IJARSCT

ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

Impact Factor: 7.301

Volume 3, Issue 3, December 2023

Performance Analysis of Atmospheric Water Extraction by Refrigerator Cum Air Conditioner

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Abstract: *India is blessed with warm and humid climatic conditions in most of its states containing huge amount of water in atmosphere which can fulfill the increasing water demands. Atmospheric water extraction is one of the technologies where fresh water is obtained from the ambient air by condensation. The atmospheric water extracting device is working on vapour compression refrigeration cycle. In this cycle the evaporator inlet temperature is maintained at a temperature lower than the dew point temperature of the atmospheric incoming air. Therefore, the moisture present in the air condenses over the coil and it will be collected. The amount of condensate depends on psychrometric conditions of incoming air. The present work concludes that atmospheric water extracting devices are most effective in hot and humid regions. when the humidity level in atmosphere is being 56%, 8.3ml/min water is extracted and when the humidity level in atmosphere is being 36%, 1.7ml/min water is extracted.*

Keywords: Vapour Compression, Refrigerator, Water extractor.

I. INTRODUCTION

India is blessed with warm and humid climatic conditions in most of its states containing huge amount of water in atmosphere which can fulfil the increasing water demands. Atmospheric water extraction is one of the technologies where fresh water is obtained from the ambient air by condensation. The atmospheric water extracting device is working on vapour compression refrigeration cycle. In this cycle the evaporator inlet temperature is maintained at a temperature lower than the dew point temperature of the atmospheric incoming air. Therefore, the moisture present in the air condenses over the coil and it will be collected. The amount of condensate depends on psychrometric conditions of incoming air. The present work concludes that atmospheric water extracting devices are most effective in hot and humid regions.

In our present project work, we want to condense the water vapour present in the unsaturated air. This is done by maintaining the evaporator temperature of the refrigeration cycle well below the dew point temperature of the incoming unsaturated atmospheric air. The atmospheric pressure, dry bulb temperature, relative humidity of the air present in the place where we are doing our project were observed. From those observations and by psychrometric chart dew point temperature of the air is found and it would be 18oC. The refrigerating effect required for achieving apparatus dew point temperature is calculated. Based on the refrigerating effect a fin made up of copper has been selected and kept inside the evaporator wherein outside unsaturated atmospheric air is made to flow by using a fan. The temperature of the incoming air would be around 32oC and when it is made to flow through that aluminium fins its temperature is getting reduced as the temperature of the aluminium fins is around 10oC (apparatus dew point temperature). As the apparatus dew point temperature (10oC) is well below the dew point temperature of the unsaturated incoming air (18oC) the water vapour present in the air condenses and it will be collected for further processing.

II. LITERATURE REVIEW

Experimental investigations of atmospheric water extraction device under different climatic conditions
Jatin Patel, Krunal Patel, Anurag Mudgal, Hitesh Panchal, Kishor Kumar Sadasivuni

DOI: 10.48175/IJARSCT-14341

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The critical investigation of atmospheric water extracting system was experimented in this paper. The test setup of AWE was integrated with a climate chamber to provide sufficient temperature and relative humidity to the inlet air stream to replicate different ambient conditions. The AWE system was tested under various ambient conditions replicated in the laboratory. The critical findings showed that the atmospheric water extraction rate was increased as the specific humidity of air increased. The average rate of water extraction was found in a range of 0.28 L/h for mild and dry condition to 1.78 L/h for humid and warm condition. The average power utilization was varied from 0.75kWh/L for humid and warm to 4.71 kWh/L dry and warm.

Condensate as a water source from vapor compression systems in hot and humid regions

Abdulghani A. Al-Farayedhi , Nasiru I. Ibrahim, P. Gandhidasan

The analytical and experimental results of the rate of condensate extraction from a 1.5ton split-type air conditioning systemin Dhahran, Saudi Arabia were presented. The experimental and analytical monthly amounts of condensate collected in kg/ton per CDD, respectively are 1.26 and 1.34 in June, 1.29 and 1.44 in July, 2.50 and 2.49 in August, and 2.33 and 2.51 in September with monthly averages of 2.00 and 1.95. The rate of condensate extraction from the system is mainly a function of the air inlet and outlet humidity ratios and temperatures. However, the effect of the humidity ratio is more significant. The trend of the condensate extraction variation generally follows the relative humidity variation. For any given relative humidity, the rate of condensate extraction increases approximately by 0.5 kg/h for every 5 °C increase in the inlet air temperature. The rate of change of condensate extraction with respect to the relative humidity is high at lower humidity and afterwards becomes lower at higher humidity. The analytical model predictions of the condensate agree well with the experimental results. The chemical analysis of the condensate indicates that the collected condensate can be used for human consumption after undergoing the required microbial processes and as an additional water source.

Performance investigation of atmospheric water harvesting systems

Farshid Bagheri, R Tu, Y Hwang and et all...

This paper presented a critical performance investigation of commercially available AWH systems. A new testbed was built that featured environmental chambers to mimic realistic operating conditions of different climates. A new testing procedure was introduced for assessing the performance of AWH systems following relevant ASHRAE and ANSI/AHRI standards. Three residential-size AWH units (nominal power of 1500W or less) were systematically tested in our lab under a variety of conditions including: warm and humid, mild and humid, cold and humid, warm and dry, mild and dry, cold and dry, and mild climates. The results showed that the water harvesting yield enhances by simultaneous increase of water content (ω) or dewpoint temperature (dewpoint) and a decrease of temperature. The average water harvesting rate varied in a range of 0.05 L/h for cold and humid to 0.65 L/h for warm and humid climates. The average energy consumption changed from 1.02 kWh/L for warm and humid to 6.23 kWh/L for cold and humid climates. In addition, an ideal AWH unit was defined as a machine capable of cooling the air stream down to a point close to but above the freezing temperature (~ 1 °C) to achieve the highest water harvesting rate at all climates. The comparisons showed an increase in the gaps between real and ideal water harvesting rates by changing from low humidity (water content) condition to high humidity condition. It denoted a higher potential of performance improvement in higher humidity areas through optimal design of AWH systems for those climates. The results also showed that: i) the considered AWH units failed to operate in cold-and-dry climate; and ii) the energy cost of AWH increased significantly in hot-and-dry conditions. A criterion, dewpoint > 2 °C, was established based on our experiment as a minimum climatic requirement for using AWH systems.

