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Design, Fabrication and Performance Evaluation of a Micro-Absorption Refrigerator

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ABSTRACT

Developments in absorption cooling technology present an opportunity to achieve significant improvements on micro-scale to buildings, cooling, heating and power systems for residential and light commercial buildings. Their resultant effects are effective, energy efficient and economical. This study therefore contributes an important knowledge and method in the development, fabrication and application of an absorption refrigerator as a better alternative to the commonly used compressor refrigerators. In its embodiment, the work focuses on the design and fabrication of the absorption chiller system with low or no vibration since there are virtually no moving parts. Also, it dovetailed into the selection of a suitable refrigerant that is economically friendly in order to reduce or eliminate its ozone depleting effect. Consequently, the design was fabricated using adapted locally sourced materials. This is to encourage local ingenuity and to reduce cost of production comparable to already made custom-imported ones. It is designed to be simple, handy and readily available to be used by anyone in case of malfunctioning and for easy relocation. Though, the main limitation of the system fabricated is the long time it uses to achieve cooling, the performance of the machine generally is very efficient as its calculated coefficient of performance (C.O.P) is 1.21, which compared favourably well with the literature value of 1.00-2.00. Also, the total cost including an over-head of 30% of the machine was estimated at forty-one thousand, two hundred and fifty-nine (N41,259.40) naira, forty kobo only based on current price structure compared to an equivalent custom-made-imported type estimated at between sixty to seventy thousand (N60,000.00 to N70,000.00) naira. Hence, the machine is affordable to all, and is highly recommended for local entrepreneurs for mass production because of its cost effectiveness, simplicity and availability of spare parts.

Keywords: *Micro-absorption chiller, cost-effectiveness, energy efficient and economical, adapted locally sourced materials, encouragement of local ingenuity, simplicity and availability.*

NOMENCLATURE

CFC = Chlorofluorocarbon
HCFC = Hydrochlorofluorocarbon
HFC = Hydrofluorocarbon
LPG = Liquified Petroleum Gas
C.O.P. = Coefficient of Performance (TR)
TR = Tonnes of refrigeration
NH_3/H_2O = Ammonia/water solution (refrigerant)
Pcs = Pieces
h_1, h_2 = Specific enthalpies (KJ/Kg)
h_3, h_4 = Superheated enthalpies (KJ/Kg)
$T_1 = T_4$ = Initial temperatures (^oC or ^oK)
$T_2 = T_3$ = Final temperatures (^oC or ^oK)
K = Thermal conductivity (W/mK)
μ = Dynamic viscosity (Kg/ms)
κ (Small kappa) = Kinematic viscosity (Kg/ms)
CV = V_n = Cabinet volume (m^3)
I_t = Insulation thickness (m)
C_C = Condenser capacity (TR)
C_E = Evaporator capacity (KJ)
V = Volume flow rate (m^3/Kg)
ν (Nu) = Specific volume (m^3)

1. INTRODUCTION

Absorption chillers are thermally driven chillers or refrigerators using a liquid refrigerant/sorbent solution and a heat source to provide cooling [1]. They provide cooling to buildings by using heat. Also, they do not only use energy than conventional equipment (simple vapour compression refrigerators), but they also cool buildings without the use of ozone depleting chlorofluorocarbons (CFC). Unlike conventional electric chillers which use mechanical energy in a vapour compression process to provide refrigeration, absorption chillers primarily use heat energy with unlimited mechanical energy for pumping. These, can be powered by natural gas, steam, or waste heat. They also transfer thermal energy from the heat source to the heat sink through an absorbent fluid and a refrigerant [2, 3].

Conversely, an absorption chiller/refrigerator as [4] stated, is a refrigerator that uses a heat source (such as solar, kerosene-fueled flame, waste heat from factories or district heating systems) to provide the energy needed to drive the cooling system. It is a popular alternative to regular compressor refrigerators where electricity is unreliable, costly, or unavailable, where noise from the compressor is problematic, or where surplus heat is available (such as from turbine exhausts or industrial processes or from solar plants, etc). It uses a heat source to provide the energy needed to drive the cooling process.

An absorption chiller/refrigerator which works on absorption principle does not have a compressor and any moving parts. Hence, it is very quiet in operation [5]. Here, instead of having a compressor which compresses the low liquid refrigerant to a high temperature regime, it uses heat to propel the refrigeration cycle instead. The heat is generated by either using a gas (propane, Liquefied Petroleum Gas (LPG) or natural gas, etc), kerosene fuelled flame (which provides the energy needed) to drive the cooling system or by the use of electricity to power the cooling system for operation.

Two main types of absorption chillers exist. The first is the gas chiller used in portable applications; e.g. motor horns, boats and remote locations without electricity; and the second, the electric absorption chiller. This is employed where a very quiet refrigerator is desirable, hotel rooms, and cold rooms [2].

Large industrial chillers and air conditioners are built using this principle. They are very economical where a source of waste heat is present and ecologically favourable since they do not need vast quantities of electricity like compressor driven refrigerators. The Absorption refrigerators powered by heat from combustion of LPG or electricity are often used for food storage in recreational vehicles. This absorption system uses a refrigerant with very low boiling point (less than 0˚F/-18˚C) [3]. When this refrigerant evaporates (boils), it takes some heat away with it, providing the cooling effect needed.

