv | specific heat of water | | Di | inside diameter of tube | | D0 | outside diameter of tube | | Df | outer diameter of the fin | | Evol | volumetric efficiency of the engine | | Gr | Grashoff Number | | h | thermal heat transfer co-efficient | | hfg | latent heat of refrigerant | | K | thermal conductivity | | L | length of tube | | Lc | equivalent diameter | | LMTD | log mean temperature difference | | niair | mass flow rate of air in to the cylinder | | ma | mass flow rate of the solution back to the absorber | | me | total mass flow rate of exhaust gas | | mf | mass flow rate of fuel | | mg | mass flow rate of the strong solution to the generator | | mr | mass flow rate of refrigerant | | mw | mass flow rate of water for a 4 cylinder diesel engine | | n | no. of cylinders | | N | rated speed | | Nu | Nusselt number | | P | power | | Pr | Prandtl Number | | Q | heat transfer rate | | Qe | heat available at exhaust pipe | heat carried away by cooling water Reynolds number temperature of ambient air temperature at absorber temperature at condenser temperature of water entering the cooling water jacket temperature of water exiting the cooling water jacket temperature at evaporator temperature available at the engine exhaust temperature at generator inlet temperature mean temperature outlet temperature surface temperature of the tube or cooling water temperature overall heat transfer co-efficient capacity velocity of flow LiBr concentration in absorbent, (lb/lb of solution) concentration in refrigerant-absorbent solution.(lb/lb of solution) co-efficient of thermal expansion dynamic Viscosity density INTRODUCTION 1. 1 CONVENTIONAL A/C SYSTEM USED IN VEHICLES The air conditioning system used usually in a vehicle is a vapor compression refrigeration system. It consists of a compressor, condenser, expansion valve, an evaporator blower set and a refrigerant which is circulated through the system. This system works by compressing the refrigerant using a compressor, which increases the pressure and temperature of the refrigerant and it vaporizes. The refrigerant is then passed through the condenser where the latent heat of the refrigerant is removed and is liquefied. This refrigerant is then passed through the expansion valve where its pressure is reduced reducing the temperature. This chilled refrigerant is then passed through the evaporator to produce the cooling effect. The blower blows the air through the evaporator to produce the required cooling inside the cabin of the vehicle. The refrigerant absorbs the heat of the air and vaporizes, which is then passed through the compressor. Hence cooling effect is produced inside the vehicle. The main disadvantage of such a system is that the required power to run the compressor is taken from the engine main shaft, hence to maintain the same power the engine has to produce more work consuming more fuel thereby reducing the mileage of the vehicle. Passenger Compartment [pic] Fig 1. 1 Conventional refrigeration system used in automobiles 1. 1. 1 Vapour compression cycle All vapour compression refrigeration systems are designed and built around these basic thermodynamic principles. * Fluids absorb heat while changing from a liquid phase to vapour phase and reject heat in changing from a vapour phase to a liquid phase. * The temperature at which a change in phase occurs is constant during the change, but this temperature will vary with the pressure. At one fixed pressure vaporization takes place only at fixed corresponding temperature. However, the temperatures of vaporization at a particular pressure are different for different fluids. * Heat will flow from a body at higher temperature to a body at lower temperature. * In Selecting metallic parts of cooling and condensing units, metals are selected which have high heat conductivity. * Heat energy and other forms of energy are mutually convertible with directional relationship imposed by second by second law of thermodynamics. 1. 1. 2 Pressure enthalpy diagram 3 in Enthalpy Fig 1. 2 Pressure enthalpy diagram A refrigerator thermodynamic cycle can be explained considering the process that the refrigerant undergoes in the two heat exchangers, compressor and expansion device. The most convenient diagram for such explanation and performance analysis is that of a pressure vs. enthalpy coordinate system, as shown in fig: The compressor receives low pressure and low temperature refrigerant at state 1 and compresses it to a high pressure. This compression process is associated with an increase of refrigerant temperature. At state 2, the high pressure, high temperature vapour enters the condenser. The refrigerant passing through the condenser rejects heat to the high temperature reservoir and changes to a saturated liquid at state 3. Then the refrigerant flows through the expansion device undergoing a drop in pressure and temperature. Finally, the low pressure, low temperature and low quality refrigerant at state 4 enters the evaporator, where it picks up heat from the low temperature reservoir reaching a dry saturated vapour state at the evaporator exit. 1. 