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Research Article

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Development of an Air Conditioner Using Water as Secondary Refrigerant

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Abstract: The research work involved the design, construction and performance evaluation of an air conditioner using water as secondary refrigerant and R134a as the primary refrigerant. The system built-up was divided into two parts; refrigeration unit and fan unit, the refrigeration unit was made to house chilled water and with the aid of pump, the chilled water is channeled via a well lagged pipe into coiled brass pipe inside the fan unit, with the help of fan arrangement placed behind the pipe carrying chilled water the cooling effect is blown out of the unit. Experimental testing of the machine was conducted under fixed and variable load conditions with the temperature and pressure both at the inlet and exit of each of evaporator, compressor and condenser in the refrigeration unit. From the data obtained the refrigerating effect, coefficient of performance and overall efficiency were all determined. The result of the performance evaluation showed that the evaporator temperature increases from 10℃ to 26℃ keeping the condenser temperature constant, the refrigerating effect increases from 95.33kJ/kg to 103.84kJ/kg, the coefficient of performance increases from 5.98 to 13.96 and the overall efficiency of the system increases from 67.65% to 74.69%. Also, as the condenser temperature increases from 42℃ to 48℃ keeping the evaporator temperature constant, the refrigerating effect decreases from 95.33kJ/kg to 88.58kJ/kg, the coefficient of performance decreases from 5.98 to 5.58 and the overall efficiency decreases from 67.65% to 62.55%. The machine was operated under steady power supply for half an hour.

Keywords: Refrigerant, refrigeration, condenser, lagged pipe, coefficient of performance

1. Introduction

Refrigeration is the process of achieving and maintaining a temperature below that of the surrounding (Tomczyk et al. 2016). Refrigeration has been extensively used to provide comfort for man, machine and as well as perishable food items. There are several methods that can be employed to achieve refrigeration process some of which are: Vapour compression refrigeration system, vapour absorption refrigeration system, solar energy-based refrigeration process, Gas circle refrigeration, Vortex tube system, steam jet refrigeration system, and thermo electric refrigeration system.

Vapour compression refrigeration system is commonly used and it comprises four processes, which are: Compression process, condensing process, expansion process and vaporization process. In the compression process the vapour refrigerant at low temperature and pressure, is compressed isentropically to dry saturated vapour at high temperature and pressure. The high temperature and pressure vapour refrigerant from the compressor is passed through the condenser where it is completely condensed at constant pressure and temperature, the vapour refrigerant is changed to liquid refrigerant. The refrigerant while passing through the condenser gives its latent heat to the surrounding condensing medium. During the expansion process, the liquid refrigerant is expanded by throttling process through the expansion device to a low pressure and temperature. During the throttling process no heat is absorbed or rejected by the liquid refrigerant. The low pressure and temperature refrigerant goes into the evaporator, the liquid mixture of the refrigerant is evaporated and changed into vapour refrigerant at constant pressure and temperature. During evaporation the liquid vapour refrigerant absorbs its latent heat of vaporization from the medium which is to be cooled and then get evaporated at constant temperature and pressure there by completing the circle (Tomczyk et al. 2016).

This system is designed to comprise of two units namely; refrigeration unit and fan blowing unit. Water is used as secondary refrigerant (at the blowing unit) and R-134a (CF_3CH_2F) 1,1,1,2-tetrafluoro ethane as the primary refrigerant (at the refrigeration unit) and is one of the best replacements for R-12. R-134a has zero ozone depletion causing potential and moderate green house effect (KPL, 2016).

The heat generating electrical components in the electrical control room of Light Section Mill of Ajaokuta Steel Company Limited (ASCL) was not an exception and thus required temperature regulation measures because electrical equipment operates within an optimal temperature range of about 40℃ (Murray, 2019). Therefore, the design and construction of air conditioning system to chill light section mill electrical control room within a temperature range of 10℃ and 26℃ will be effective and efficient in handling temperature regulation of the electrical room.

Human and machine thermal comforts are very essential in any manufacturing industry as their comfort can greatly improve rate of production. In an attempt to achieve this, different types of normal conventional air conditioning system have in the past been installed in the electrical control room of Light Section Mill (since the shutdown of the central refrigeration house) but could not meet up with the aim of installation as a result of frequent breakdown due to excessive heat generated by the electrical components.

Therefore, the need to develop this refrigeration system is to maintain the temperature of the electrical control room so as to enable optimal performance of the electrical gadgets. The aim of this research work is to developed an air conditioning system using water as secondary refrigerant and to have the capacity to produce cool air within the temperature range of 10 ℃ and 26 ℃.

Refrigeration is the cooling of space, substance or system to lower and/or maintain its temperature below the ambient one. In other words, refrigeration is artificial cooling (Oyelami and Bolaji, 2016). Energy in the form of heat is removed from a low temperature reservoir and transferred to a high temperature reservoir. Air conditioning refers to the treatment of air so as to simultaneously control its temperature, moisture content, cleanliness, odour and circulation, as required by occupants, a process, or products in the space (Tomczyk et al. 2016). The subject of refrigeration and air conditioning has evolved out of human need for food and comfort, and its history dates back to centuries (Neuburger, 2003).