Direct estimation of absolute precipitable water in oceanic regions by GPS tracking of a coastal buoy

C. David Chadwell, Yehuda bock and et all…

We demonstrate that PW can be estimated directly using GPS tracking of an ocean surface platform 8 km from shore with 1-2 mm accuracy every 30 minutes. Within coastal regions, GPS data recorded at floating platforms can provide direct estimation of PW for inclusion into weather forecasting, calibration of space-based microwave radiometers and climate studies. Given that spiess et al. [1998] demonstrated centimeter-level positioning of a surface platform 150 km from shore it is likely PW can be retrieved at surface platforms in the open ocean[Chadwell, 1998; Cardellachetal., 2000]. Experiments are underway to test GPS recovery of PW at floating platforms 40, 150 and 500 km from shore reference sites.

III. REFRIGERATION SYSTEM

3.1 DOMESTIC REFRIGERATOR

The working principle of a domestic refrigerator is exactly the same as that of an air conditioner. A schematic diagram of the refrigerator is shown in figure.

Like the air conditioner, it also consists of the following four basic components:

(i) Evaporator
(ii) Compressor
(iii) Condenser
(iv) Expansion device

But there are some design features which are typical of a refrigerator. For example, the evaporator is located in the freezer compartment of the refrigerator. The freezer forms the coldest part of the cabinet with a temperature of about -15°C, while the refrigerant evaporates inside the evaporator tubes at -25°C. Just below the freezer, there is a chiller tray. Further below are compartments with progressively higher temperatures. The bottom-most compartment which is meant for vegetables is the least cold one. The cold air being heavier flows down from the freezer to the bottom of the refrigerator. The warm air being lighter rises from the vegetable compartment to the freezer, gets cooled and flows down again. Thus, a natural convection current is set up which maintains a temperature gradient between the top and the bottom of the refrigerator. The temperature maintained in the freezer is about -15°C, whereas the mean inside temperature of the cabinet is 7°C. The design of the condenser is also a little different. It is usually a wire and tube or plate and tube type mounted at the back of the refrigerator. There is no fan. The refrigerant vapour is condensed with the help of surrounding air which rises above by natural convection as it gets heated after receiving the latent heat of condensation from the refrigerant. The standard condensing temperature is 55°C.

3.2 REFRIGERATION CYCLE

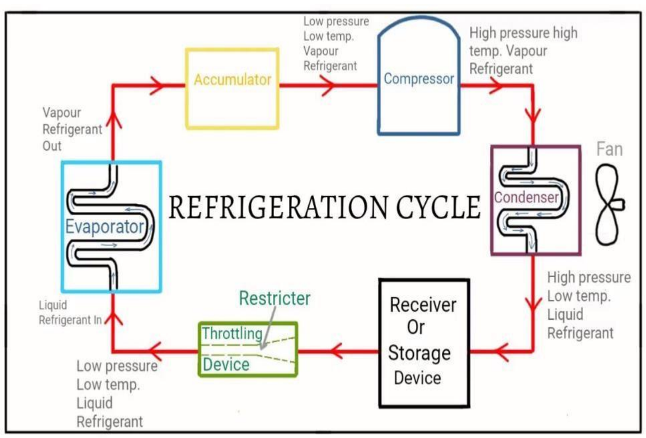

Fig 3.1.0 Refrigeration cycle

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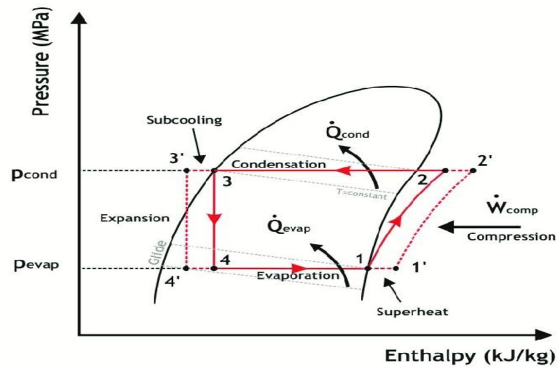

Fig 3.1.1 P-h Diagram for vapour compression

3.3 EVAPORATOR

An evaporator is used in an air-conditioning system to allow a compressed cooling chemical, such as R-22 (Freon) or R-410A, to evaporate from liquid to gas while absorbing heat in the process. It can also be used to remove water or other liquids from mixtures. The process of evaporation is widely used to concentrate foods and chemicals as well as salvage solvents. In the concentration process, the goal of evaporation is to vaporize most of the water from a solution which contains the desired product. In the case of desalination of sea water or in Zero Liquid Discharge plants, the reverse purpose applies, evaporation removes the desirable drinking water from the undesired product, salt.

One of the most important applications of evaporation is in the food and beverage industry. Foods or beverages that need to last for a considerable amount of time or need to have certain consistency, like coffee, go through an evaporation step during processing.

In the pharmaceutical industry, the evaporation process is used to eliminate excess moisture, providing an easily handled product and improving product stability. Preservation of long-term activity or stabilization of enzymes in laboratories are greatly assisted by the evaporation process.Another example of evaporation is in the recovery of sodium hydroxide in Kraft pulping. Cutting down waste-handling cost is another major reason for large companies to use evaporation applications. Legally, all producers of waste must dispose of waste using methods compatible with environmental guidelines; these methods are costly. By removing moisture through vaporization, industry can greatly reduce the amount of waste product that must be processed.

3.4 COMPRESSOR

Vapor-compression refrigeration or vapor-compression refrigeration system (VCRS), in which the refrigerant undergoes phase changes, is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems.

Fig. 3.3. Compressor in Refrigerator

Refrigeration may be defined as lowering the temperature of an enclosed space by removing heat from that space and transferring it elsewhere. A device that performs this function may also be called an air conditioner, refrigerator, air source heat pump, geothermal heat pump or chiller (heat pump).

3.5 CONDENSER

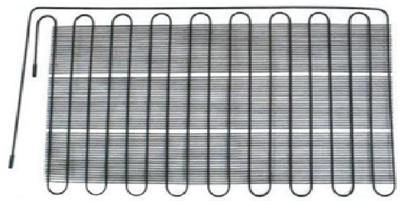

Fig. 3.4. Condenser in Refrigerator System

In systems involving heat transfer, a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant.Condensers are typically heat exchangers which have various designs and come in many sizes ranging from rather small (hand-held) to very large industrialscale units used in plant processes. For example, a refrigerator uses a condenser to get rid of heat extracted from the interior of the unit to the outside air. Condensers are used in air conditioning, industrial chemical processes such as distillation, steam power plants and other heat-exchange systems. Use of cooling water or surrounding air as the coolant is common in many condensers.

3.6 CAPILLARY TUBE

A thermal expansion valve (often abbreviated as TEV, TXV, or TX valve) is a component in refrigeration and air conditioning systems that controls the amount of refrigerant flow into the condenser thereby controlling the superheating at the outlet of the evaporator. Thermal expansion valves are often referred to generically as "metering devices".