2 DRAWBACKS OF VAPOUR COMPRESSION REFRIGERATION SYSTEM Though this system is the most efficient of all the refrigeration system still it has some disadvantages: * A vapour compression system has more, tear and noise due to moving parts of the compressor. * The amount of work required to compress the gas in the compressor is very high. * It strictly depends on electric power or mechanical power and cannot be used at places where these recourses are not available. * The capacity of vapour compression system drops rapidly with lowered evaporator pressure. * The performance of a vapour compression system at partial loads is poor. * In the vapour compression system, it is essential to superheat the vapour refrigerant leaving the evaporator so that no liquid may enter the compressor. * VAPOUR ABSORPTION REFRIGERATION SYSTEM 2. 1 INTRODUCTION The vapour absorption refrigeration is one of the oldest methods of producing refrigerating effect. The principle of vapour absorption was first discovered by Michael Faraday in 1824 while performing a set of experiments to liquefy certain gases. The first vapour absorption refrigeration machine was developed by a French scientist Ferdinand Carre in 1860. This system may be used in both the domestic and large industrial refrigerating plants. The refrigerant, commonly used in a vapour absorption system is ammonia. The vapour absorption system uses heat energy, instead of mechanical energy as in vapour compression systems, in order to change the conditions of the refrigerant required for the operation of the refrigeration cycle. The function of a compressor, in a vapour compression system, is to withdraw the vapour refrigerant from the evaporator. It then raises its temperature and pressure higher than the cooling agent in the condenser so that the higher pressure vapours can reject heat in the condenser. The liquid refrigerant leaving the condenser is now ready to expand to the evaporator conditions again. This refrigeration system consists of a condenser, an expansion valve and an evaporator similar to a Vapour

Compression Refrigeration System. But the compressor of the Vapour Compression Refrigeration System is replaced 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. A Qc Qg COHDEHSOR 4 GEHERATOR / (gj Expansion g 0 Restrictor â–¡ 2. o D W O o 3 EVAPORATOR ABSORBER n Pump Qe Qa Fig

2. 1 Block diagram of a vapour absorption refrigeration system The power required for pumping is almost negligible and hence we get refrigerating effect from a Vapour Absorption Refrigeration System without any mechanical power being done on it. But the refrigerating effect produced from a Vapour Compression Refrigeration System is comparatively higher than that produced from a Vapour Absorption Refrigeration System of same capacity. 2. 2 TYPES OF VAPOUR ABSORPTION SYSTEMS There are different types of vapour absorption systems which employ different combination of refrigerant and absorbents to produce the refrigerating effect. Some of the basic vapour absorption systems are: 2. 2. 1 Aqua-Ammonia Vapour Absorption System. This is the simplest of all the systems. This system employs water as the absorbent and ammonia as the refrigerant. Along with the generator it employs an analyzer and a rectifier to remove the components of water from the refrigerant, since the heat is high enough to vapourize both refrigerant and absorbent. Therefore the system employs too many components and hence the system is complicated. 2. 2. 2 LiBr-E^O Vapour Absorption System. The lithium-bromide absorption refrigeration system uses a solution of lithium-bromide in water. In this system water is being used as a refrigerant whereas lithium bromide, which is a highly hyroscopic salt, as an absorbent. The lithium bromide solution has a strong affinity for water vapour because of its very low vapour pressure. Since lithium bromide solution is corrosive, therefore inhibitors should be added in order to protect the metal parts of the system against corrosion. Lithium chromate is often used as a corrosion inhibitor. This system is very popular for air conditioning in which low temperatures not below 0°C are required. 2.