In olden days refrigeration was achieved by natural means such as the use of ice or evaporative cooling. The art of making ice by nocturnal cooling was perfected in India (kharagpur,2021). In this method ice was made by keeping a thin layer of water in a shallow earthen tray, and then exposing the tray to the night sky. Compacted hay of about 0.3 m thickness was used as insulation. The water looses heat by radiation to the atmosphere , which is at around -55 ˚C and by early morning hours the water in the trays freezes to ice (kharagpur,2021). Evaporative cooling has been used in India for centuries to obtain cold water in summer by storing the water in earthen pots. The water permeates through the pores of earthen vessel to its outer surface where it evaporates to the surrounding, absorbing its latent heat in part from the vessel, which cools the water (kharagpur,2021).

Vapour-compression refrigeration uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. All such systems have four components: a compressor, a condenser, a metering device or thermal expansion valve (also called a throttle valve), and an evaporator (Adeyemo, S. B, 2000). Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapor and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapour is then in the thermodynamic state known as a superheated vapour and it is at a temperature and pressure at which it can be condensed with either cooling water or cooling air flowing across the coil or tubes.

The superheated vapour then passes through the condenser. This is where the circulating refrigerant rejects heat from the system as it cools and condenses completely. The rejected heat is carried away by either the water or the air (whichever may be the case).

The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid and vapor refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated.

The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapour mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature. The evaporator is where the circulating refrigerant absorbs and removes heat which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser.

To complete the refrigeration cycle, the refrigerant vapour from the evaporator is again a saturated vapour and is routed back into the compressor (Rao, 2003).

Figure 1 shows a typical single stage vapor compression system and Figure 2 shows the temperature-enthropy diagram.

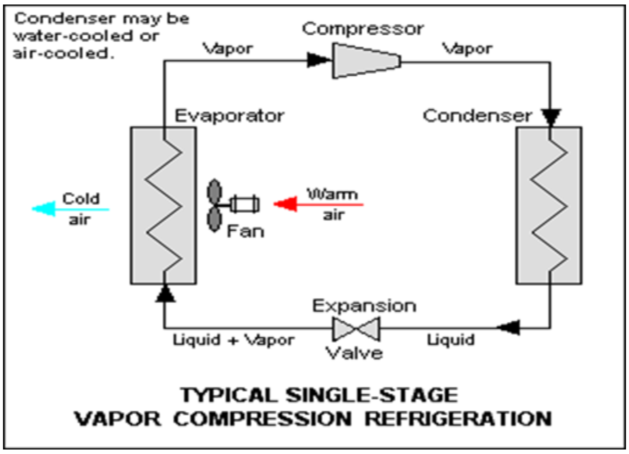

Figure 1: Vapor compression refrigeration

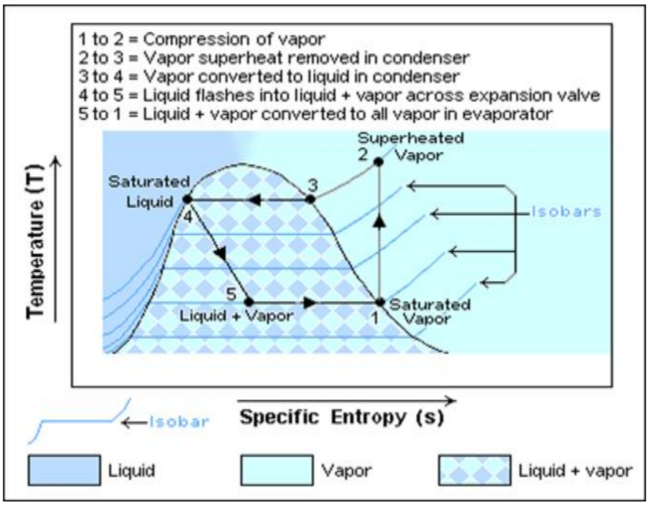

Figure 2: Temperature–Entropy diagram

Air conditioning is often part of a larger heating and cooling system (Gish, 2021).In many ways air conditioning and refrigeration systems are very similar. Both use specially designed chemicals, the physical effects of the compression and expansion of gases, and the conversion of gas to liquid to reduce the temperature of air. The varying uses of these systems, however, mean refrigeration and air conditioning systems have a handful of key differences in the design and operation.

According to Gish (2021), air conditioners have circulation systems designed to project cool air away from the units while refrigeration units have circulation systems designed to retain coolant in a confined space.

Refrigeration systems circulate cooled liquids and gases through a series of tubes and vents. Cool air from within a refrigerator is sucked into a compressor that recycles the gas through the tubes. Air conditioners, while also employing tubes in the coolant system, have fans for the dispersal of air. Unlike refrigeration systems, which keep gases contained to a pre-determined space, air conditioning systems disperse cool air throughout areas of unknown volume (Gish, 2021).

Both air conditioning and refrigeration units depend on converting liquid to gas in the cooling process, but the manner in which they achieve this is different for each system.