Expansion valves are flow-restricting devices that cause a pressure drop of the working fluid. The valve needle remains open during steady state operation. The size of the opening or the position of the needle is related to the pressure and temperature of the evaporator. There are three main parts of the expansion valve that regulate the position of the needle. A sensor bulb, at the end of the evaporator, monitors the temperature change of the evaporator. This change in temperature creates a change in pressure on the diaphragm.

For example, if the temperature in the evaporator increases, the pressure in the diaphragm increases causing the needle to lower. Lowering the needle allows more of the working fluid into the evaporator to absorb heat. The pressure at the inlet of the evaporator affects the position of the needle and prevents the working fluid from flowing back into the compressor. Since the pressure before the valve is higher than the pressure after the valve, the working fluid naturally flows into the evaporator. The pressure at the inlet of the evaporator acts on the diaphragm. There is also a spring providing a constant pressure closing the valve needle. The spring constantly restricts the amount of working fluid entering the evaporator.

Fig. 3.5. Capillary tube (expansion device) in Refrigerator.

The pressure spring can be adjusted to increase or decrease pressure based on temperature needs. The pressure created by the spring acts on the opening of the valve. When the pressure of the sensor bulb acting on the diaphragm is greater than the combined pressure of the evaporator and spring, the valve opens to increase the flow rate of the working fluid. An increase of flow rate lowers the temperature of the evaporator and allows for more heat absorption.

3.7 REFRIGERANT R-134a

R134a is also known as Tetrafluoro ethane (CF3CH2F) from the family of HFC refrigerant. With the discovery of the damaging effect of CFCs and HCFCs refrigerants to the ozone layer, the HFC family of refrigerant has been widely used as their replacement. It is now being used as a replacement for R-12 CFC refrigerant in the area of centrifugal, rotary screw, scroll and reciprocating compressors. It is safe for normal handling as it is non-toxic, non-flammable and non-corrosive. Currently it is also being widely used in the air conditioning system in newer automotive vehicles. The manufacturing industry use it in plastic foam blowing. Pharmaceuticals industry use it as a propellant.

It exists in gas form when expose to the environment as the boiling temperature is -14.9°F or -26.1°C.This refrigerant is not 100% compatible with the lubricants and mineral based refrigerant currently used in R-12. Design changes to the condenser and evaporator need to be done to use this refrigerant. The use of smaller hoses and 30% increase in control pressure regulations also have to be done to the system.

Properties of R-134a

S.No	Properties	R-134a
1	Boiling Point	-14.9°F or -26.1°C
2	Auto-Ignition Temperature	1418°F or 770°C
3	Ozone Depletion Level	0
4	Solubility In Water	0.11% by weight at 77°F or 25°C
5	Critical Temperature	252°F or 122°C
6	Cylinder Colour Code	Light Blue
7	Global Warming Potential (GWP)	1200

Detection of Leaks

When you suspect a leak of R-134a in your air conditioning system, detection can be done by using one of the following 5 methods. The simplest method and cost effective is by the use of soap solution. Workshops may use more sophisticated equipment's to do this.

Fluorescent Dyes
Soap Solution
Electronic Leak Detectors
Halogen selective detectors
Ultrasonic leak detectors

IV. TECHNICAL MEASUREMENTS

4.1 TEMPERATURE MEASUREMENTS

Refrigerator is mainly used to maintain the temperature lower than the surrounding temperature. It is essential to measure the temperature of the refrigerant at the every inlet and outlet of the system components. This measuring temperature plays a vital role in the evaluation of the whole system performance. So, temperature of the refrigerant at the inlet and outlet of the evaporator, compressor, condenser and expansion device should be noted.

4.2 PRESSURE MEASUREMENTS

Temperature difference is the main term to do a heat transfer process from lower to higher temperatures. This temperature difference can be made by pressure of the refrigerant. Because, the pressure is directly proportional to temperature. Hence, we are using compressor and expansion device to make a pressure difference. So the pressure of the refrigerant at the every components should be measured.

4.3 ENERGY CONSUMPTION

For the better performance of the system consumption of electrical energy should be minimum while using new refrigerant when compared with existing one. This energy consumption of the system can be measured by using total running time of the compressor to produce certain amount of work.

4.4 REFRIGERATING EFFECT

Refrigerating effect produced from the system per unit time period should be measure by using the difference in enthalpy values at the inlet and outlet of the evaporator with mass flow rate of refrigerant.

RE = h2 - h4

4.5 WORK INPUT

The vapour refrigerant at low pressure p1 and temperature T1 is compressed isentropically to dry saturated vapour as shown by the vertical line 1-2 on T-s diagram and by the curve 1-2 on the p-h diagram. The pressure and temperature rises from p1 to p2 and T1 to T2 respectively. The work done during isentropic compression per kg of refrigerant is given by

W =h2 - h1

4.6 COEFFICIENT OF PERFORMANCE

The coefficient of performance is the ratio of heat extracted in the refrigerator to the work done on the refrigerant. It is also known as theoretical coefficient of performance. Mathematically,

COP = $\boldsymbol{Refrigeratingeffect}$ / $\boldsymbol{Workinputt}$

COP = $\boldsymbol{h2-h4}$ / $\boldsymbol{h2-h1}$

V. PSYCHROMETRIC SYSTEM

5.1 PSYCHROMETRIC PROPERTIES

The science which deals with the study of behaviour of moist air (mixture of dry air and water vapour) is known as psychrometry.

5.2 DRY AIR

The dry air is nothing but the air without moisture or water vapour. The pure dry air is a mixture of number of gases such as nitrogen, oxygen, carbon dioxide, hydrogen etc., among these nitrogen and oxygen other gases present only in negligible quantity. So, the volumetric composition of dry air is 77% of nitrogen and 23% of oxygen.

5.3 MOIST AIR

It is a mixture of dry air and water vapour. The amount of water vapour present in the moist air varies with temperature.

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5.4 MOISTURE

The water vapour present in the air is known as moisture.

5.5 DRY BULB TEMPERATURE (DBT)

The temperature measured by an ordinary thermometer is known as dry bulb temperature. It is generally denoted by tdb.