2. 3 Domestic Electrolux (Ammonia Hydrogen) Refrigerator. This type of refrigerator is also called three fluids absorption system. The main purpose of this system is to eliminate the pump so that in the absence of moving parts, the machine becomes noise-less. The three fluids used in this system are ammonia, hydrogen and water. The ammonia is used as a refrigerant because it possesses most of the desirable properties. It is toxic, but due to absence of moving parts, there is very little chance for leakage and the total amount of refrigeration used is small. The hydrogen being the lightest gas is used to increase the rate of evaporation of the liquid ammonia passing through the evaporator. The hydrogen is also non-corrosive and insoluble in water. This is used in the low pressure side of the system. The water is used as a solvent because it has the ability to absorb ammonia readily. 2. 3 REFRIGERANT - ABSORBER PAIRS 2. 4 COMPONENTS The basic components of a vapour absorption refrigeration system are: 2. 4. 1 Absorber Weal;: solution from generator Vapours from evaporator Fig 2. 2 A simple absorber Absorber is one of the important parts of a Vapour Absorption Refrigeration System. It is the place where weak solution from the generator is mixed with the vapours from the evaporator. During this process of mixing heat is liberated, so an arrangement for carrying away the heat generated during the mixing should be made for the efficient working of the refrigeration system. A simple figure of an absorber is shown below. The weak solution from the absorber is sprayed on to the vapours of refrigerant coming from the evaporator to speed up the process of mixing. The formed strong solution of refrigerant and the absorber is then pumped using a pump. 2. 4. 2 Generator From Pump | To Condenser -> I i > | | | | | | | | | | | | | | | | | | | | | | | | | |

| | | | | To A | jsorber | Heating Coil| Fig 2. 3 A generator The generator of a Vapour Absorption Refrigeration System is the most important component of the whole system. This is the place where heat from the burned gases is supplied to the strong solution of refrigerant and absorber. This heat energy supplied to the generator is absorbed by the mixture to liberate the refrigerant vapour. So it is nothing but a heat exchanger, and the whole working of the refrigeration system depends on this heat exchanger. A generator has to be designed according to the requirement of the refrigeration needed and the source of heat available. 2. 4. 3Condenser A condenser is used to remove the latent heat of the refrigerant coming from the generator. It consists of a number of tubes which is provided with a large number of fins to remove maximum amount of heat from the refrigerant. A condenser is usually made of copper tubes which increases the heat transfer rate from the refrigerant to the surrounding. This is designed based upon the amount of heat to be removed and the surrounding in which it is removed. 2. 4. 4 Evaporator This is in the form of coils where heat is absorbed by the refrigerant from the surroundings when the cold refrigerant is passed through it. It is basically copper tubes (to have maximum heat absorbing capacity) having a number of turns. 2. 4. 5 Expansion device It is a device to reduce the pressure of the refrigerant from high pressure to low pressure, thus reducing the temperature of the refrigerant. 2. 4. 6 Pump Any pump which could discharge the solution from low pressure to high pressure could be used. The selection of the pump depends upon the amount of the solution to be pumped for producing the required effect from absorber to generator. CHAPTER 3 LITERATURE SURVAY 3. 1 VAPOUR ABSORPTION SYSTEMS IN IC

ENGINES There are only very few work done on this topic of using vapour absorption refrigeration system as air conditioner for the automobile. Some of them are: 3. 2 WORK DONE BY ANGELO CANTONI, ROME, ITALY This invention comprises a vapour generator member connected to a condenser which is itself connected, by way of a pressure reduction valve, to an evaporator connected to an absorber which receives the liquid present in the lower zone of the generator and from which liquid is fed to the upper zone of the generator, there being provided in the generator a heat exchanger through which the engine cooling liquid flows. Hence it uses heat of the cooling water as the source of heat for the generator. 3. 3 WORK DONE BY I HORUZ, BURSA, TURKEY The work done by I Horuz consists of using exhaust heat of the automobile as the heat source for the generator. He used two heat exchangers one with insulation and the other without insulation for transferring heat to the solution of the absorption system. He plotted the results obtained after conducting various performance tests on the engine under different running conditions. VAPOUR ABSORPTION REFRIGERATION SYSTEM IN AUTOMOBILES 4. 1 INTRODUCTION It is well known that an IC engine has an efficiency of about 35-40%, which means that only one-third of the energy in the fuel is converted into useful work and about 60-65% is wasted to environment. In which about 28-30% is lost by cooling water and lubrication losses, around 30-32% is lost in the form of exhaust gases and remainder by radiation, etc. In a Vapour Absorption Refrigeration System, a physicochemical process replaces the mechanical process of the Vapour Compression Refrigeration System by using energy in the form of heat rather than mechanical work. The heat required for running of a Vapour Absorption