In the process of refrigeration, the heat is carried from the low temperature reservoir to the high temperature (against the second law of thermodynamics). The refrigerant is the fluid that is used in the vapour compression refrigeration system for carrying the heat from the substance or the fluid to be cooled and throw it to the atmosphere (Dreepaul, 2017).

In the beginning when the vapour compression system was discovered the refrigerant mostly used for large cooling applications were ammonia and carbon dioxide. These refrigerants were not found to be suitable for the small cooling applications (kiran, 2009).

First generation refrigerants were in use for almost one hundred years (1830 ~ 1930) were a variety of volatile compounds (Ethers, carbon IV oxide, ammonia, sulphure IV oxide, hydrocarbons, water etc.) and methyl chloride (CH_3Cl) are toxic gases (Dreepaul, 2017). Several fatal accidents occurred in the 1920s because of methyl chloride leakage from refrigerators, which pushed the entire world to look for next generation refrigerants.

The second-generation refrigerants which are chlorofluorocarbons (CFCs) (1930s) and later hydrochlorofluorocarbons (HCFCs) (1940s) were invented by Thomas Midgley Jr (aided by Charles Franklin Kettering). The refrigerants such as chlorofluorocarbons CFCs, hydrochlorofluorocarbons HCFCs, hydrofluorocarbons HFCs, ammonia NH_3 and water H_2O where used between (1931 ~ 1990).

Third Generation Refrigerants includes chemical groups, such as hydro-fluoro-carbons (HFCs) compounds that do not damage the ozone layer as that was the perceived environmental danger at that time. Examples of refrigerant in this generation are: HFCs, HCs, CO_2, NH_3, H_2O. They were used between (1990 ~ 2010).

However, as the effects of refrigerant leakages on global warming and climate change has become imminent, next generation refrigerants are required (Whitman et al., 2012).

The compressors are one of the most important parts of the refrigeration cycle. The compressor receives low temperature and pressure refrigerant from the evaporator, compresses the refrigerant and causes it to flow into the condenser, where it gets cooled (Whitman et al., 2012). It then moves to the expansion valve or throttle valve, and then to the evaporator and it is finally sucked by the compressor again.

Evaporator is the component of the refrigeration system where the heat dissipated from a hot medium is removed. An evaporator contains refrigerant in liquid form and will absorb heat when it evaporates, thus this conditional change produces cooling in a refrigerating process.

This is the wire-and-tube type condenser that will be used in the refrigeration unit. The purpose of the condenser is to remove the amount of heat that is equal to the sum of the heat absorbed in the evaporator and the heat produced by compression.

A capillary tube is a long, narrow tube of constant diameter made from copper. It is one of the commonly used throttling devices in refrigeration and air conditioning system. It is a metering device that controls the refrigerant flow by pressure drop. The principle of operation of the capillary tube is the flow resistance caused by a long, narrow tube, throttling the refrigerant pressure.

Cosnier et al. carried out an exhaustive experimental study of a novel air-water based thermoelectric cooling uni - This study explores a novel air-water based thermoelectric cooling unit and investigates its performance. It examines the adjustment of the thermoelectric hot side temperature and compares the results to previous studies.

Cosnier et al. performed an experimental and numerical study on a thermoelectric module that cools or warms an air flow. The experimental results confirmed the feasibility of cooling or heating air through thermoelectric modules.

Lineykin et al carried-out research on Water-Based Air Conditioner Cools without Harmful Chemicals" - This study discusses a water-based air conditioning technology that has the potential to replace the traditional air-cooling principle used in modern-day air conditioners. It highlights the environmental benefits of this technology.

Chen et al. perform research on Water-Based Thermal Energy Storage for Heating and Air Conditioning" - This study evaluates the potential of water-based thermal energy storage (TES) in shifting HVAC loads for residential buildings. It provides insights into the use of water-based TES for heating and air conditioning applications.

T.H. Wang et al. carryout research on the metalorganic framework for efficient water-based ultra-low cooling" - This study focuses on cooling devices, such as air conditioning units, and investigates a metalorganic framework for efficient water-based ultra-low cooling. It examines the correlation between lab-based experiments and previous studies.

2. Materials and Methods

Materials

The system comprises two main units namely; refrigeration unit and blowing unit. Both units were designed and fabricated as cuboids of dimensions 0.48m × 0.48m ×0.33m. the material common to the both units are; 2mm thick mild steel plate, angle bar, aluminum sheet, pipes, silicon, scotch cost, water pump and lagging material. In addition to the material of the refrigeration unit are; compressor, evaporator, condenser, receiver, thermostat, pressure gauge and temperature sensor. Also to the blowing unit are fan and duct. All these materials were sourced locally.

Method

The refrigeration unit is a well lagged box confinement which was made to house recirculation water. It was constructed by cutting the selected plate and insulator to suitable sizes which were joined together to form a rigid box while the evaporating coils were lined inside. The evaporator was designed and immersed in water contained in the compartment of the refrigeration unit. The system is charged with R124a as the working fluid and connected to electric supply for test-run. Two pipes of a specified length were connected into the refrigeration unit. One of the pipes serves as the suction line while the other serves as the returning line. During the course of the operation, chill water from the refrigeration unit is channeled through the suction line with the help of pump and is made to pass into coils of pipes arranged inside the fan unit. An axial fan is made to blow over coils of pipes arranged inside the fan unit carrying chilled water from the refrigeration unit and thus the cooling effect is directed to the outside environment through a duct. The water was made to be in circulation through the suction and returning line with the help of water pump attached to the suction line.