The major differences between a compression refrigerator and an absorption refrigerator are that in the former, the refrigerant is changed from gas back to a liquid after being compressed mechanically so that the cycle repeats itself, while in the latter, during absorption, the gas changes back into liquid using heat energy. Hence, the vapour compression refrigerator uses heat energy to change the condition of the refrigerant from the evaporator as the vapour absorption refrigerator utilizes only heat energy to change the condition of the refrigerant from the evaporator. Also, in the vapour absorption type of refrigerator, the compressor is replaced by an absorber, a pump, a generator and a pressure reducing valve, respectively [5]. These components in vapour absorption system perform the same function as that of a compressor in vapour compression system. The other difference also lies in the type of refrigerant used. Compressor refrigerators typically use an HCFC (Hydro chlorofluorocarbon) or HFC (hydrofluorocarbon), while absorption refrigerators use ammonia or water [3].

Absorption chillers come in two commercially available designs: single-effect and double-effect. The single-effect machine provides a thermal coefficient of performance (C.O.P.) of 0.7, while the double-effect machine provides about 40% more in efficiency, but requires a higher grade of thermal input [6]. In single-effect absorption machine, all condensing heat cools and condenses in the condenser, from where it is released to the cooling water, while a double effect machine adopts a higher heat temperature generator.

The performance of an absorption chiller is described in terms of its C.O.P. given as the ratio of heat extracted in the refrigerator to the work done on the refrigerant which invariably could be taken as the theoretical C.O.P. [5].

The schematic of the working principle of an absorption chiller is as represented in Figure 1.

2. REVIEW OF RELATED LITERATURES

The use of ice to refrigerate and thus preserve food goes back to prehistoric times [7, 8]. Through the ages, the seasonal harvesting of snow and ice was a regular practice of most of the ancient cultures. Ice and snow were stored in caves or dugouts lined with straw or other insulating materials. However, it was not until the middle of the 20th century after many modifications and consolidated researches in that respect [9, 10, 11, 12, 13, 14] that refrigeration units were designed for installation on trucks or lorries. Refrigerated vehicles hitherto were used to transport perishable goods, such as frozen foods, fruits and vegetables, and temperature-sensitive chemicals. Most modern refrigerators keep the temperature between -40 and 20^{o}C, and have a maximum payload of around 24,000Kg gross weight in Europe [15].

With the invention of synthetic refrigerants based mostly on a CFC chemical, safer refrigerators were possible for home and consumer use. Freon, a trademark of the Dupont Corporation refers to these CFCs, which later was overtaken by the advent of HCFC and HFC refrigerants developed in the late 1920s. These refrigerants were considered at the time to be less harmful than the commonly used refrigerants of the time, including methyl formate, ammonia, methyl chloride, and SO_2. The intent was to provide refrigeration equipment for home use without danger. These CFC refrigerants answered that need. In the 1970s, though the compounds were found to be reacting with atmospheric ozone, an important protection against solar ultraviolet radiation, and their use as a refrigerant worldwide was curtailed in the Montreal Protocol of 1987 [15].

On application, the most widely used current applications of refrigeration probably are for air conditioning of private homes and public buildings, and refrigerating foodstuffs in homes, restaurants and large storage warehouses. The use of refrigerators in kitchens for storing fruits and vegetables has allowed adding fresh salads to the modern diet year round, and storing fish and meats safely for long periods. Also, dairy products are constantly in need of refrigeration, and it was only discovered in the past few decades that eggs needed to be refrigerated during shipment rather than waiting to be refrigerated after arrival at the grocery store. Meats, poultry and fish must be kept in climate-controlled environments before being sold. To keep fruits and vegetables edible longer, refrigerators/chillers are employed.

In this treatise "Design, fabrication and performance evaluation of a micro-absorption chiller for efficient refrigeration", ammonia/water (NH_3/H_2O) was utilized as the refrigerant. The research study was conceived to overcome, reduce and/or eliminate drastically the imminent problems associated with the use of CFCs as refrigerants in the compressor refrigerators since they possess high rate of ozone depletion factor and affinity which could be poisonous and dangerous to human health and consequently pollute the environment and atmosphere.

The significant advantages derivable in adopting and commercializing this design are enormous. First, the refrigerant (NH_3/H_2O) has high cooling and refrigerating effect. Second, the entire system is noiseless since it has no moving part. Also, it has no compressor but an absorber and hence, its operation is very quiet. Since it uses heat to propel the refrigeration cycle, its C.O.P. is very high. Further, as the pumped circulation of the sorbent solution on the absorption chiller replaces the compression of the refrigerant, the energy and work required by the pump are significantly less than required by the compressor.

However, the limitation of this system is the cost criterion which is the primary constraint on the widespread adoption of the unit. Also, the low thermal efficiency of a single-effect absorption system made the system non-competitive with readily available free waste heat. The absorption system only requires greater pump energy than an electric chiller. Consequently, the chiller requires larger cooling tower capacity than an electric chiller due to the large volume of water.