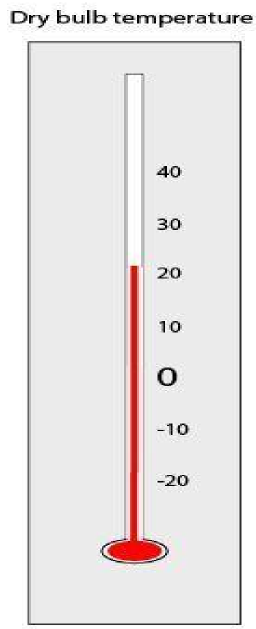

Fig 5.5 dry bulb temperature

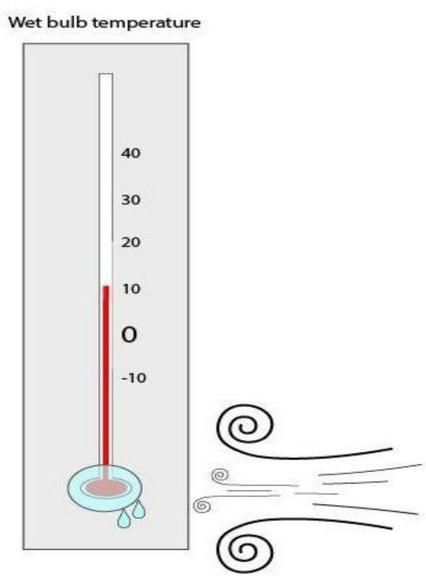

Fig 5.6Wet bulb temperature

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5.6 WET BULB TEMPERATURE (WBT)

It is the temperature of air measured by a thermometer when its bulb is covered with wet cloth and is exposed to a current rapidly moving air. It is denoted by t_w

5.7 DEW POINT TEMPERATURE (DPT)

It is the temperature at which the water vapour present in air begins to condense when the air is cooled. For saturated air, the dry bulb, wet bulb and dew point temperature are all same.

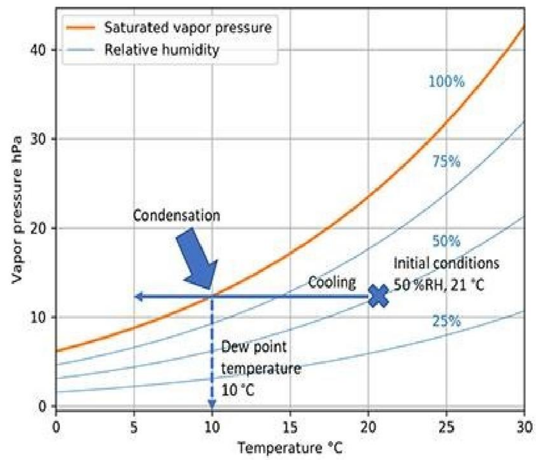

Fig 5.7 Dew point temperature

5.8 SPECIFIC HUMIDITY(OR) HUMIDITY RATIO (OR) MOISTURE CONTENT

It is defined as the mass of water vapour present in one kg of dry air. It is the ratio of the mass of water vapour to the mass of dry air in a given volume of the moisture.

5.9 RELATIVE HUMIDITY

Relative humidity plays a major role in the comfort air conditioning and industrial air conditioning to compare with specific humidity. It is defined as the of the actual mass of water vapour in a given volume to the saturated mass of water in same volume and temperature.

5.10 TOTAL ENTHALPY

Total enthalpy of moist air is the sum of the enthalpy of dry air and the enthalpy of water vapour associated with the dry air.

VI. PSYCHROMETRIC PROCESSES

6.1 PSYCHROMETRIC PROCESSES

Maintaining a living space or industrial facility at the desired temperature and humidity requires some processes called *psychrometric processes. The* different types of psychrometric are as follows.

1.Sensible heating process
2.Sensible cooling process
3.Humidification process
4.Dehumidification process
5.Heating and humidification process
6.Cooling and dehumidification process
7.Adiabatic mixing air streams process
8.Evaporative cooling process

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6.2 SENSIBLE HEATING PROCESS

Sensible heating process is a process during which the dry bulb temperature of air is increased. The process occurs at constant moisture content. The air passes over a hot and dry surface which might be pipe coil using steam or hot water , electrical resistance or an air to air heat recovery unit.

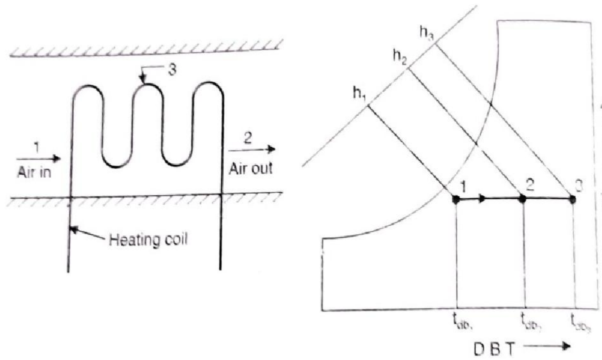


Fig. 10.8. Sensible heating. Fig. 10.9

Fig 6.2 Sensible heating process

6.3 SENSIBLE COOLING PROCESS

Sensible cooling is the removal of heat from the air without changing the moisture content. On the psychrometric chart (right) , the cooling process moves from right to left in a horizontal line. This process does not change the humidity ratio or dew point temperature of the air.

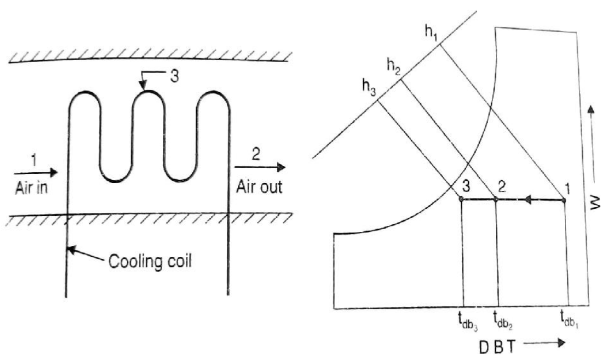
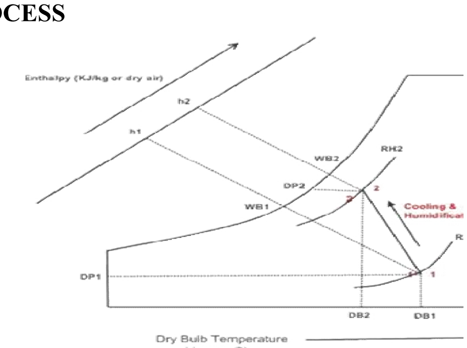


Fig. 10.10. Sensible cooling. Fig. 10.11

Fig 6.3 Sensible cooling process

6.4 HUMIDIFICATION PROCESS



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The process in which the moisture or water vapor or humidity is added to the air without changing its dry bulb temperature is called as humidification process. Humidification process along with cooling or heating is used in number of air conditioning applications.

