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EFFECT OF SUB COOLING AND AIR VELOCITY ON WATER GENERATION FROM AIR USING VAPOR COMPRESSION CYCLE

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ABSTRACT:

Now a days India to facing problem of water shortage hence it is necessary to find the other ways to achieve water. Atmospheric water generation (AWG) is the one of the process which is under experimentation by the scientist around the world. In this dissertation report AWG is developed based on Vapor Compression cycle (VCC). Efforts are put on condensation of maximum moisture in air by enhancing the performance of VCC by employing subcooling using water cooled condenser. And it is observed that it is possible to produce large amount of water if system is enlarged by size. Though the system running cost is higher but its side product like cooled air and hot water from the condenser indirectly saves the energy consumption to cool the air and heat the water for different purposes. Average range of 700 to 1600 ml of water generated running the system for 14 hours per day during December 2016 and January 2017. Subcooling improves the water generation indirectly by increasing the performance of VCC. Simulation is done for the system with subcooling and without subcooling and the results shows that COP of the subcooled system is 12-14% more than without subcooled system. A system without subcooling collected only average 700 ml of water per day. This shows that practically subcooled system is average 50% efficient as far as water condensation is concern. The air velocity of the fresh air entering in the evaporator also plays the vital role in deciding the amount of water condensation from air, it is found that at 4-6 m/sec of air velocity maximum water collection is take place.

KEYWORDS: EWG, VCC, Sub-cooling, Dehumidification, Water cooled condenser, R134a.

I. INTRODUCTION:

An atmospheric water generator (AWG) is a device that extracts water from humid ambient air. Water vapour in the air is condensed by cooling the air below its dew point, exposing the air to desiccants, or pressurizing the air. Unlike a dehumidifier, an AWG is designed to render the water potable. AWGs are useful where pure drinking water is difficult or impossible to obtain, because there is almost always a small amount of water in the air that can be extracted. The extraction of atmospheric water may not be free of cost, because significant input of energy is required to drive some AWG processes. Certain traditional AWG methods are completely passive, relying on natural temperature differences, and requiring no external energy source. Research has also developed AWG technologies to produce useful yields of water at a reduced (but non-zero) energy cost. Hence sub cooling is one of the way to reduce the compressor work is mentioned in this paper, so that power consumption for the same amount of water condensation will be reduce which will ultimately increase the efficiency of the system. Speed of air entering in the evaporator is also important to control at particular speed so that maximum water to be condensed i.e. if fan speed is high then water droplets formed may get flown away with water or at very slow speed evaporator work will go waste without producing much water because of less fresh air supplied.

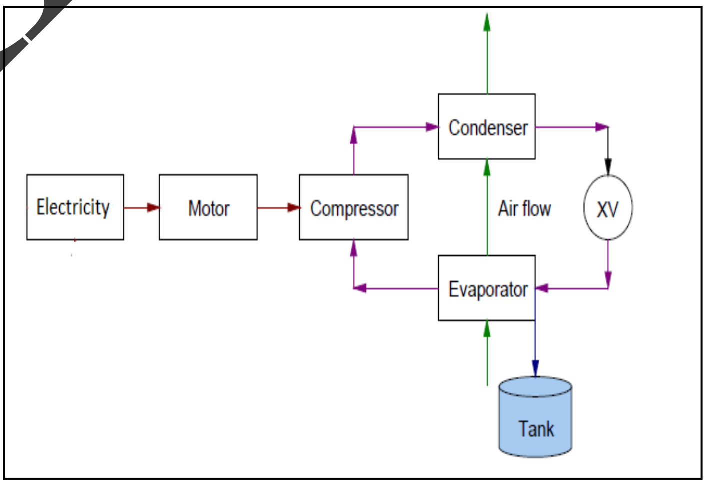

Fig.1 Schematic Diagram of EWG Using Electricity

Hence this paper focuses on the following objectives, 1. To extract Atmospheric Water Generation using Vapor Compression System because this is more efficient refrigeration system. 2. Increase the performance of system by sub-cooling of refrigerant in condenser. 3. Use of the air from the evaporator for cooling or conditioning. 4.

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Enhance the generation of water by controlling the speed of air entering in the evaporator.