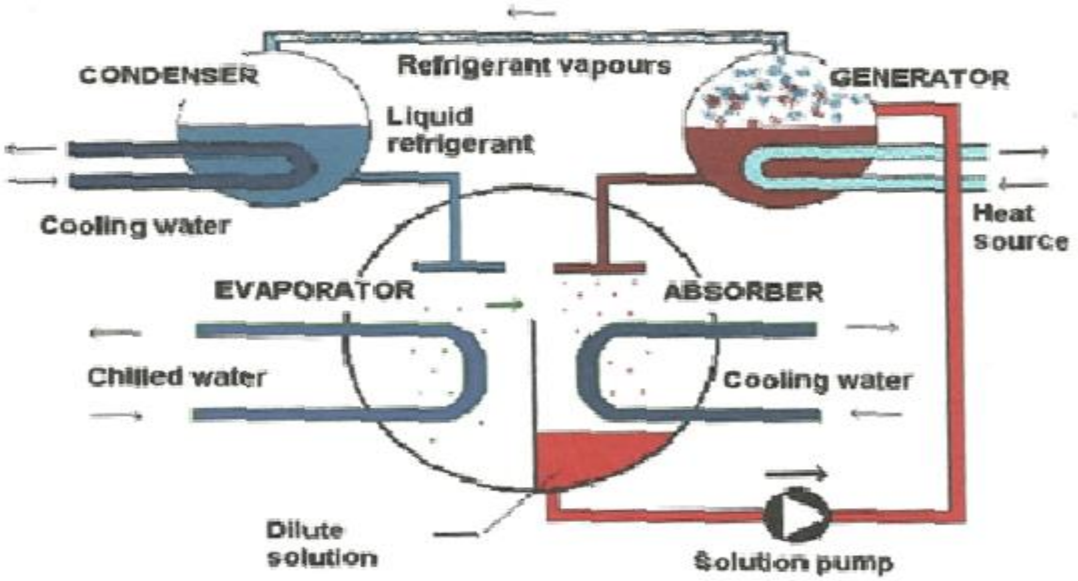

Figure 1: Working principle of an absorption chiller

3. MATERIALS AND METHODS

3.1 Problems Associated with Other Conventional Materials

The following are some of the problems being faced with when using other conventional materials such as copper, aluminum, HCFC or CFC refrigerants.

i. Reaction of NH_3/ H_2O refrigerant with copper leads to leakage of pipe.

ii. There is high production rate of component parts; and

iii. It leads to high cost of production, etc.

3.2 Material Selection

The first step taken in selecting materials from a variety of materials (aluminum, copper, steel, alloys, etc) was by carefully defining categorically the requirements of the desired components. This was followed by checking these requirements so as to make the selected materials readily available.

3.3 Materials Used

The major materials used are steel metal pipes (for the fabrication of some components like condenser, heat sink, evaporator, etc); wood (used for the construction of the body frame/casing); and NH_3/H_2O refrigerant as the refrigerant for the absorption refrigerator.

3.4 Fabrication Processes of the Absorption Chiller

The fabrication processes of this absorption chiller involve three stages only:

i. Sourcing and furnishing of the wood;

ii. Gas welding; and

iii. Electric arc welding processes of the steel materials, respectively.

The casing for the chiller was done using wood; and has the dimensions: length 45.5cm, height 50cm and breathe 30cm, respectively. From this dimensions, the wood was sawed, planned and polished. Afterwards, the various dimensions were brought together and joined using gum (top bond) and nails where needed. The backside was covered with a flat wood throughout for easy passage of the steel pipes.
Secondly, a flat metal sheet was brought out and cut to a size of length 8cm and width 4.5cm with a hole bored in its middle where 0.635cm (¼ inch) pipe with internal diameter of 0.6cm (6mm) was passed through the sheet metal to fabricate the heat sink. Consequently, an electrical welding method was used to tag the flat metal of about 44pcs to the pipe.

According to [5], the number of turns of the condenser affects the cooling effects of a refrigeration system. Thus, the maximum number of turns required for efficient refrigeration was estimated at 6 turns. Hence, the condenser was fabricated with a 1.27cm (½ inch) steel pipe of 1cm (10mm) internal diameter. This was made by bending the steel pipe with a spring pipe bender to the required shape and number of turns needed.

Also, the set-up was then welded to the charging aggregate containing 0.04Kg of NH_3 and 1.59cm (5/8 inch) pipe was passed through to the evaporator, while a 1.27cm (½ inch) pipe was welded electrically to the generator. The pipe carries the anhydrous NH_3 to the generator for heating, while the generator was covered with a fiber to prevent heat loss by convection. Some of the components which were not fabricated due to non feasibility of the fabricating process or non availability of the technical know-how were: the generator, evaporator, thermostat, charging aggregate and the heating filament, respectively which were procured from the market.

Finally, the whole set-up assembly of the micro-absorption refrigerator fabricated is as presented in Figure 2. Other configurationally views of the system as designed and fabricated are as depicted in Figures 3 (a-d), respectively.