Refrigeration System can be obtained from the exhaust of any vehicle working with an IC engine, which would otherwise be exhausted into the atmosphere. Hence using a Vapour Absorption Refrigeration System will not only prevent the loss of power from the vehicles engine but will also produce refrigeration using the low grade energy (i, e. exhaust) from the engine. The use of a Vapour Absorption Refrigeration System will also reduce pollution by reducing the amount of fuel burned while working the conventional vapour compression refrigerating unit. 4. 2 METHODS OF IMPLEMENTATION IN AN AUTOMOBILE For a road transport utilizing Vapour Absorption Refrigeration System heat energy can be supplied in two ways: 4. 2. 1 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. 4. 2. 2 Using waste heat of the IC engine Another method is 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. EXPERIMENTAL IC ENGINE 5. 1 INTRODUCTION In an IC engine, fuel (usually petrol or diesel) is combusted inside the cylinder due to which the piston moves outward and rotates the crank, and hence the engine produces work. In IC engines the combustion of the fuel produces heat, which is converted to mechanical work using the piston and crank arrangement. From the heat produced from combustion of fuel only 30% (approx) of heat is converted into useful mechanical work. The remaining heat energy is wasted into the atmosphere in the form of: (i) heat carried away by the cooling water, (ii) heat taken away by the exhaust gases, (iii) heat carried away by the lubricating oil, (iv) and, heat lost by radiation. The cooling water and exhaust gases carry away the maximum amount of heat from the engine, ie around 60% (approx). This heat is called the low grade energy of the engine. 5. 2 THE ENGINE Let us consider an engine of an automobile on which the vapour absorption refrigeration system is to be implemented. 5. 2. 1 Engine parameters The IC engine based on which the calculations are done is * Make - Hindustan Motors * Model - Ambassador * No of cylinders, n = 4. * Power, P = 60 bhp at 2000 rpm. * Capacity, V = 1717cc. * No of strokes = 4. * Fuel used = diesel. * Air-fuel ratio, A/F = 15: 1 5. 3 WASTE HEAT OF THE ENGINE The main two areas through which the heat is exhausted into the atmosphere from the engine are the cooling water and the exhaust gases. It is necessary to calculate the amount of heat energy carried away by the exhaust gases and the cooling water. 5. 3. 1 Exhaust gas heat - Volumetric efficiency of the engine, Evoi = 70%. Rated speed, N = 2000 rpm Mass flow rate of air into the cylinder, ma = VN Evoi/2 = 0. 001717x2000x0. 7/2 ma= 0. 02m3/s. Mass flow rate of fuel, mf = ma/(A/F ratio) = 0. 02/15 mf = 0. 001335 kg/sec Total mass flow rate of exhaust gas, me= ma+mf = 0. 021335 kg/s. Specific heat at constant volume of exhaust gas Cpe= lkj/kgk. Temperature available at the engine exhaust, te= 300°C. Temperature of the ambient air, ta = 40°C Heat available at exhaust pipe Qe = meCpe(te-ta) = 0. 021335xlx(300-40) Qe= 5. 5kW 5. 3. 2 Cooling water heat Temperature of water entering the cooling water jacket, tcj= 50°C. Temperature of water exiting the cooling water jacket, tco= 80°C. Mass flow rate of water for a 4 cylinder diesel engine, mw= 0. 1 kg/s. Specific heat of water, Cpw= 4. 18 kj/kgk Heat carried away by cooling water Qw = mwCpw(tC0-tcj) = 0. 1x4. 18x(80 -50) Qw= 12. 54 kW. 5. 4 FINAL VALUE Heat available at exhaust gas = 5. 5 kW Heat carried by cooling water = 12. 54 kW CHAPTER 6 PROPOSED PROJECT 6. 1 INTRODUCTION As we have already calculated the amount of heat available at the exhaust and in the cooling water, which enables us to implement a vapour absorption refrigeration system with in the automobile. The absorbent-refrigerant combination used is LiBr-H2O. Using this solution will eliminate the use of rectifier, analyzer, etc. The proposed system as shown below: HOT WATER FROM ENGINE JACKET EXHAUST FROM CYLINDER GENERATOR PREHEATER CONDENSOR EXHAUST OUT COLD WATER TO RADIATOR im CONTROL J> VALVE EXPANS1CN VALVE PUMP ABSDRBER Fig 6. 1 Block diagram of the system EVAPORATOR 6. 2 CONSTRUCTION There are basically eight components, let us see the construction of each in detail: 6. 2. 1 Pre-heater This is a container containing coiled tubes through which the solution passes. It is placed in between the generator and the pump of the absorber. Cooling water is passed through the container, ie it is placed in the path way of hot water flowing from the engine jacket to the radiator. The quantity of cooling water inside the pre-heater is always fixed. The coils for the flow of solution are made of copper to have maximum heat transfer from the cooling water to the solution and the remaining parts are of cast iron. 6. 2. 2 Generator It is basically a container where the solution is maintained at constant level. The exhaust pipe is passed through it and its heat is extracted in the generator. It has two exits and an inlet. From the two exits, one is for the flow of refrigerant to the condenser and the other for the flow of solution back to absorber. The exhaust pipe passing through the generator is made of copper while the other components are made of steel. 