Every other component such as compressor, condenser, expansion valve, thermostat, pressure gauge and digital thermometer were predesigned and were bought based on the estimated heat load and were fixed. During the course of the experiment, the temperature and pressure of the compressor, condenser and evaporator were measured with the aid of pressure gauge and digital thermometer fixed at the inlet and exit of each of the aforementioned components. The system was designed and run for a period of time, then at an interval of time readings were taken from each sensors location. During experimentation on the system, constant supply of electric power was ensured by using a generator.

Figure 3 shows the p-h diagram of the refrigeration system

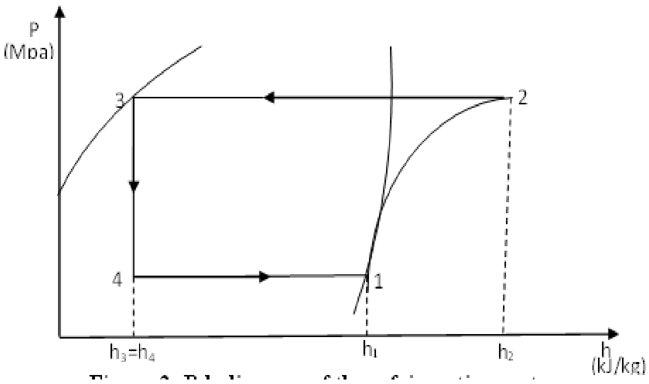

Figure 3: P-h diagram of the refrigeration system

Figure 4 shows the T-S diagram of the refrigeration system

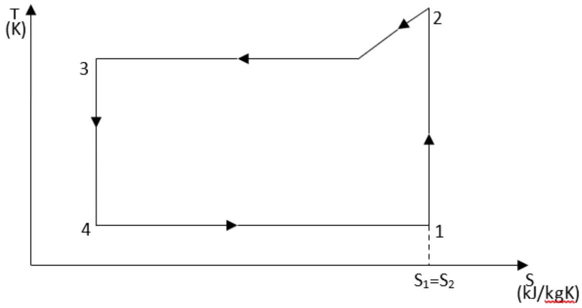

Figure 4: T-S diagram of the refrigeration system

Figure 5 shows the schematic illustration of the air conditioner using water refrigerant.

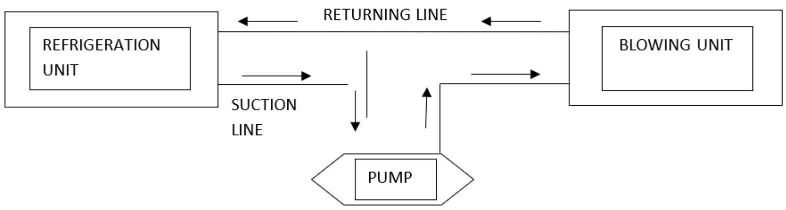

Figure 5: Schematic illustration of Air conditioner using water as secondary refrigerant

involved, in investigating the performance of an air conditioner using water as secondary refrigerant in the blowing unit and also investigation of R134a as a replacement for freon R12 which was as the primary refrigerant in the refrigeration unit. R134a has zero ozone depleting potential and a bit high global warming potential. The experimental refrigeration house with a blowing unit was developed with the joints specially welded to avoid leakages. The system was designed taking into consideration, the following assumptions: (a) steady state operation; (b) no pressure loss through pipelines, that is, pressure changes only through the compressor and the capillary tube; (c) heat losses or heat gains from or to the system are neglected. Some important performance characteristics like operating pressure, refrigeration capacity, coefficient of performance (COP) and compressor discharge temperature were considered.

Cooling Load Estimation

The followings are the loads that were estimated;

1. Transmission load
2. Internal load; (machines, people and lighting)
3. Equipment load
4. Infiltration load
5. Factor of safety

Estimation of transmission load;

Dimensions of the room are 5m long, 4m wide and 3m high.

The ambient air is 35 ℃ at 50% RH, the internal air is 10℃ at 75% RH

U value for the walls (hollow blocks) is 0.34 W/m2K, 0.13 W/m2K for the floor, 1.82 W/m2K for the door and for the roof is 0.28 W/m2K

The floor temperature is 16 ℃

Using;

$$Q = \frac{(U \times A \times \Delta T \times time)kWh}{1000} \qquad 1$$

Where;

Q is heat load (kWh)