6.5 DEHUMIDIFICATION PROCESS

Dehumidification is a highly energy intensive process, especially in humid climates and for building topologies that require strict space humidity setpoints. Subcooling of air to condense out moisture using chilled water or refrigerant is the most common method for dehumidifying

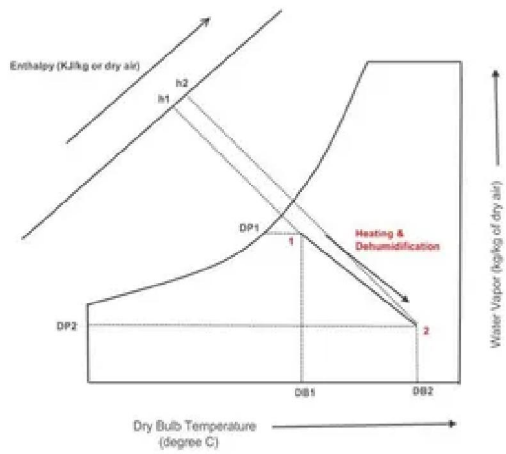


Fig 6.5 Dehumidification process

6.6 HEATING AND HUMIDIFICATION PROCESS

In heating and humidification process of the air, the dry bulb temperature as well as the humidity of the air increases. The heating and humidification process is carried out by passing the air over spray of water, which is maintained at temperature higher than the dry bulb temperature of air or by mixing air and the steam.

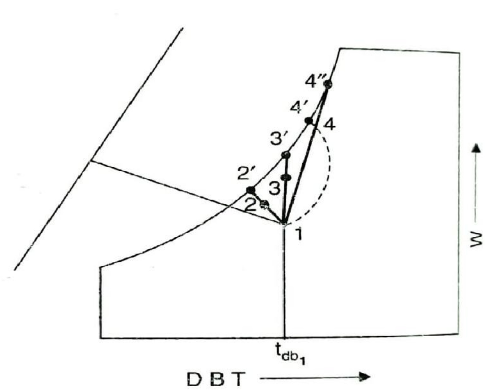


Fig 6.6 Heating and humidification process

6.7 COOLING AND DEHUMIDIFICATION PROCESS

The process in which the air is cooled sensibly and at the same time the moisture is removed from it is called as cooling and dehumidification process. Cooling and dehumidification process is obtained when the air at the given dry bulb and dew point temperature is cooled below the dew point temperature.

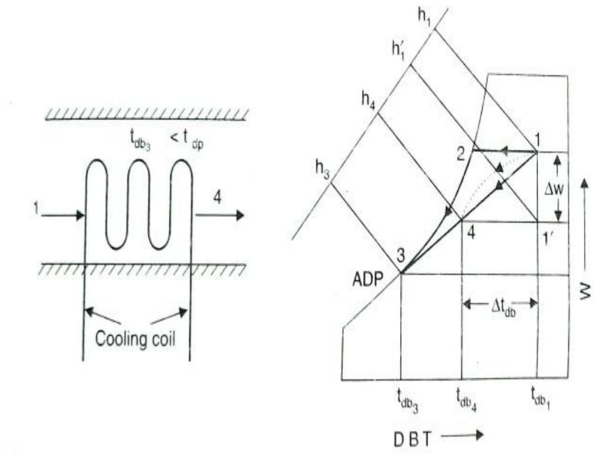


Fig 6.7 Cooling and dehumidification process

6.8 EVAPORATIVE COOLING PROCESS

Evaporative cooling is a process that uses the effect of evaporation as a natural heat sink. Sensible heat from the air is absorbed to be used as latent heat necessary to evaporate water. The amount of sensible heat absorbed depends on the amount of water that can be evaporated.

VII. EXPERIMENTAL SETUP AND PROCEDURE

7.1 EXPERIMENTAL PROCEDURE

The working principle of a domestic refrigerator is exactly the same as that of an air conditioner. A schematic diagram of the refrigerator is shown in figure. Like the air conditioner, it also consists of the following four basic components:

(i)Evaporator

(ii)Compressor

(iii)Condenser

(iv)Expansion device

But there are some design features which are typical of a refrigerator. For example, the evaporator is located in the freezer compartment of the refrigerator. The freezer forms the coldest part of the cabinet with a temperature of about -15°C, while the refrigerant evaporates inside the evaporator tubes at -25°C. Just below the freezer, there is a chiller tray. Further below are compartments with progressively higher temperatures. The bottom-most compartment which is meant for vegetables is the least cold one. The cold air being heavier flows down from the freezer to the bottom of the refrigerator. The warm air being lighter rises from the vegetable compartment to the freezer, gets cooled and flows down again. Thus, a natural convection current is set up which maintains a temperature gradient between the top and the bottom of the refrigerator. The temperature maintained in the freezer is about -15°C, whereas the mean inside temperature of the cabinet is 7°C. The design of the condenser is also a little different. It is usually a wire and tube or plate and tube type mounted at the back of the refrigerator. There is no fan. The refrigerant vapour is condensed with the help of surrounding air which rises above by natural convection as it gets heated after receiving the latent heat of condensation from the refrigerant. The standard condensing temperature is 55°C.

7.2 MODIFIED WORK

In our present project work, we want to condense the water vapour present in the unsaturated air. This is done by maintaining the evaporator temperature of the refrigeration cycle well below the dew point temperature of the incoming unsaturated atmospheric air. The atmospheric pressure, dry bulb temperature, relative humidity of the air present in the place where we are doing our project were observed. From those observations and by psychrometric chart dew point temperature of the air is found and it would be 18oC. The refrigerating effect required for achieving apparatus dew point temperature is calculated.

IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.301
Volume 3, Issue 3, December 2023

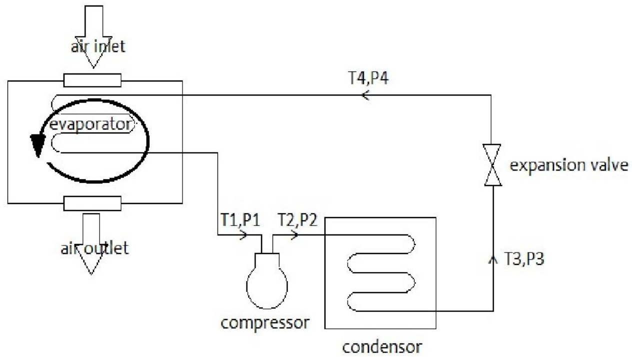
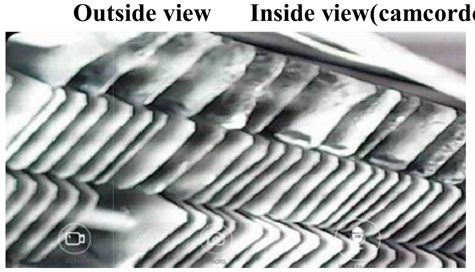


Fig 7.2 Line diagram of atmospheric water extraction by vapour compression refrigeration using R-134a

Based on the refrigerating effect a fin made up of copper has been selected and kept inside the evaporator wherein outside unsaturated atmospheric air is made to flow by using a fan. The temperature of the incoming air would be around 32oC and when it is made to flow towards the evaporator coil its temperature is getting reduced as the temperature of the evaporator is around 10oC (apparatus dew point temperature). As the apparatus dew point temperature (10oC) is well below the dew point temperature of the unsaturated incoming air (18oC) the water vapour present in the air condenses and it will be collected for further processing.