6. 2. 3 Condenser Usually the condenser of an automobile is of an oval cross-section. It is made of aluminum to have easy transfer of heat from the refrigerant coming from generator to the atmosphere. A large number of fins are provided to increase the surface area and thereby increase the heat transferred from the refrigerant to the atmosphere. 6. 2. 4 Expansion valve A needle valve is used to drop the pressure of the refrigerant from high pressure to low pressure side. A needle valve can be easily adjusted to obtain the required pressure within the system. 6. 2. 5 Evaporator The refrigerant from the expansion valve enters the evaporator where the cold refrigerant absorbs heat from the surroundings. To have maximum heat transfer from surroundings to the refrigerant the evaporator is made of copper tubes. 6. 2. 6 Absorber This is the container which has two inlets, one for the refrigerant coming from the evaporator while the other for the weak solution coming from the generator. The one exit is for pumping the solution to the generator. It has a perforated sheet to strain the solution coming from the generator to have a proper mixing of the weak solution with the refrigerant coming from the evaporator. Fins are provided around the container to increase the surface area, to remove the heat developed during the mixing of the refrigerant and the weak solution. 6. 2. 7 Pump Since the system is small the flow rate required is also small. Hence a fuel pump is used to pump solution from the absorber to the generator. The power to run the pump is derived from the engine battery. 6. 2. 8 Control valve This is placed in between the generator and the absorber to bring the solution pressure from high pressure to low pressure. The control valve may be another needle valve which could also be used to control the flow rate of the weak solution back to the absorber. 6. 3 WORKING OF THE SYSTEM The strong solution at 35°C is pumped from the absorber to the pre-heater where the solution of the strong solution is increased to 75°C from the cooling water at 80°C. This solution then enters the generator where the refrigerant, ie water at 40°C gets vapourizes and is passed through the condenser, where the latent heat is removed from the refrigerant. This refrigerant is then passed through the expansion valve to bring the temperature to around 10°C, after which it is passed through the evaporator coil to absorb the latent heat of the refrigerant at 10°C. The vapourized refrigerant then enters the absorber where the weak solution coming from the generator gets mixed liberating heat. This formed solution is again pumped to the generator using the pump and the cycle is repeated again. ANALYSIS OF VAPOUR ABSORPTION SYSTEM 7. 1 INTRODUCTION Vapour absorption refrigeration system employing LiBr-H20 solution is employed to produce the required refrigerating effect. There are two operating pressures in the system; one is the high pressure side which includes generator and the condenser, while the other is the low pressure side which includes the absorber and the evaporator. An expansion device is used to bring the solution from high pressure side to low pressure side. Using LiBr-H20 solution in the system the use of analyzer and the rectifier is eliminated as required for the aqua-ammonia system. Hence the system becomes simpler and the number of components required for the system is also reduced. 7. 2 ANALYSIS. 8 Generator Condenser 7^ 4/ 9 Heat Exchanger ^ 11 Absorber Evaporator 12 Fig 7. 1 Vapour absorption system with a pre-heater Taking Temperatures of the system as given below, Temperature at generator, tg = 100°C Temperature at Condenser, tc = 40°C Temperature at Evaporator, te = 10°C Temperature at Absorber, ta = 35°C Let, ma - Mass flow rate of the solution back to the absorber mr - Mass flow rate of refrigerant mg - Mass flow rate of the strong solution to the generator xa - LiBr concentration in absorbent, (lb/lb of solution) Xb- LiBr concentration in refrigerant-absorbent solution.(lb/lb of solution) Latent heat of refrigerant at 10°C, hfg = 2247. 7 kJ/kg Refrigerating effect required, R. E = 0. 5 TR 1. 75 kJ/s Also, Therefore, RE mrxhfg By mass balancing, We know that Also, Hence, Therefore, Hence, mr = R. E / hfg = 1. 75/2477. 7 m, = 0. 71 gm/sec mg = ma + mr Dividing throughout by mr mg/mr = ma/mr + 1 ma/mr = xb/(xa-xb) = 0. 57/(0. 62 - 0. 57) = 11. 4 gm/gm of solution ma = mrx0. 71 = 11. 4x0. 71 ni;) - - 8. 094 gm/sec mg/ mr= 11. 4 + 1 = 12. 4 gm/gm of solution mg = mrx0. 71 = 12. 4x0. 71 m„ = 8. 804 gm/sec COP of a vapour absorption system, COP = (Te/(Tc-Te))((Tg-Tc)/Tg) = (10/(40-10))((100-40)/l 00) COP = 0. 2 7. 3 FINAL VALUES To produce 0. 5 TR inside the automobile cabin it is required to have mass flow rate of refrigerant, mr = 0. 71 gm/s mass flow rate of strong solution from absorber to generator, mg = 8. 804 gm/sec mass flow rate of weak solution from generator to absorber, ma = 8. 