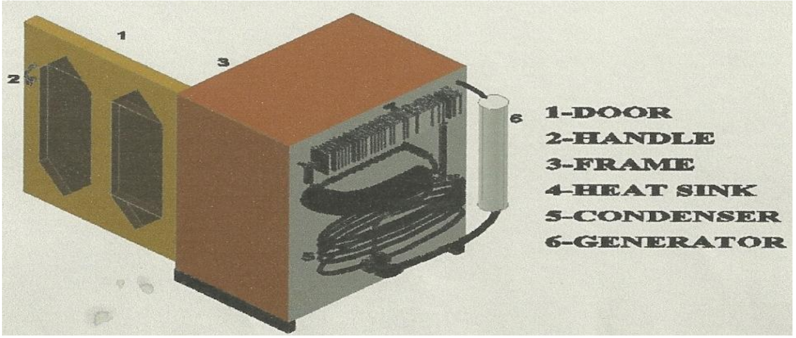

Figure 2: The whole set-up assembly of the micro-absorption refrigerator

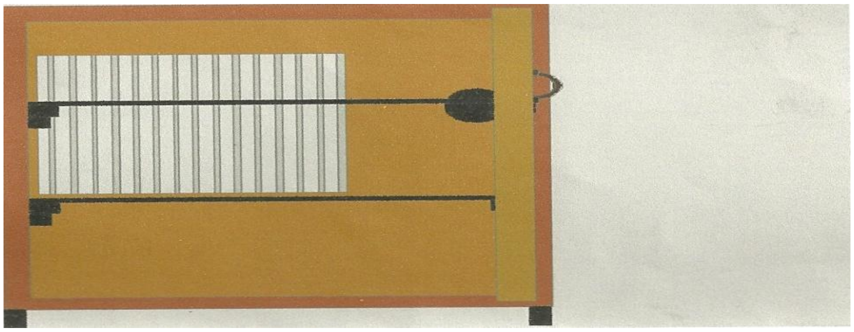

Figure 3 (a): Front view of the micro-absorption refrigerator

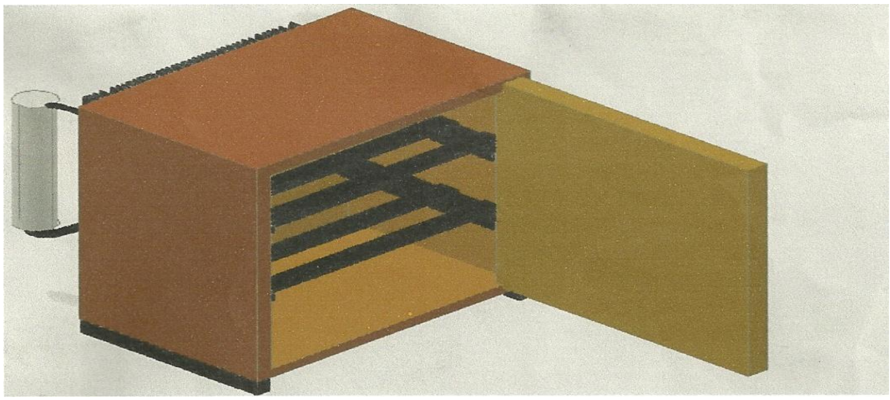

Figure 3 (b): Side view of the micro-absorption refrigerator

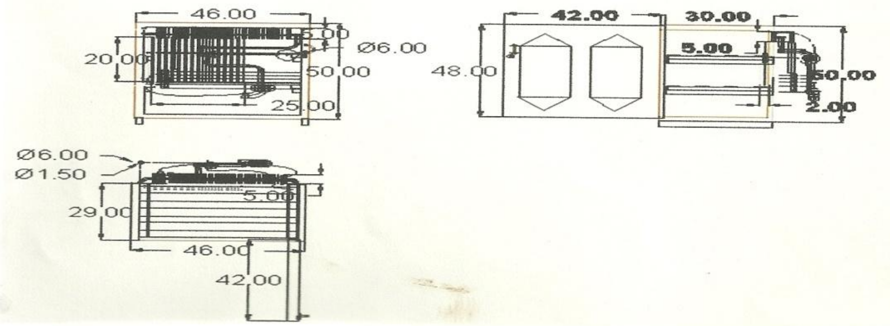

Figure 3 (c): Orthogonal view of the micro-absorption refrigerator (Dimensions in cm)

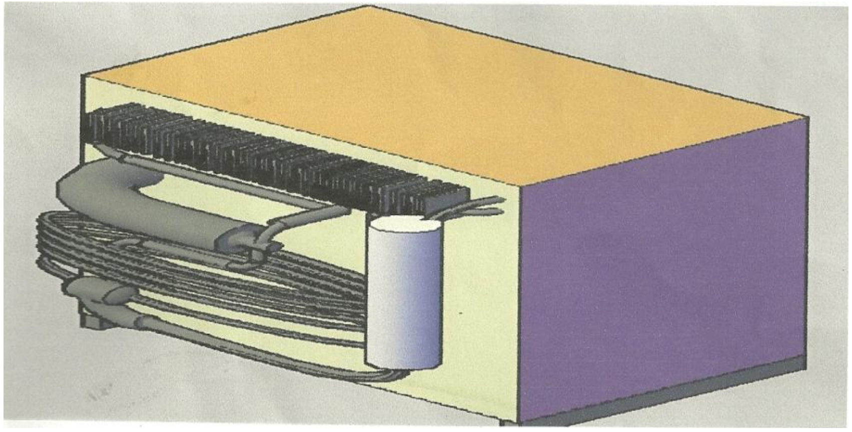

Figure 3 (d): Back view of the micro-absorption refrigerator

4. RESULTS AND DISCUSSIONS

4.1 Specifications of Parameters from the Psychrometric Chart

These involve all values gotten from the psychrometric chart and tables, respectively for NH_3 and specified thus:

Operational temperature range = -15°C to 35°C (258K to 308K); Boiling point = 33.3°C (306.3K); Critical temperature = 132.4°C (405.4K); Critical pressure = 112.8bar;

h_1 = 253.375KJ/Kg;
h_2 = 1458.56KJ/Kg;
h_3 = 1590.625KJ/Kg;
h_4 = 1711.36KJ/Kg;
h_1, h_2 = Specific enthalpies; h_3 and h_4 = Super-heated enthalpies;

T_1 = T_4 = 27°C (300K); T_2 = T_3 = 5°C (278K) [16, 17]; where:

T_1 = T_4 = Initial temperatures and T_2 = T_3 = Final temperatures.