U is heat transfer coefficient

A is surface area of walls, roof, floor and door

ΔT is change in temperature between the outdoor and the indoor temperature = 25 °C

$$Q_w = \frac{(U \times A \times \Delta T \times time)kWh}{1000} \quad 2$$

$$Q_r = \frac{(U \times A \times \Delta T \times time)kWh}{1000} \quad 3$$

$$Q_f = \frac{(U \times A \times \Delta T \times time)kWh}{1000} \quad 4$$

$$Q_d = \frac{(U \times A \times \Delta T \times time)kWh}{1000} \quad 5$$

Estimation of internal load;

a) Internal load – electrical gadget

$$Q = \frac{machine \times time \times wattage}{1000} \quad 6$$

$$Q_r = \frac{machine \times time \times wattage}{1000} \quad 7$$

$$Q_c = \frac{machine \times time \times wattage}{1000} \quad 8$$

$$Q_t = \frac{machine \times time \times wattage}{1000} \quad 9$$

$$Q_{rs} = \frac{machine \times time \times wattage}{1000} \quad = \quad 10$$

Internal heat load – people

It is assumed that one person working for half an hour and emits 100W for the purpose of this experiment.

$$Q_p = \frac{people \times time \times heat}{1000} \quad 11$$

Internal heat load – lighting

$$Q_L = \frac{lamp \times time \times wattage}{1000} \quad 12$$

Estimation of equipment load – fan motor

$$Q_F = \frac{fan \times time \times wattage}{1000} \quad 13$$

Estimation of infiltration load;

This is the heat load from air infiltration due to opening and closing of the entrance door. It is estimated using;

$$Q_{inf} = \frac{changes \times volume \times energy \times (temp\ out - temp\ in)}{3600} \quad 14$$

Where;

Changes is number of volume changes per day

Volume is the volume of the room

Energy is energy per cubic meter per degree Celsius

Temp out is air temperature outside

Temp in is air temperature inside

3600 is to convert from kJ to kWh

It is estimated that there were 20 volume air changes per day due to the door opening, the volume was calculated at 60m^3 each cubic of new air provides 2 kJ/°C, the air outside is 35 °C and the air inside is 10 °C

$$Q_{inf} = \frac{changes \times volume \times energy \times (temp\ out - temp\ in)}{3600} \quad 15$$

Since the system was operated for half of an hour, therefore Q_{inf} = 0.35kWh

Total cooling load

This is the summation of all the individual's cooling loads calculated;

Transmission load = 0.4139 kWh

Internal load = 0.2600 kWh

Equipment load = 0.5595 kWh

Infiltration load = 0.3500 kWh

Total = 1.5834 kWh

Factor of safety

This is applied so as to account for errors and variation from design. For the purpose of this design 20% was considered.

Therefore, the total cooling load was multiplied by 1.2

Total cooling load = 1.5834 kWh * 1.2 = 1.9001 kWh

Therefore, the design of this system was centered on achieving Refrigeration Capacity Q_{Ref} to handle 1.9001 kWh load.

Determination of heat load

Heat permeates and leaves the refrigerating unit via different means. In this project work, the heat load involved is subdivided into three different categories, namely;

i. Heat conducted through the walls of the refrigerating space
ii. Product heat load
iii. Service load

Heat conducted through the walls of the refrigerating/cooling space;

Heat conducted through the walls of the evaporator is dependent on the overall coefficient of heat transfer, surface area and temperature difference between the inside and the outside box. In this design the following operations were performed;

$$External\ dimention = length \times breadth \times height = 0.48 \times 0.48 \times 0.33 = 0.076m^3 \quad 16$$

$$Internal\ dimention = length \times breadth \times height = 0.38 \times 0.38 \times 0.23 = 0.033m^3 \quad 17$$

$$A_{ins} = \{(width \times breadth) + (breadth \times height) + (breadth \times width)\} \times 2 \quad 18$$

$$A_{ins} = \{(0.48 \times 0.38) + (0.38 \times 0.23) + (0.38 \times 0.48)\} \times 2 = 0.9044m^3$$

The rate of heat conducted through the walls of the refrigerated space $q_{conduct}$ is estimated as follow;

$$q_{conduct} = U \times A \times \Delta T \quad 19$$

Where;

U is overall heat transfer coefficient

A is surface area of the insulator

ΔT is change in temperature

$$\frac{1}{U} = \frac{1}{h_i} + \frac{x_1}{K_1} + \frac{x_2}{K_2} + \frac{x_3}{K_3} \dots \dots \dots \frac{x_n}{K_n} + \frac{1}{h_0} \quad 20$$

Where,

h_i is inside convection coefficient = 11.2W/mK

h_o is outside convection coefficient = 23.9 W/mK

x is thickness of the insulator = 0.05m = 0.05m

K is thermal conductivity of the insulator = 0.022 W/mK

U = 0.4160

But $q_{conduct} = U \times A \times \Delta T$

The quantity of heat conducted (Q_{cond}) through the walls of the evaporator in half an hour of steady operation is;

$$Q_{cond} = q_{conduct} \times t \quad 21$$

Where;

Q_{cond} is heat transfer by conduction

t is time in seconds = (30 × 60) seconds = 1800 sec

Product heat load

In order to estimate the product heat load, the capacity of the cooling chamber was considered and hence the mass water it contained was estimated

Let; C_{box} be capacity of the cooling box

$$C_{box} = H_i \times B_i \times W_i \quad 22$$

Where; H_i, B_i and W_i are the inner height, inner breadth and inner width of the cooling box and the values are; 0,38m, 0.38m and 0.23m respectively.

$$Q_{prod} = M_w \times C_w \times \Delta T \quad 23$$

Where;

Q_{prod} is product heat load

M_w is mass of water = 33.212kg

C_w is specific heat capacity of water =4.187kJ/kgK

Service Load

This was assumed to be equal to five percent of the heat load from the two other sources Q_{cond} and Q_{prod}

Let Q_{serv} = service load

$Q_{serv} = (Q_{cond} + Q_{prod}) \times 5\%$ 24

Total heat load (Q_{total})

$Q_{total} = Q_{cond} + Q_{prod} + Q_{serv}$ 25

Therefore, refrigeration unit is rated by the amount of heat it can remove within a time frame. Taking the time to absorb the above heat load to be 30mins.