Outside view Inside view(camcorder)



Water droplets forming

VIII. EXPERIMENTAL OBSERVATION AND CALCULATION

8.1OBSERVED READING FROM EXPERIMENTAL SET UP (CASE 1)

S. No	Pressure (P bar)				Temperature (T^0C)			
	P_1	P_2	P_3	P_4	T_1	T_2	T_3	T_4
1	0.68	10.31	10.3	0.68	37	49	50	0

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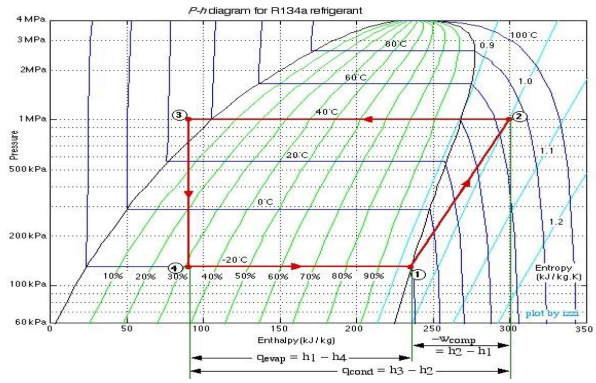

Fig 8.1.0 R134a refrigeration cycle

P1 – Pressure of refrigerant at the exit of the evaporator is equal to the pressure of refrigerant at the inlet to the compressor

P2 – Pressure of refrigerant at the exit of the compressor is equal to the pressure of refrigerant at the inlet to the condenser

P3 – Pressure of refrigerant at the exit of the condenser is equal to the pressure of refrigerant at the inlet to the evaporator

P4 – Pressure of refrigerant at the exit of the expansion is equal to the pressure of refrigerant at the inlet to the evaporator

T1 – Temperature of refrigerant at the exit of the evaporator is equal to the temperature of refrigerant at the inlet to the compressor

T2 – Temperature of refrigerant at the exit of the compressor is equal to the temperature of refrigerant at the inlet to the condenser

T3 – Temperature of refrigerant at the exit of the condenser is equal to the temperature of refrigerant at the inlet to the evaporator

T4 – Temperature of refrigerant at the exit of the expansion is equal to the temperature of refrigerant at the inlet to the evaporator.

h1 – Enthalpy of refrigerant at the exit of the evaporator is equal to the enthalpy of refrigerant at the inlet to the compressor.

h2 – Enthalpy of refrigerant at the exit of the compressor is equal to the enthalpy of refrigerant at the inlet to the condenser

h3 – Enthalpy of refrigerant at the exit of the condenser is equal to the enthalpy of refrigerant at the inlet to the evaporator.

h4 – Enthalpy of refrigerant at the exit of the expansion is equal to the enthalpy of refrigerant at the inlet to the evaporator

COP, by using this formula

COP $= \boldsymbol{Refrigeratingeffect} / \boldsymbol{Workinputt}$

COP $= ^{\boldsymbol{h2-h4}} / \boldsymbol{h2-h1}$

Following values are taken from Refrigeration table

(R – 134 a)

h_1 = 475 kJ / kg

h_2 = 560 kJ / kg

h_4 = 275 kJ / kg

mass flow rate of refrigerant = 6.96 Kg / min

Refrigerating effect = (h2 – h4) ×mR

Refrigerating effect =1983 KJ / min

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Work input to the compressor

$= (h_2 - h_1) \times m_R$

$= (560 - 475) \times 6.96$

COP = $h2 - h4$ / $h2 - h1$

R134a REFRIGERATION CYCLE

COP = 3.3

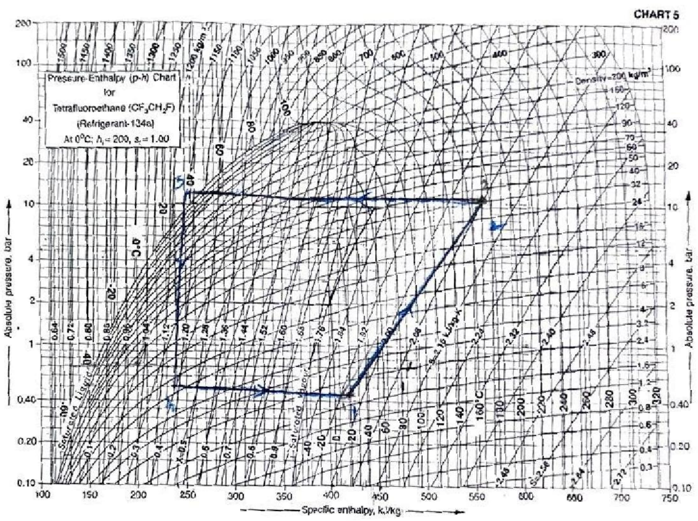


Fig 8.1.1 pressure, enthalpy chart

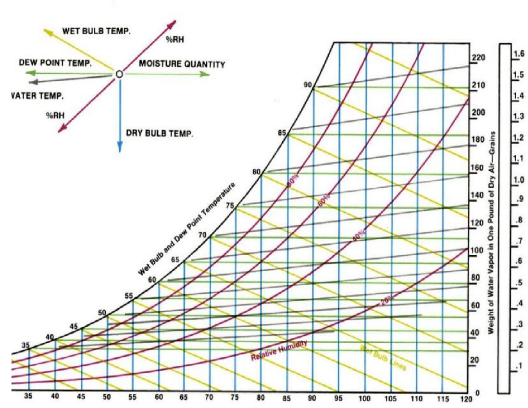
Properties of Air at inlet:

Apparatus dew point Temperature of the coil ($t_{dp,A}$) = 10^0C

Dry bulb Temperature of inlet air ($t_{db,1}$) = 32^0C

Relative Humidity of inlet air (□) = 56%

Work input to the compressor = 85 KJ / min



From Psychrometric chart

Dew point Temperature of the inlet unsaturated air (t_{dp}) = 17^0C

From Observation

Dry bulb Temperature of exit air ($t_{db,2}$) = 16.2^0C

W1 = 0.016 kg / kg of dry air

Water vapour in the leaving air (or) the specific humidity of leaving air at point 2