094 gm/sec Co-efficient of Performance, COP = 0. 2 DESIGN 8. 1 INTRODUCTION 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. 8. 2 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. 8. 2. 1 Design of pre-heater Mass flow rate of LiBr-H20 solution, m = 8. 804 g/s Inlet temperature of the LiBr-F^O solution, tj = 35 °C Outlet temperature of the LiBr-H20 solution, t0 = 75 °C Surface temperature of the tube or cooling water temperature, ts = 80 °C Mean temperature, tm =(ti + to) = (35+80V2 tm = 57. 5 °C Properties of water at tm = 57. 5°C Density p = 983 kg/m3 Thermal Conductivity, K = 0. 649 W/m °C Prandtl Number, Pr = 2. 96 Dynamic Viscosity, ju = 0. 462x10'3 Kg/ms Tube through which LiBr-HiO solution passes Taking outside Diameter of the tube, D0 = 0. 012 m And taking inside Diameter of the tube, Dj = 0. 01 m Velocity of LiBr-H20 solution through the tube V = m/Ap = 0. 008804 /(7. 85xl0" 5x983) = 0. 114m/s Reynolds Number, Re = pVd/n = (983x0. 114x0. 01) / (0. 462xl0" 3) = 2426. 32 For forced convection through circular tubes Nusselt Number, Nu = 0. 023Re° 8Pr°3 = 0. 023 (2426. 32)°8(2. 96)03 = 16. 26 Also, Nu = hDi/K Therefore, heat transfer co-efficient, h = NuK/Di = (16. 26x0. 649)/0. 01 h = 1055. 16 W/mK Log Mean Temperature Difference, LMTD = [(ts - tj) - (ts -10)] / In [(ts - ti)/(ts - to)] = [(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 = mCpAT = 0. 008804x4. 18x40 Q = 1. 472 kW Area of flow through tubes, A = 7tD0L = 7tx0. 012xL Where, L is the length of the tube. L = Q/ [hx7ix0. 012 (LMTD)] = 1. 472xl03 / [1055. 16x7tx0. 012xl8. 2] L = 2. 033 m 8. 2. 2 Final dimensions Dimensions of the designed pre-heater Outside Diameter of the tube, D0 = 0. 012 m Inside Diameter of the tube, Dj = 0. 01 m Length of the tube, L = 2 m [pic] Fig 8. 1 Isometric view of pre-heater 8. 3 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. 8. 3. 1 Design of generator Outside Diameter of the exhaust gas tube, D0 = 0. 04 m Temperature of the exhaust gas at the exhaust tube, ts = 300 °C Temperature of the solution, t = 75 °C Temperature required at the generator, tg = 100°C Mean temperature, tm= (ts+t)/2 = (300+75)/2 = 187. 5 °C Properties of water at tm = 187. 5 °C Density p = 7. 87 kg/m3 Thermal Conductivity, K = 0. 0775 W/mK PrandtlNumber, Pr = 0. 902 Dynamic Viscosity, pi = 0. 133x10'3 Kg/ms Co-efficient of thermal expansion, P = 1/tm = 1/(187. 5+273) | 3 = 0. 00217 /K Considering it as a convective heat transfer problem. Grashoff Number, Gr = (3xgx(ts-t)xD02p2 / u2 = 0. 002 1 7x9. 81x225x0. 042x7. 872 / (0. 133xl0~3)2 = 26852706 Nusselt Number, Nu = 0. 47x(Gr. Pr)° 25 = 0. 47x(26852706x0. 902)025 Nu = 33 Also, Nu = hD0/ K Convective Heat Transfer Co-efficient, h = NuK/D0 = 33x0. 0775 /0. 04 = 63. 883 W/m2K i. e. h = 64 W/m2K Mass flow rate of refrigerant, mr = 0. 71 gm/s = 0. 71xl0" 3 Kg/s Latent heat of the refrigerant at 100 °C Heat required at Generator Q = mrxCpx(tg -1) + mrxhfg = 0. 71xl0" 3x4. 2x(100 -75) + 0. 71xl0" 3x2257 =

1. 7 kW Heat Transfer Rate Q = hA(ts-t) 1. 7 = 64x7ix0. 04xLx22 5 Contact area, A = 7tD0L = 7tx0. 04xL Length of the Tube, L = 1700/64x7tx0. 04x225 = 0. 94m L = lm 8. 3. 2 Final dimensions Dimensions of the designed generator Outside Diameter of the exhaust gas tube, D0 = 0. 04 m Taking inside diameter of the exhaust gas tube, D; = 0. 038 m Length of the tube required for the required heat transfer, L = 1 m Fig 8. 2 Isometric view of generator 8. 4 CONDENSER Assume rectangular cross section of the condenser coil of thickness, a = 2 2 0. 5x10" m & width b = 1. 8x10" m. The condenser is used to remove the latent heat of the refrigerant at temperature t = 40 °C i. e. hfg = 2406. 9 kJ/kg at a mass flow rate of = 0. 71x10" 3 Kg/s. 8. 4. 1 Design of condenser Taking Properties of steam at t = 40 °C Density p = 0. 05 kg/m3 Thermal Conductivity, K = 0. 632 W/mK Dynamic Viscosity, ju = 0. 0101x10'3 Kg/ms c = b/a= 1. 8/0. 5 = 3. 6 Lc= 1. 55a = 1. 55x0. 5xl0" 2 = 7. 75xl0" 3m Velocity of Refrigerant, V = mr/A = 0. 71xl0" 3/(1. 8x0. 5xl0" 4) = 8 m/s Reynolds Number, Re = pLcv/p = 0. 05x7. 75xl0" 3x8 / (O. OlOlxlO" 3) Re = 300 The value of Reynolds No. is less than 2000, hence the flow is Laminar Therefore for forced convection through tubes of rectangular cross section, we have Nusselt Number, Nu = 4. 1xRe°xPr°xl = 4. 1 Also, Nu = hjLc/K Inside convective heat transfer co-efficient hj = NuK/Lc = 4. 1x0. 632/(7. 75xl0" 3) hj = 334. 35 W/m2K Air side heat transfer co-efficient Taking temperature of air entering the condenser surface, ti = 30 °C Taking temperature of air leaving the condenser surface, to = 38 °C Assuming velocity of air flow, Va = 2 m/s Mean temperature, tm = (tj+t0)/2 = (30+38V2 = 34 °C Properties of air at mean temperature tm = 34 °C Density p = 1. 1774 kg/m3 Thermal Conductivity, K = 0. 02624 W/mK