Refrigeration capacity Q_{Ref} for the system was estimated as;

$$Q_{Ref} = \frac{Q_{Total}}{30 \times 60}$$ 26

Determination of the system operating conditions

Refrigerant = r134a

T_{Evap} = 10 ℃ = 273K

T_{Cond} = 42 ℃ = 315K

Refrigerating effect, $R_e = h_1 - h_4$ 27

$$Q_{Ref} = \dot{m} \times R_e$$ 28

Work done by the compressor, Wc

$Wc = h_2 - h_1$ 29

Compressor power, Pc

$Pc = \dot{m}(h_2 - h_1)$ 30

From the result above (Pc), compressor size was selected such that its relative output power should be able to carry out double of the required heat load. Therefore, a 1hp compressor was selected for the refrigeration unit for effective and smooth operation.

Heat rejected by the condenser; Q_c is given by;

$Q_c = \dot{m} \times (h_2 - h_3)$ 31

Determination of coefficient of performance COP

$$COP = \frac{Heat\ absorbed\ from\ evaporator}{Compressor\ work} = \frac{R_e}{W_c}$$ 32

$$COP = \frac{95.33}{15.95} = 5.98$$

Determination of efficiency;

$$\eta = \frac{COP}{COP_{Ideal}}$$ 33

where;

η = Efficiency

COP = 5.98

COP_{ideal} = ?

Assuming Carnot cycle, the coefficient of performance COP_{ideal} is given by;

$$COP_{Ideal} = \frac{T_E}{T_C - T_E}$$ 34

$$\eta = \frac{5.98}{8.84} * 100\% = 67.65\%$$

Design of the Evaporator

Determination of the total length of the evaporator tube.

Using;

$$L = \frac{A}{\pi \times D}$$ 35

Where;

L = total length of tube

π = 3.142

A = Area

D = diameter of the tube

To estimate the Area; Using;

$$Q_{Ref} = U \times A \times \Delta T$$ 36

Where;

Q_{Ref} = 2.038 kW
U = Overall heat transfer coefficient
A = surface through which heat is being transferred
ΔT = change in temperature between inside and outside of evaporator = 315K – 283K = 32K
To estimate the overall heat transfer coefficient;

$$\frac{1}{U} = \frac{1}{h_i} + \frac{x_1}{K_1} + \frac{x_2}{K_2} + \frac{x_3}{K_3} \dots \dots \dots \frac{x_n}{K_n} + \frac{1}{h_0} \quad 37$$

Where;
x is thickness of the evaporator tube = 0.001m
K is thermal conductivity of the insulator = 0.022 W/mK
h_i is inside convection coefficient = 0.088 kW/m^{2}K
h_o is outside convection coefficient = 0.097 kW/m^{2}K
U is 0.0460kW/m^{2}K
The total length of the evaporator tube was determined to be 3.7 m

Design of the condenser

Heat rejected by the condenser, Q_c = 2.3703 kW
Volumetric flow rate of the liquid refrigerant, V

$$V = \frac{\dot{m}}{\rho_r} \quad 38$$

Where;
$\dot{m}$ is mass flow rate of the refrigerant = 0.0213 kg/s
ρ_r is density of the refrigerant = 4.25 kg/m^3
Therefore;

Inner diameter of the condenser tube is calculated using;

$$D = \sqrt{\frac{4 \times A}{\pi}} \quad 39$$

Therefore, a tube with inner diameter of 9.54mm equivalent to (3/8)″ was selected for the design