Also, the thermal properties at room temperature and constant pressure are:

Thermal conductivity, K = 22.19W/mK; Dynamic viscosity, μ = 1.25Kg/ms;

$$\text{Kinematic viscosity, } \kappa = \frac{dynamic\ viscosity}{density} \qquad (1)$$

Density of NH_3 vapour = 0.73Kg/m^3; Ammonia molecular weight = 17.03g/ml; Ammonia melting point = -78°C (195K); Specific volume of ammonia vapour = 1.411m^3/Kg; and Specific heat capacity of NH_3 = 0.028KJ/mol, respectively.

4.2 Experimental Tests and Results

In actualizing the aims of this study, performance tests were carried out after the equipment had been assembled. The machine was put on and ten different temperature and pressure readings were taken starting from a standard room temperature of 27°C (300K) made within an interval of 30 minutes each. The experimental result is as shown in Table 1 and represented graphically on a temperature-pressure diagram in Figure 4, respectively. These were obtained through interpolation of values as presented here-under.

Table 1: Experimental results obtained

S/No	t (min)	t (hrs)	Temperature (°C)	Pressure (bar)	Specific enthalpy		Super- heated enthalpy (h_{f1})	Properties (h_{g1})
					h_f (KJ/Kg)	hg (KJ/Kg)		
1	0	0	27	10.670	308.55	1467.15	1606.65	1731.15
2	30	0.5	24	9.722	294.1	1465.2	1602.7	1726.3
3	60	1.0	20	8.570	275.1	1462.6	1597.2	1719.3
4	90	1.5	18	8.035	265.5	1461.1	1594.4	1715.9
5	120	2.0	16	7.529	256.0	1459.5	1591.7	1712.5
6	150	2.5	14	7.045	246.6	1457.8	1588.9	1709.1
7	180	3.0	12	6.585	237.2	1456.1	1586.0	1705.7
8	210	3.5	10	6.149	227.8	1454.3	1583.1	1702.2
9	240	4.0	8	5.736	218.5	1452.5	1580.1	1698.4
10	270	4.5	5	5.161	204.4	1449.55	1575.5	1693.05
Total					**2533.75**	**14585.80**	**15906.25**	**17113.60**

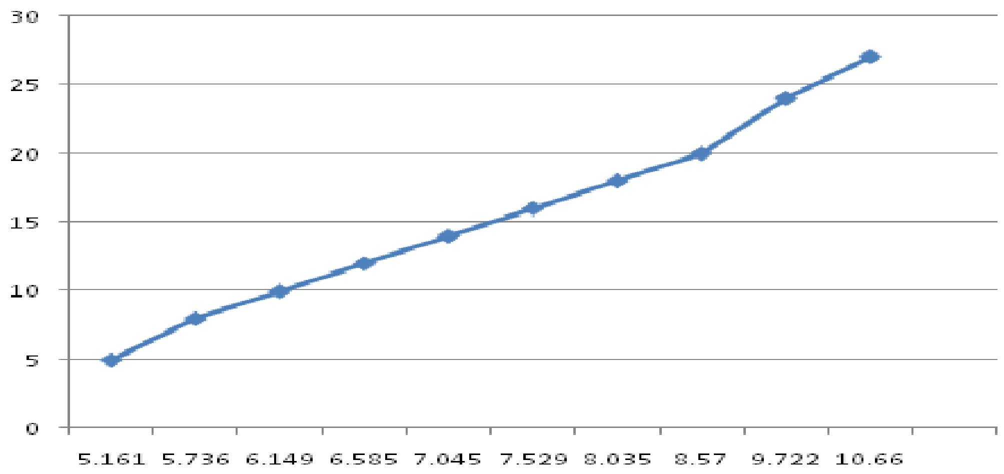

Figure 4: Graph of temperature against pressure

It is to be noted that the experiment could have been taken under different environmental conditions (such as: in a place under low temperature environment like where an air conditioner had already cooled the environment; and in an environment where there is an increased heat source like in a bakery with an oven in operation) in order to determine effectively the performance in terms of the C.O.P. of the machine for variation of experimental test data. But however, these were limited and hence not undertaken due to non-availability of regular power supply in MOUAU and its environ within the periods of the testing. Thus, these de-limited comparison which could have been made for the analysis to ascertain its performance at various environmental conditions.

4.2.1 Parametric Interpolation of Variables at 27^{o}C

Equation 2 was used for the interpolation to obtain the values of the parameters at 27^{o}C for a higher temperature region which were not on the properties tables. Thus:

$$\text{Interpolation equation} = \frac{C_1-B_1}{C_1-A_1} = \frac{C_2-B_2}{C_2-A_2} \qquad (2)$$

Hence:

(a) For the pressure at 27^{o}C:

$$\frac{28-27}{28-26} = \frac{10.99-x}{10.99-10.34} \Longrightarrow \frac{1}{2} = \frac{10.99-x}{0.65}$$

$0.65 = 2(10.99 - x) = 21.98-2x$
$2x = 21.98 – 0.65 = 21.33$
$\therefore$ Pressure, $x = 10.67$bar

(b) For specific enthalpy, h_f:

$$\frac{28-27}{28-26} = \frac{313.4-x}{313.4-303.7} \Longrightarrow \frac{1}{2} = \frac{313.4-x}{9.7}$$

$9.7 = 2(313.4 - x) = 626.8-2x$
$2x = 626.8 – 9.7 = 617.1$
$\therefore$ $x = 308.55$KJ/Kg = h_f

(c) For specific enthalpy, h_g:

$$\frac{28-27}{28-26} = \frac{1467.8-x}{1467.8-1466.5} \Longrightarrow \frac{1}{2} = \frac{1467.8-x}{1.3}$$