W2 = 0.010 kg / kg of dry air

Specific volume of entering air at point 1 Vs1 = 0.87 m3 / kg of dry air

Enthalpy of entering air at point 1 h1 = 73 kJ / kg of dry air

Enthalpy of air at point A ha = 67 kJ / kg of dry air

Enthalpy of leaving air at point 2 h2 = 42 kJ/kg of dry air

We know that mass of air flowing through the cooling coil,

ma = $\boldsymbol{V1}$ / $\boldsymbol{Vs1}$

= $\mathbf{0.5}$ / 0.87

= 0.57 kg / min

Capacity of the cooling coil in tonnes of refrigeration TR

= ma (h1 – h2)

= 0.57 (73 - 42)

= 17.57 kJ / min

= 17.57 / 210

(1 TR = 210 kJ / min)

Capacity of the cooling coil in tonnes of refrigeration TR = 0.084 TR

Amount of water vapour extracted per minute

= m_a (W_1 – W_2)

= 0.56 (0.016 – 0.010)

Amount of water vapour extracted per minute = 0.00836 kg / min

THE PSYCHROMETRIC CHART VALUE IS

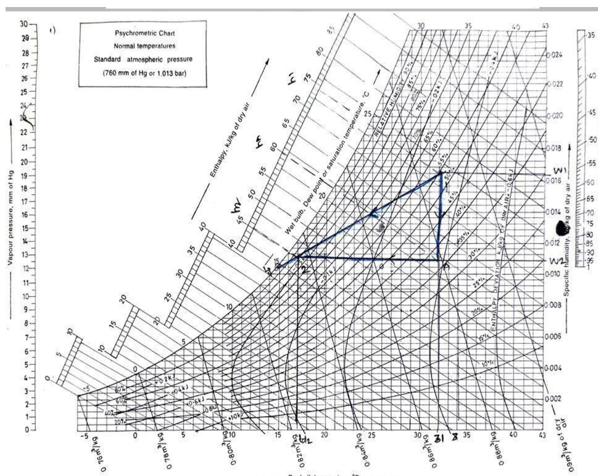


Fig 8.1.3 Psychrometric chart values for 56% relative humidity

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8.2 OBSERVED READINGS FROM EXPERIMENTAL SET UP (CASE 2)

SI.No	Pressure (P bar)				Temperature (T^0C)			
	P_1	P_2	P_3	P_4	T_1	T_2	T_3	T_4
1	0.68	10.31	10.3	0.68	90	140.08	130	90

Table 8.2 observed readings from experimental set up (case 2)

P1 – Pressure of refrigerant at the exit of the evaporator is equal to the pressure of refrigerant at the inlet to the compressor

P2 – Pressure of refrigerant at the exit of the compressor is equal to the pressure of refrigerant at the inlet to the condenser

P3 – Pressure of refrigerant at the exit of the condenser is equal to the pressure of refrigerant at the inlet to the evaporator

P4 – Pressure of refrigerant at the exit of the expansion is equal to the pressure of refrigerant at the inlet to the evaporator

T1 – Temperature of refrigerant at the exit of the evaporator is equal to the temperature of refrigerant at the inlet to the compressor

T2 – Temperature of refrigerant at the exit of the compressor is equal to the temperature of refrigerant at the inlet to the condenser

T3 – Temperature of refrigerant at the exit of the condenser is equal to the temperature of refrigerant at the inlet to the evaporator

T4 – Temperature of refrigerant at the exit of the expansion is equal to the temperature of refrigerant at the inlet to the evaporator.

h1 – Enthalpy of refrigerant at the exit of the evaporator is equal to the enthalpy of refrigerant at the inlet to the compressor

h2 – Enthalpy of refrigerant at the exit of the compressor is equal to the enthalpy of refrigerant at the inlet to the condenser.

h3 – Enthalpy of refrigerant at the exit of the condenser is equal to the enthalpy of refrigerant at the inlet to the evaporator

h4 – Enthalpy of refrigerant at the exit of the expansion is equal to the enthalpy of refrigerant at the inlet to the evaporator

COP, by using this formula

COP = $\boldsymbol{Refrigerating\ effect\ /\ Work\ inputt}$

COP $=^{h2-h4}$ / $\boldsymbol{h2-h1}$

Following values are taken from Refrigeration table (R – 134 a)

$\boxed{\text{COP = 5.76}}$

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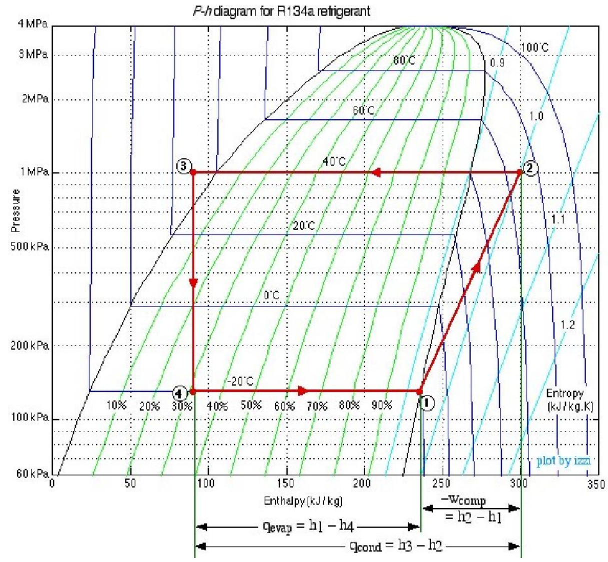

Fig 8.2.0 R134a refrigeration cycle

h_4 = 392.4 kJ / kg
h_2 = 423.2 kJ / kg
h_1 = 241.82 kJ / kg
Mass flow rate of the refrigerant (m_R) = 6.96 kg / min
Refrigerating effect =1226 KJ / min
Work input of compressor = $m_R(h_2 – h_1)$
= 6.98 (423.2 – 392.4)
Work input of compressor =214 KJ / min

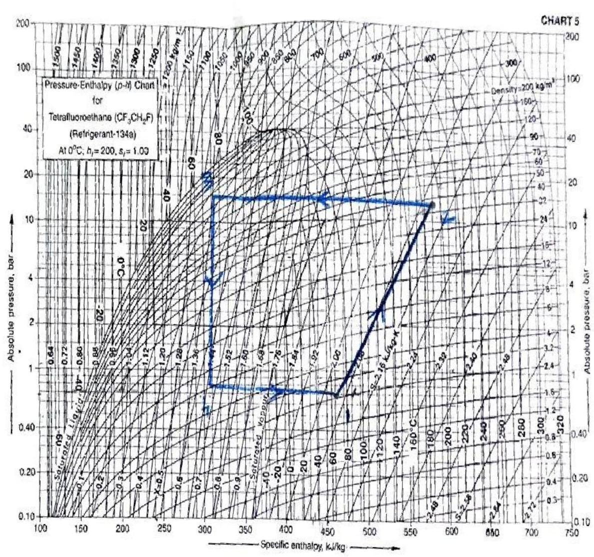

Fig 8.2.1 pressure, enthalpy chart

Properties of Air at inlet :
Apparatus dew point Temperature of the coil (tdp A) = 100^0
Dry bulb Temperature of the inlet air (tdb1) = 340^0
Humidity Relative humidity= 36% (from by using galaxy sensor App).