Fabrication and testing of the air conditional

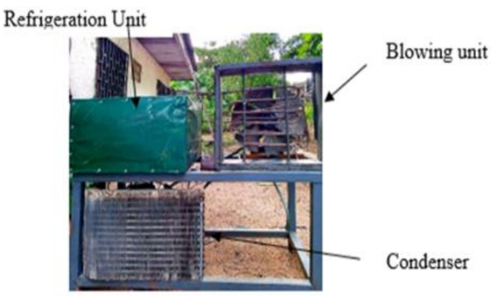

Plate 1: Front elevation of the machine

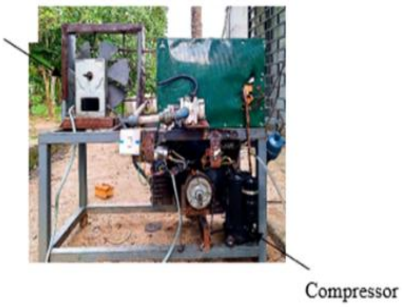

Plate 2: Back elevation of the machine

Plate 3: Top view of the machine

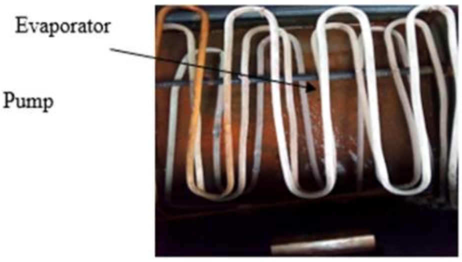

Plate 4: Chilling process of the evaporator

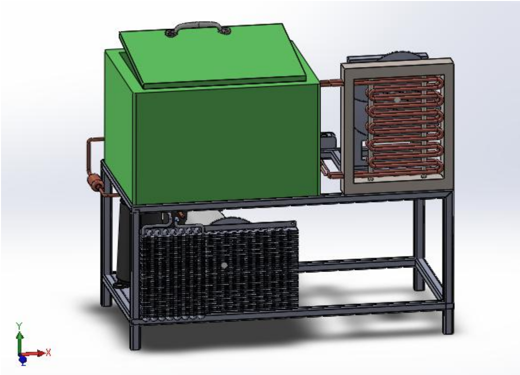

Plate 1: the front elevation of the machine

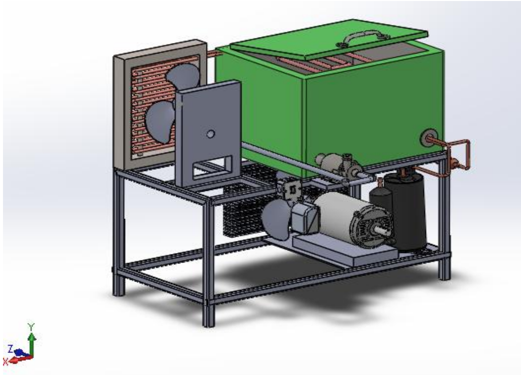

Plate 2: the back elevation of the machine

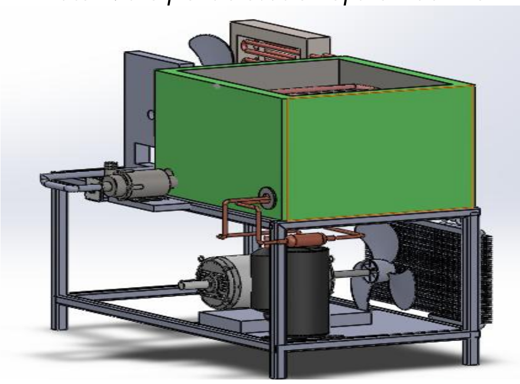

Plate 3: the side view (left) of the machine

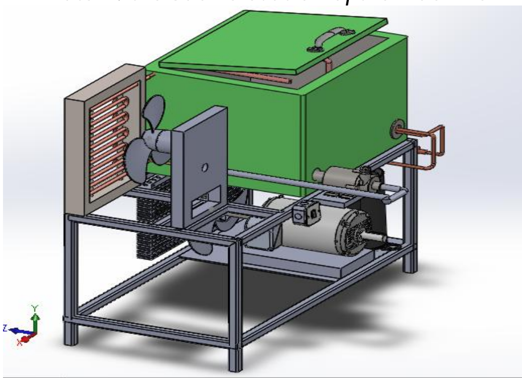

Plate 4: the side view (right) of the machine

3. Results and Discussion

From the result obtained during the course of the experiment, the refrigerating effect (Re), coefficient of performance (COP) and the overall efficiency (η) were all determined, analyzed and discussed as follows: shown in Figure 6-8 when the evaporator temperature increases from 10℃ to 26℃ at an interval of 4℃ keeping all other parameter constant, the coefficient of performance increases from 5.98 to 7.10 to 8.61 to 10.74 to 13.96; the refrigerating effect increases from 95.33kJ/kg to 97.54kJ/kg to 99.70kJ/kg to 101.80kJ/kg to 103.84kJ/kg and overall efficiency (ηwhole) increases from 67.65% to 69.27% to 70.98% to 72.81% to 74.69%.