$1.3 = 2(1467.8 - x) = 2935.6-2x$
$2x = 2935.6 – 1.3 = 2934.3$
$\therefore$ $x = 1467.15$KJ/Kg = h_g

(d) For superheated enthalpy, h_{f1}:

$$\frac{28-27}{28-26} = \frac{1608.0-x}{1608.0-1605.3} \Longrightarrow \frac{1}{2} = \frac{1608.0-x}{2.7}$$

$2.7 = 2(1608.0 - x) = 3216.0-2x$
$2x = 3216.0 – 2.7 = 3213.3$
$\therefore$ $x = 1606.65$KJ/Kg = h_{f1}

(e) For superheated enthalpy, h_{g1}:

$$\frac{28-27}{28-26} = \frac{1732.7-x}{1732.7-1729.6} \Longrightarrow \frac{1}{2} = \frac{1732.7-x}{3.1}$$

$3.1 = 2(1732.7 - x) = 3465.4-2x$
$2x = 3465.4 – 3.1 = 3462.3$
$\therefore$ $x = 1731.15$KJ/Kg = h_{g1}

4.2.2 Parametric Interpolation of Variables at 5^{o}C

Similarly, the values of the parameters at 5^{o}C for a lower temperature region which were not on the properties tables are obtained thus:

(a) For the pressure at 5^{o}C:

$$\frac{6-5}{6-4} = \frac{5.346-x}{5.346-4.975} \Longrightarrow \frac{1}{2} = \frac{5.346-x}{0.371}$$
$0.371 = 2(5.346 - x) = 10.692 - 2x$
$2x = 10.692 - 0.371 = 10.321$
$\therefore$ Pressure, $x = 5.161$bar

(b) For specific enthalpy, h_{f2}:

$$\frac{6-5}{6-4} = \frac{209.1-x}{209.1-199.7} \Longrightarrow \frac{1}{2} = \frac{209.1-x}{9.4}$$

$9.4 = 2(209.1 - x) = 418.2 - 2x$
$2x = 418.2 - 9.4 = 408.8$
$\therefore$ $x = 204.4$KJ/Kg $= h_{f2}$

(c) For specific enthalpy, h_{g2}:

$$\frac{6-5}{6-4} = \frac{1577.0-x}{1577.0-1574.0} \Longrightarrow \frac{1}{2} = \frac{1577.0-x}{3}$$

$3 = 2(1577.0 - x) = 3154.0 - 2x$
$2x = 3154.0 - 3 = 3151.0$
$\therefore$ $x = 1575.5$KJ/Kg $= h_{g2}$

(d) For superheated enthalpy, h_{g3}:

$$\frac{6-5}{6-4} = \frac{1694.9-x}{1694.9-1691.2} \Longrightarrow \frac{1}{2} = \frac{1694.9-x}{3.7}$$

$3.7 = 2(1694.9 - x) = 3389.8 - 2x$
$2x = 3389.8 - 3.7 = 3386.1$
$\therefore$ $x = 1693.05$KJ/Kg $= h_{g3}$

Further, the values of the specific enthalpies and the superheated enthalpies, respectively were obtained by taken the average of each enthalpy; where: $h_{f1} = h_3$ and $h_{g1} = h_4$. This was done by adding each enthalpy and dividing them by 10 which is the number of experiments carried out; hence:

i. $h_f = h_1 = \frac{2533.75}{10} = 253.375$KJ/Kg
ii. $h_g = h_2 = \frac{14,585.8}{10} = 1458.58$KJ/Kg
iii. $h_{f1} = h_3 = \frac{15906.25}{10} = 1590.625$KJ/Kg
iv. $h_{g1} = h_4 = \frac{17113.6}{10} = 1711.36$KJ/Kg

4.2.3 Other Parameters Estimated

(a) Cabinet (chiller) casing:

The cabinet areas were calculated by considering both sides of the six faces of the walls. Hence:

Cabinet areas = (up and down) + (two opposite sides) + (other two opposite sides) (3a)

Mathematically:

$$A_n = (2WL) + (2WH) + (2LH) \text{ cm}^2$$

Or: $A_n = 2(WL + WH + LH)$ (3b)

Thus:

$$A_n = 2(30 \times 45.5 + 30 \times 50 + 45.5 \times 50)$$

$$A_n = 2(1365 + 1500 + 2275) = 2(5140)$$
$\therefore$ $A_n = 10280\text{cm}^2$ or 1.028m^2

(b) Cabinet volume, CV:

Based on the inside dimensions of the cabinet, the insulation thickness (I_t) on both sides of the six faces were not included in determining the volume. However, for this design, an insulation thickness of 2.3cm was utilized which was the thickness of the wood used for the chiller casing after sawing and planning. Hence, according to [18]:

$$V_n = [(L - 2I_t)\ x\ (W - 2I_t)\ x\ (H - 2I_t)] \quad (4)$$

$= [(45.5 - 2\ x\ 2.3)]\ x\ [(30 - 2\ x\ 2.3)]\ x\ [(50 - 2\ x\ 2.3 = 45.5-4.6x30-4.6x50-4.6 = 40.9\ x\ 25.4\ x$ 45.4

$\therefore$ $V_n = 47164.244\text{cm}^3$ or 0.047164244m^3
$\approx 0.0472\text{m}^3 = CV$

(c) Mass Flow Rate:

This is obtained from:

$$M = \frac{\textit{Refrigeration capacity of the system}}{\textit{Refrigerating effect of the refrigerant}} \quad (5a)$$

$$\Longrightarrow M = \frac{\textit{Cabinet volume}}{\textit{Refrigerating effect of the refrigerant}} \quad (5b)$$

Mathematically:

$$M = \frac{CV}{h_{fg}} = \frac{CV}{h_4 - h_1} \quad (5c)$$

Thus: $M = \frac{0.0472}{1711.36-253.375} = \frac{0.0472}{1457.985}$

$\therefore$ $M = 3.2373\ x\ 10^{-5}\ KJ^{-1}Kgm^3$

or $0.000032373 KJ^{-1}Kgm^3$

(d) Condenser Capacity:

It is the heat rejected by the refrigerant in unit time in the condenser. This is given as:

$$C_c = M(h_2 - h_3) \qquad (6)$$

Hence:

$C_c = 3.2373\ x\ 10^{-5}\ (1590.625 - 1458.58)$
$= 3.2373\ x\ 10^{-5}\ (132.045)$
$\therefore \quad C_c = 4.2747\ x\ 10^{-3}$TR
or 0.0042747TR (Tonnes of refrigeration).

(e) Refrigeration effect is the quantity of heat absorbed by a unit mass from the refrigerated space. It takes place at the evaporator. Here:

W = 0

$$\text{Thus: } Q = (h_4 - h_1) = h_{fg} \qquad (7)$$

$\therefore \quad Q = 1457.985$KJ

(f) Evaporator Capacity:

This is the capacity at which heat is removed from the refrigerated space. It is given as:

$$C_E = M(h_4 - h_1) \qquad (8)$$

Thus: $C_E = 3.2373\ x\ 10^{-5}\ (1457.985)$

$\therefore \quad C_E = 0.04720$KJ

(g) Volume flow rate (V): This is the amount of saturated vapour (m^3) produced when 0.04kg of refrigerant vapourized; which is dependent on the refrigerant, NH_3. This is determined as:

$$V = M\nu \qquad (9)$$

Thus: $V = 3.2373\ x\ 10^{-5}\ (1.411)$

$\therefore \quad V = 4.5678\ x\ 10^{-5} m^3/Kg$

or $0.000045678 m^3/Kg$

where: ν = Specific volume of ammonia as specified.

(h) Coefficient of performance (C.O.P.): This is used to measure the performance of the refrigeration system expressing its output to input ratio and given as:

$$\text{C.O.P} = \frac{h_4 - h_1}{h_2 - h_1} \qquad (10)$$

Hence: $\text{C.O.P.} = \frac{1711.36-253.375}{1458.58-253.375} = \frac{1457.985}{1205.205}$

$\therefore$ C.O.P. = 1.2097 ≈ 1.21

(i) Kinematic viscosity, κ: This is given as:

$$K = \frac{dynamic\ viscosity}{density} \qquad (11)$$

$\therefore \quad K = \frac{1.25Kg/ms}{0.73Kg/m^3} = 1.71233 m^2 S^{-1}$

(j) Work done by the generator, W: This is given as:

$$Q = MCdT = MC(T^1 - T^2) = W \qquad (12)$$

Thus: $Q = 3.2373\ x\ 10^{-5}\ x\ 0.028\ x\ (300 - 278)$
$= 3.2373\ x\ 10^{-5}\ x\ 0.028\ x\ 22$
$\therefore \quad Q = 1.99418\ x\ 10^{-5} J$ or $0.000019942\ J$ = W

4.3 Discussion of Results

The experimental results of the performance of the micro-absorption chiller test conducted show that the machine fabricated has a C.O.P. of 1.21. This conforms to the standard normal performance of a single-effect machine that produces a C.O.P. of about 1.00 to 2.00 [2, 3, 19]. The results defined the characteristics of the machine and showed that its performance is in line with the C.O.P. of all other single-effect refrigerators or chillers.

The machine was powered by a 250volts generator. These suggest that the produced absorption system has a good working condition in which temperature, pressure or any other environmental property cannot reduce its performance similar to already custom-made imported ones.

5. COST ANALYSIS AND EVALUATION OF THE MACHINE

Table 2 shows the cost implications of the materials used in the fabrication of the machine.

The labour cost is the hour-charge per day for the completion of the work. This implies the amount paid for the fabrication. The labour cost for the completion of this machine as evident in Table 2 was five thousand, five hundred (N5, 500.00) naira only. Also, the cost of the machine equals the summation of the cost of the materials and the labour cost, respectively. Hence, the total cost as inferred from the Table was estimated at thirty one thousand, seven hundred and thirty-eight (N31, 738.00) naira only. This amount represents the total cost for the production of this micro-absorption chiller. However, the amount excluded the cost of transportation and other miscellaneous expenses incurred. Based on these, an overhead cost of about 30% was estimated which brought the final cost to forty one thousand, two hundred and fifty-nine (N41, 259.40) naira, forty kobo only.