Dynamic Viscosity, p. = 1. 983x10'5 Kg/ms Equivalent diameter, Lc = V(2(a2+b2)) = V(2(0. 5xl0" 2)+(1. 8xl0" 2)) Lc = 0. 02642 m Reynolds Number, Re = pLcVa /u. = 1. 1774x0. 02642x2/(1. 983xl0" 5) Re = 3137. 35 Forced convection heat transfer for air flow normal to cylinders of various cross sections. Nusselt Number, Nu 0. 43 + 0. 248xRe 0. 612 Nu h0Lc/K Outside convective heat transfer co-efficient 0 h, NuK/Lc = 34. 655x0. 02624/0. 02642 â– 0 h, = 34. 42 W/m2K Overall Heat Transfer Co-efficient 1/U = (1/hi) + (1/ho) = (1/334. 35)+ (1/34. 42) = 0. 032 U = 31. 2W/m2K Log Mean Temperature Difference LMTD = [(t - tj) - (t -10)] / In [(t - tj)/(t - to)] = [(40 - 30) - (40 - 38)] / In [10/2] = 4. 97 °C = 5 +273 LMTD = 278 K Area, A = Q / U(LMTD) = 1710/(31. 2x278) = 0. 1969 m2 Therefore Length of the Tubes without Fins, L = A/ Lc = 0. 1969/0. 02642 L = 7. 45 m 8. 4. 2 Final dimensions Dimensions of the designed condenser Width of the tube, b = 0. 018 m Thickness of the tube, a = 0. 005 m Length of the tube, L = 7. 45 m 8. 5 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. 8. 5. 1 Design of evaporator Taking outside diameter of the tube, D0 = 0. 01 m Taking inside diameter of the tube, Dj = 0. 008 m The temperature of the refrigerant in the evaporator coil is t = 10°C. The refrigerant in the evaporator absorbs the latent heat and vapourizes. Hence, taking properties of the refrigerant at t = 10°C. Density p = 999 kg/m3 Thermal Conductivity, K = 0. 509 W/m °C Prandtl Number, Pr = 13. 02 Dynamic Viscosity, p = 1. 755x10'3Kg/ms Velocity of the refrigerant flowing through the tube, V = m/Ap = 0. 71x10" 3 / (7i/4x0. 0082x999) = 0. 01414 m/s Reynolds Number, Re = pVd/p = (999x0. 01414x0. 008) / (1. 755xl0" 3) = 64. 387 For forced convection through circular tubes Nusselt Number, Nu = 0. 023 Re08Pr°4 = 0. 023 (64. 387)° 8(13. 02)04 = 1. 8 Also Nu = hjDj/K Inside heat transfer coefficient hi = NuK/Di = 1. 8x0. 509/0. 008 hj = 114. 51 W/m2K Assuming the velocity with which the air is passed through the coils be Va = 2 m/s. Taking temperature of the air entering the evaporator, tj = 40°C. Taking temperature of the air exiting the evaporator, t0 = 20°C. Mean temperature, tm = (tj + to)/2 = (40 + 20)/2 tra = 30°C Properties of water at tm = 30°C Density, p = 1. 1 kg/m3 Thermal Conductivity, K = 0, 02650W/mk Dynamic Viscosity, p. = 1. 983x10'5 Kg/ms Reynolds number, Re = SvDo/jx = I. lx2x0. 01/(1. 983xl0" 3) = 1109. 43 Nusselt number, Nu = 0. 583xRe0'471 = 0. 583x[l 109. 43]0473 Nu =. 15. 845 Also Nu = hoDo/K Outside heat transfer co-efficient h0 = NuK/D0 = 15. 845x0. 02650/0. 01 h0 = 42 W/m2K Overall heat transfer co-efficient, 1/U = l/hi+l/h0 = 1/114. 351 + 1/42 = 0. 03255 U = 30. 7 W/m2K Log Mean Temperature Difference, LMTD = [(ts - ti) - (ts -10)] / In [(ts - ti)/(ts -10)] = [(40 - 10) - (20 - 10)] / In [30/10] = 18. 2 °C = 18. 2 + 273 LMTD = 291. 2 K Amount of heat absorbed by the refrigerant, Q = mrxhfg Latent heat of refrigerant corresponding to 10°C, hfg= 2477. 9 kJ/kg Mass flow rate of the refrigerant, mr= 0. 71xl0" 3 Q = 0. 71xl0" 3x 2477. 9 Q = 1. 76kW Also Q = UA(LMTD) Area of flow through tubes, A = 7tD0L = TixO. O lxL Where, L is the length of the tube. L = Q/[Ux7iD0x(LMTD)] = 1760 / [30. 72x71x0. 01x291. 2] L - 6. 26 m 8. 5. 2 Final dimensions Dimensions of the designed evaporator Outside Diameter of the tube, D0 = 0. 01 m Inside Diameter of the tube, Dj - 0. 008 m Length of the tube, L = 6. 26 m 8. 6 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. 8. 6. 1 Design of the absorber Heat in the solution coming from the generator = 1. 7 kW Heat in the refrigerant coming from the evaporator = 1. 76 kW Therefore, total heat to be removed from the absorber, Q = 1. 7 + 1. 76 i Q = 3. 46 kW A temperature of 40oC has to be maintained in the absorber, i, e tm = 40°C. Taking Properties of air at t = 40 °C Density p = 1 kg/m3 Thermal Conductivity, K = 0. 029 W/mK Dynamic Viscosity, p = 2x10'5 Kg/ms Prandtl number, Pr = 0. 7 Let the velocity of air passing over the surface of the absorber, v = 10 m/s Assuming outside diameter of the absorber to be D0 = 0. 076 m Reynolds number, Re 8vDo/(i Nu 0. 023xRe U8xPr â– 0. 4 0. 023x 3800u 8x0. 7 Nu 91. 95 Also Nu hoD0/K Outside heat transfer co-efficient h0 = NuK/D0 = 91. 95x0. 029/0. 076 h0 = 35. 1W/m2K Difference in temperature of the refrigerant and the outside air At = 60 K Heat transfer rate, Q = h0AAt Hence amount of surface area required - A = 3. 46xl03/(35. 1x60) A = 0. 164 m2 -Taking a container with outside diameter, D0 = 76 mm -Total length, L = 205 mm -Diameter of the fin Df = 109 mm -No. of fins, n = 7 -Length of the surface without fins, h = 125 mm Length of the surface with fins, 12 = 205 - 125 = 80 mm Surface area of the container without fins, Ai = 7tD0li = 71x0. 076x0. 125 A, = 0. 29845 m2 Surface area of the container with fins, A2 = 2n7t(Df-D0)l2 = 14x7tx(0. 109-0. 076)x0. 08 A2 = 0. 116113 m2 Therefore total surface area of the container, A = Ai+ A2 = 0. 29845 + 0. 116113 A = 0. 145 m2 As the surface area of the taken container is approximately equal to the required surface area, it can be used as the absorber. CONCLUSION 9. 