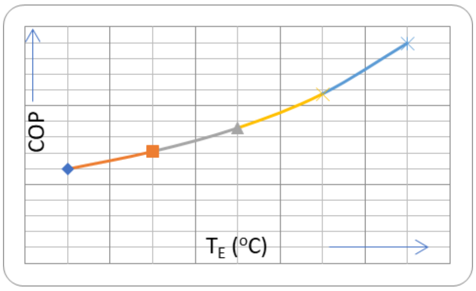

Figure 6: Effect of variation in evaporator temperature on COP

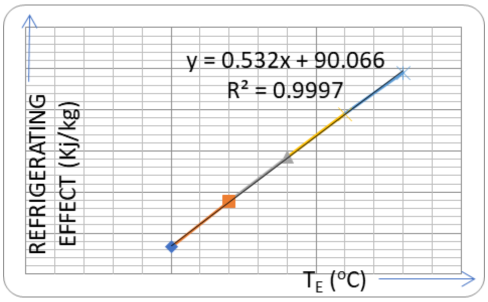

Figure 7: Effect of variation in evaporator temperature on Refrigerating effect

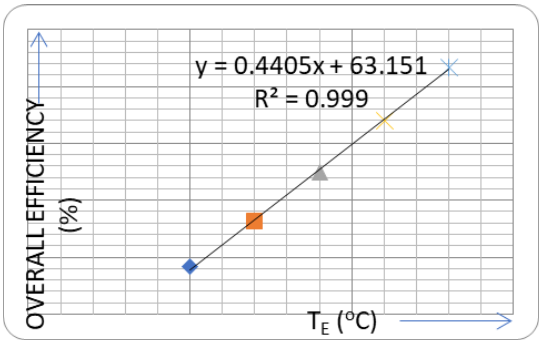

Figure 8: Effect of variation in evaporator temperature on overall efficiency

As shown in Figure 9-11, the condenser temperature was varied from 42 ℃ to 48 ℃ at an interval of 2 ℃, the coefficient of performance decreases from 5.98 to 5.83 to 5.69 to 5.58, the refrigerating effect decreases from 95.33kJ/kg to 93.11 kJ/kg to 90.87 kJ/kg to 88.58 kJ/kg and the overall efficiency of the system decreases from 67.65% to 66.04% to 64.22% to 62.55%.

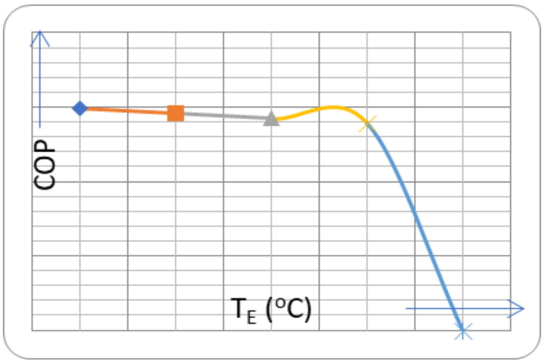

Figure 9: Effect of variation in condenser temperature on COP

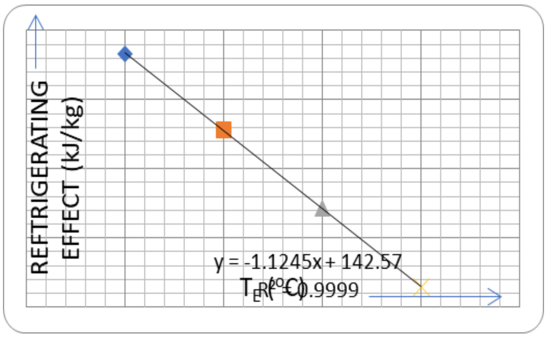

Figure 10: Effect of variation in condenser temperature on Refrigerating effect

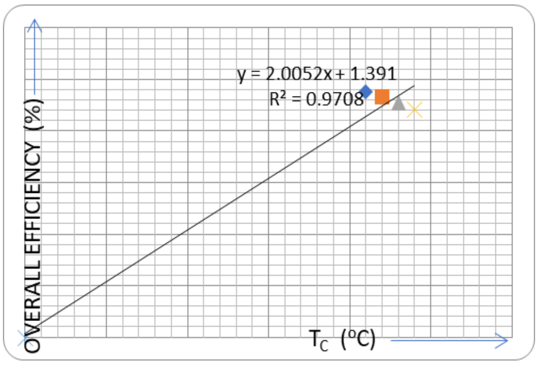

Figure 11: Effect of variation in condenser temperature on overall efficiency

ITEM NO.	PART NAME	DESCRIPTION	QTY.
1	Welded frame	Mild steel	1
2	Condenser		1
3	Refrigeration box	Sheet metal	1
4	Compressor and accumulator	1HP	1
5	Evaporator		1
6	Fan motor		1
7	switch-1-pole-2-way_asm	plastics	1
8	fan blade	plastics	2
9	Water pump	0.25HP	1
10	blowing unit chiller pipe	Brass	1
11	Drier		1
12	Extension pipe	Brass and PVC	5
13	Refrigeration unit box lid	sheet metal	1
14	lid handle	Aluminium	1
15	connector	PVC	1

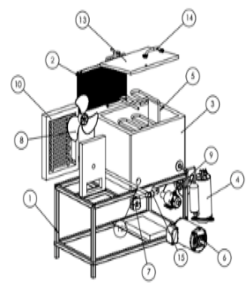

Figure 12: the exploded view of the machine

4. Conclusion

The result obtained from the various tests depicts effectiveness of the machine and the design goal achieved within the envisaged time frame. The result reveal that the designed machine exhibit a very impressive transformation capacity compared with some other conventional air conditioner especially in an area where much heat is generated such as the electrical control room of Light Section Mill of ASCL and where large volume of cooling is required. The machine was designed in such a way that the refrigerating unit can be placed at a distance from the blowing unit dependent on the capacity of the pump. The machine can be dismantled and assembled for ease of services and repairs with a little technical knowhow.

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