Table 2: Cost implications and analysis of the machine

S/No	Components		Specifications	Quantity	Cost (~~N~~)
1	Materials	Body (wood)	(50 x 40.5 x 30) (H x L x B) cm^3	1	3,800.00
2		Condenser (steel metal)	(1.27 x 27 x 10) (D x L x B) cm^3	1	2,500.00
3		Evaporator (Aluminium)	(29 x 25) cm^2	1	2,238.00
4		Heat sink (steel metal)	0.64 x 35 x 60) (H x L x B) cm^3	1	2,700.00
5		Generator	(35 x 7) 250 volts	1	4,500.00
6		Charging aggregate	0.4kg of ammonia gas	1	5,300.00
7		Thermostat		11	1,100.00
8		Paint	Black coloured oil paint	1	500.00
9		Wood sprang	Cream coloured	2	2,200.00
10		Fused plug	13Amp (250 volts)	2	50.00
11		Wire		3yards	300.000
12		Aluminium handle		1	150.00
13		Key lock		1	100.00
14		Connection box		1	100.00
15		Formica		1 yard	700.00
Sub-total (Materials)					**26, 238.00**
16	**Labour**				**5,500.00**
Total					**31,738.00**
Overhead/Grand total @ 30% factor					**41, 259.40**

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The design and fabrication of this micro absorption chiller was partly done using adapted locally sourced materials since some parts/components were not fabricated but procured from the market. The machine was designed to be handy, simple and used by any one, and at any place. It was designed to be simple in case of malfunctioning and for easy relocation.

The operation of the machine is electrical by plugging it to a power source. The main limitation of the system is the time it uses to cool. But generally, the performance of the machine is very efficient as its calculated C.O.P. was 1.21 which compared favourably well with the literature value of 1.00-2.00.

6.2 Recommendations

This machine was designed to reduce the impact of emission emanating using HCFCs or CFCs as refrigerants to the atmosphere and to preserve perishable goods. However, the system is limited to only electrical power source. Hence, it is recommended that other sources of powering the machine (solar, waste heat, etc) should be encouraged for further studies to improve its operation and performance. It is also proposed that high aluminum pipe materials should be used as the condenser. This will increase the capacity of the generator thus speeding up the heating process of the system.

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REFERENCES

[1] Swikipedia, *Absorption Chillers*. www.sustainable-buildings.org/wiki/index.php/Absorption_chillers.

[2] Grosse, A. (2010). *Introduction to Absorption Cooling Systems.* http://www.wikipedia.org/mk/absorption.

[3] Gramyd, E. (2005). *A Bjorn Palm Refrigerating Engineering,* Stockholm Royal Institute of Technology, Chapters 3 and 4.

[4] Wikipedia, *Absorption Refrigerator*. www.en.wikipedia.org/wiki/Absorption_refrigerator.

[5] Khurmi, R.S. and Gupta, J.K. (2005). *A Textbook of Refrigeration and Air- conditioning*, Reprint Edition, Printed by Rajendra Ravindra Printers and Published by Eurasia Publishing House (P) Ltd, New Delhi, India; pp.1-37.

[6] American Society of Heating, Refrigerating, and Air-conditioning Engineers: ASHRAE and International Institute of Ammonia Refrigeration: IIAR (2005). *Thermally-activated-absorption-chillers*; http://www.osha.gov/sltc/etolsammonia-refrigeration/receiving/storage:html; http://www.ecre.energy.gov/de/pdt; www.wikepedia/wiki/absorption_chiller.

[7] Wikipedia,*Refrigeration*; http://www.en.wikipedia.org/wiki/Refrigeration; http://www.marketequip.com/documents/history of refrigeration.pdf.

[8] Wikipedia,*Refrigeration*; http://www.en.wikipedia.org/wiki/Refrigeration; http://www.wvu.edu/~exten/infores/pubs/fypubs/136.wlg.pdf.

[9] Wikipedia, *The Advent of Mechanical Refrigeration Alters Daily Life and National Economies throughout the World-Science and its Times: 1800-1899*; Retrived: 2007-05-20; http://www.en.wikipedia.org/wiki/Refrigeration.

[10] Arora, R.C. *Mechanical Vapour Compression Refrigeration*, Refrigeration and Air-conditioning, New Delhi, India: PHI Learning, pp.3; ISBN 81-203-3915-0; http://www.en.wikipedia.org/wiki/Refrigeration.

[11] Wikipedia, *Cooling by Evaporation (Letter to John Lining)*, Benjamin Franklin, London, June 17, 1758; http://www.en.wikipedia.org/wiki/Refrigeration.

[12] Burstall, A.F. (1965). *A History of Mechanical Engineering*, The MIT Press; ISBN 0-262-52001-X; http://www.en.wikipedia.org/wiki/Refrigeration.

[13] Wikipedia, *Improved Process for the Artificial Production of Ice*; US Patent Office, Patent 8080, 1851; http://www.en.wikipedia.org/wiki/Refrigeration.

[14] Wikipedia, *J & E Hall International-History*; http://www.en.wikipedia.org/wiki/Refrigeration.

[15] Wikipedia, *Modern Marvels*; Retrieved 2007-05-20; http://www.en.wikipedia.org/wiki/Refrigeration.

[16] Avallone, E.A. and Baumeister III, T. (1997). *Psychrometric Chart and Tables for Some Liquid Refrigerants*, Marks' Standard Handbook for Mechanical Engineers, Tenth Edition International Editions, McGraw-Hills Publishers.

[17] Robert, P. (1996). American Society of Heating, Refrigerating and Air-conditioning Engineers' (ASHRAE) Hand Book.

[18] Ugwu, H.U. and Ogbonnaya, E.A. (May 2012). *Design and Adaptation of a Commercial Cold Storage Room for Umudike Community and Environs*, International Organization for Scientific Research (IOSR) Journal of Engineering, Vol.2, Issue 5, pp.1234-1250.

[19] Dorgan, C.B. and Anderson, O.E. (1995). *Application Guide for Absorption Cooling/Refrigeration using Recovered Heat*, Vol.7, pp.64; Published in 1995 by American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE), Atlanta, Georgia, USA.