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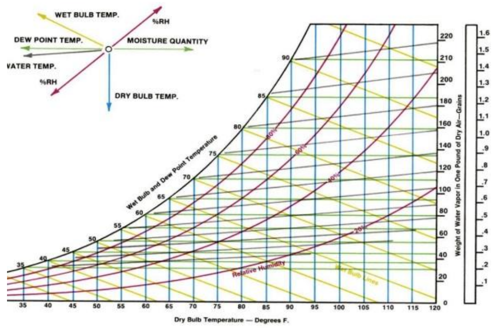

8.2.2 Psychrometric chart

The following values are taken from psychrometric chart

Dew point Temperature of the inlet unsaturated air (tdp) = 220C

From observation,

Dry bulb temperature of exit air (tdb2) = 17.20C

Water vapour in the entering air (or) the specific humidity of entering air at point 1

W1 = 0.012 kg / kg of dry air

Water vapour in the leaving air (or) the specific humidity of leaving air at point 2

W2 = 0.009 kg / kg of dry air

Specific volume of entering air at point 1 Vs1 = 0.87 m3 / kg of dry air

Enthalpy of entering air at point 1 h1 = 66 kJ / kg of dry air

Enthalpy of air at point A hA = 57 kJ / kg of dry air

Enthalpy of leaving air at point 2 h2 = 30 kJ / kg of dry air

We know that mass of air flowing through the cooling coil,

= 0.57 kg / min

Capacity of the cooling coil in tonnes of refrigeration

= ma (h1 – h2)

= 0.57 (66 - 57)

= 5.103 kJ / min

= 5.103 / 210

(∵ 1 TR = 210 kJ / min)

Capacity of the cooling coil in tonnes of refrigeration = 0.024 TR

Amount of water vapour extracted per minute

= ma (W1 – W2)

= 0.57 (0.012 – 0.09)

Amount of water vapour extracted per minute = 0.0017 kg / min

THE PSYCHROMETRIC CHART VALUE IS

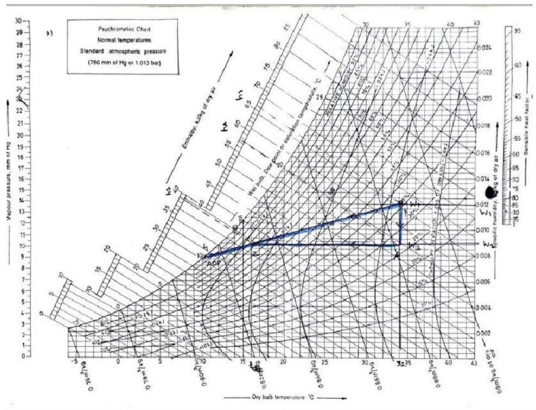

Fig 8.2.3 Psychrometric chart values for 36% relative humidity

Time vs water extracted:

Time in min (X Axis)	30	60	90	120	150
Power consumed in KW (Y axis)	0.175	0.350	0.525	0.700	0.875

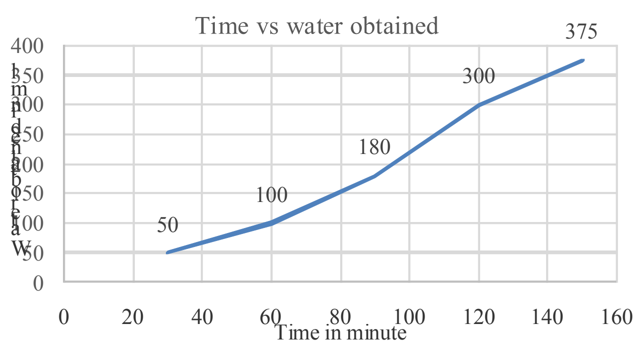

Fig 8.3.0 time vs water extracted

Time vs power consumed:

Time in min (X Axis)	30	60	90	120	150
Power consumed in KW (Y axis)	0.175	0.350	0.525	0.700	0.875

Table 8.3.1 time vs power consumed

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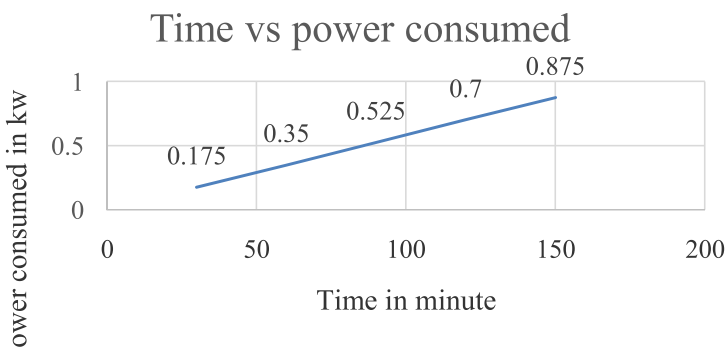

Fig 8.3.1 time vs power consumed

IX. RESULTS AND DISCUSSION

If the dew point temperature of the incoming air decreases the required refrigerating effect increases which in turn increase the work input to the compressor. Therefore, COP of the refrigeration system decreases. Amount of water extracted is also getting decreased.

If the dry bulb temperature ($t_{db,1}$) of the incoming air increases the required refrigerating effect decreases which in turn decrease the work input to the compressor. Therefore, COP of the refrigeration system increases. Amount of water extracted is also getting increased.

If the relative humidity of the incoming air increases the amount of water extracted is also getting increased.

Sl. No	**(h_2-h_4)**	**(h2 - h1) ×m_R**	$\frac{h2-h4}{h2-h1}$	**(t_{dp1}A)**	**(t_{dp})**	**(t_{db}1)**	**Relative humidity**	(W_1 – W_2) × m_R ml / min
1	1983.6	591.6	3.3	10 ^{0}C	17 ^{0}C	32 ^{0}C	56%	8.36
2	1226	214	5.17	14 ^{0}C	22 ^{0}C	34 ^{0}C	36%	1.7

Table 9 comparison of case1 and case2

X. CONCLUSION

This paper presented the performance and analysis of atmospheric water extraction by vapour compression refrigeration using R-134a, India is blessed with warm and humid climatic conditions in most of its states containing huge amount of water in atmosphere which can fulfil the increasing water demands. Atmospheric water extraction is one of the technologies where fresh water is obtained from the ambient air by condensation. From the result and discussion, we can conclude that if the inlet air with high dry bulb, dew point temperatures and relative humidity is available more amount of water can be extracted per unit minute.

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