1 INTRODUCTION With all the designed components it is possible to install a vapour absorption refrigeration system in an automobile working using the waste heat of the vehicle engine to produce refrigerating effect inside the automobile cabin. Using a vapour absorption refrigeration system within a automobile as an air conditioner will not only reduce the fuel consumption of the vehicle while working but will also provide many other advantages. 9. 2 ADVANTAGES OF USING VAPOUR ABSORPTION SYSTEM IN AUTOMOBILES The use of a Vapour Absorption Refrigeration System in road transport vehicles has the following advantages: * No dedicated IC engine is required for the working of the refrigerating unit. No refrigerant compressor is required. No extra work is required for the working of the refrigerating unit. Reduction in weight of unit. Reduction in capital cost. Reduction in fuel cost. Reduced atmospheric pollution. Reduced maintenance. Reduced noise pollution. 8. 6. 2 Final Dimensions Dimensions of the designed absorber Outside diameter of the absorber, D0 = 76 mm Total length of the absorber, L = 205 mm Outer diameter of the fins, Df = 109 mm No. of fins, n = 7 CONCLUSION 9. 1 INTRODUCTION With all the designed components it is possible to install a vapour absorption refrigeration system in an automobile working using the waste heat of the vehicle engine to produce refrigerating effect inside the automobile cabin. Using a vapour absorption refrigeration system within a automobile as an air conditioner will not only reduce the fuel consumption of the vehicle while working but will also provide many other advantages. 9. 2 ADVANTAGES OF USING VAPOUR ABSORPTION SYSTEM IN AUTOMOBILES The use of a Vapour Absorption Refrigeration System in road transport vehicles has the following advantages: * No dedicated IC engine is required for the working of the refrigerating unit. No refrigerant compressor is required. No extra work is required for the working of the refrigerating unit. Reduction in weight of unit. Reduction in capital cost. Reduction in fuel cost. Reduced atmospheric pollution. Reduced maintenance. Reduced noise pollution. 9. 3 DIS-ADVANTAGES OF USING VAPOUR ABSORPTION SYSTEM IN AUTOMOBILES Though the system has a large number of advantages, there are also some disadvantages. These are: * Refrigerating effect will be reduced or will be difficult to produce should the vehicle be at rest or in a very slow moving traffic condition. Improper design of the generator may reduce the engine performance. Accommodation of the system on the vehicle is also a big task. * The refrigerating effect produced using a Vapour Absorption Refrigeration System is less compared to a Vapour compression Refrigeration System. 9. 4 METHODS OF IMPROVEMENT Since the Vapour Absorption Refrigeration System working with the exhaust of an IC engine is dependent on the exhaust gas temperature and hence the engine speed, a built in eutectic plates could provide temporary cooling effect during conditions when the vehicle is moving slowly or at rest. Such plates could be recharged by redirecting the cooling effect from the main body to the eutectic plates during off load periods of continuous full load travel. Another method is that the Vapour Absorption Refrigeration System could be run using a natural fired engine when the vehicle is at rest or in slow speed condition and during other conditions it could utilize the exhaust of the engine. REFRENCES 1. 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(2002) 'Steam Tables', New Age International Publishers., 2nd edition. 10. Rajput R K (2006) 'A textbook of Internal combustion engines', Laxmi Publications (P) Ltd., 1st edition. 11. Rajput R K (2007)' Heat And Mass Transfer', S. Chand & Company Ltd., 3rd edition. 12. Wilbert F Stoecker / Jerold W Jones (2004) 'Refrigeration & Air Conditioning', McGraw Hill International editions, 2nd edition, pp 328 - 338. ---------------------- | SI. No. | Refrigerant | Absorber | State of Absorber | | 1 | Ammonia | Water | Liquid | | 2 | Ammonia | Sodium thiocynate | Solid | | 3 | Ammonia | Lithium nitrate | Solid | | 4 | Ammonia | Calcium Chloride | Solid | | 5 | Water | Lithium Bromide | Solid | | 6 | Water | Lithium Chloride | Solid | | 7 | Methylene chloride | Dimethyl ether of tetra ethylene glycol | Liquid | Table 2. 1 Refrigerant - Absorber Pairs [pic] Strong solution to pump [pic] | Point | Temp | Pressure | Weight LiBr | Flow rate of refrigerant | Enthalpy | | |(°C) |(mm of Hg) | |(gm/sec) |(KJ/Kg) | | 1 | 100 | 93 | 0. 62 | 11. 4 |- | | 2 |- | 93 | 0. 62 | 11.

4 |- | | 4 | 35 | 9. 2 | 0. 57 | 12. 4 |- | | 7 |- | 93 | 0. 57 | 12. 4 |- | | 8 | 100 | 93 | 0 | 1 |- | | 9 | 40 | 93 | 0 | 1 | 42 | | 11 | 10 | 9. 2 | 0 | 1 | 42 | | 12 | 10 | 9. 2 | 0 | 1 | 2519. 8 | Table 7. 1 Properties of refrigerant at each point of the system 34. 655 Also 1x10x0. 076/(2x10°) 3800 Nusselt number, . 0. 4 Fig 8. 3 Isometric view of absorber