Magrini A. and all, (2015), worked on "Integrated systems for air conditioning and production of drinking water – Preliminary considerations" in this paper preliminary investigation on a design of an integrated HVAC system for the air conditioning of a hotel combined with water production is presented. The preliminary calculations show that the produced water could be efficiently used to produce drinking water [1]. Abdulghani A. Al-Farayedhi and all, (2014) worked on "Condensate as a water source from vapor compression systems in hot and humid regions" in this paper, analytical and experimental investigations in determining the condensate from a vapor compression air conditioning system as an additional water source are presented. The condensate is dominantly affected by the air humidity and temperature. [2]. S.A. Nada and all, (2015), worked on "Performance analysis of proposed hybrid air conditioning and humidification–dehumidification systems for energy saving and water production in hot and dry climatic regions", the proposed systems aim to energy saving and systems utilization in fresh water production. The results show that (i) the fresh water production rates of the proposed systems increase with increasing fresh air ratio, supply air temperature and outdoor wet bulb temperature, (ii) powers saving of the proposed systems increase with increasing fresh air ratio and supply air temperature and decreasing of the outdoor air wet bulb temperature, (iii) locating the evaporative cooling after the fresh air mixing remarkably increases water production rate, and (vi) incorporating heat recovery in the air conditioning systems with evaporative cooling may adversely affect both of the water production rate and the total cost saving of the system [3]. Ahmed M. Hamed and all, (2010), worked on "A technical review on the extraction of water from atmospheric air in arid zones". If the experience of the studies carried out in desiccant cooling is applied in this area, improved and more efficient units could be designed. Collecting dew is still a viable option to get water from air, however, the application of dew collection is restricted by the availability of dew [4]. Xiaohui She and all, (2014), worked on "A proposed subcooling method for vapor compression refrigeration cycle based on expansion power recovery". In a main refrigeration cycle, expander output power is employed to drive a compressor of the auxiliary subcooling cycle, and refrigerant at the outlet of condenser is subcooled by the evaporative cooler, which makes the hybrid system get much higher COP [5]. Gustavo Pottker and Pega Hrnjak, (2014), worked on "Effect of the condenser subcooling on the performance of vapor compression systems". It is shown that, as condenser subcooling increases, the COP reaches a maximum as a result of a trade-off between increasing refrigerating effect and specific compression work [6]. Margarita Castillo-Tellez et all worked on "Experimental study on the air velocity effect on the efficiency and fresh water production in a forced convective double slope solar still". It is shown that the fresh water production in single and double slope solar stills (DSSS) depends on the rates of simultaneous processes of evaporation and condensation, where optical material properties, solar irra- diance, temperature, velocity and air direction and the operating mode, natural or forced convection, are involved. Experimentally demonstrated that the thermal efficiency and production increment when the air ve- locity increases up to the value limit around 5.5 m/s and it then decreases at higher velocities and the velocity of 3.5 m/s is considered to be the optimum [7]. Justin P. Koeln, (2014), worked on "Optimal subcooling in vapor compression systems via extremum seeking control: Theory and experiments". In this paper, an alternative system architecture, which utilizes a receiver and an additional electronic expansion valve, is used to provide independent control of condenser subcooling. Simulation and experimental results show there exists an optimal subcooling which maximizes system efficiency; however, this optimal subcooling changes with operating conditions [8].

Water present in air	Water extracted	Dry air
0.0012 kg	0.0048 kg	1 kg
5 kg	2 kg	518.13 kg

II. DESIGN OF SYSTEM:

Design and Selection of Components: At DBT=260 C & RH= 46% [9]. We get dew point temperature =13.49^0 C. Specific humidity = 0.012 kg of water/kg of dry air.

TABLE I Calculation for amount of dry air Table Styles

$$\text{Specific humidity} = \frac{\text{Amount of water present in air}}{\text{1 kg of dry air}}$$

By taking references from Research papers,[9]
Extraction efficiency = 40%
Water to be extracted = 2 liter.
For 2 liters of water extraction we require 5 kg of water to be present in air.
For this 518.13 kg of air is required
Qair= 518.13/1.77 = 440.21/(24 x 60 x60) = 5.09 x 10-3 m3/sec.

A. EVAPORATOR DESIGN:

Q_{air} = Face area x Velocity of fresh air

5.09×10^{-3} = Face area x 0.1

Average velocity of air measured inside room using Anemometer = 0.1 m/sec, Face area = 0.0509 m^2. Evaporator of such area available in market is [23 x 23] cm^2 fin and tube type evaporator. Thus face area of evaporator = 0.0529 m^2.

B. COMPRESSOR DESIGN:

Refrigeration effect

$$= m_a C_p dT + m_w . L \quad (1)$$

$$= \frac{518.13 \times 1.005 \times (26-17)}{24 \times 60 \times 60} + \frac{2 \times 2260}{24 \times 60 \times 60}$$

= 106.49 W

From LG compressor catalogue for Cooling capacity of 106.5 W Compressor with cooling capacity of 107W is available MA42LPJG.

C. CONDENSER DESIGN:

Here we are using water sub cooled condenser for minimizing size and to increase the performance.

Nusselt No., $Nu = \frac{h_0 Lc}{K}$

$$Ra = Gr \times P$$

$$Gr = \frac{D^3 \times \varrho^2 \times g \times \Delta T \times \beta}{\mu^2}$$

It is assumed that water enters at 26^0C and is heated up to 48^0C. $\Delta T = 48 - 26 = 22^0$ C, $\beta = 1/T_{avg}$, $T_{avg} = 37^0C = 310K$

$\beta = 1/310 = 3.225 \times 10^{-3}$ K^{-1}

From property table, dynamic viscosity of water μ at 37^0 C is,

$\mu = 0.6733 \times 10^{-3}$ hence Gr =393265.22.

From property table, Prandtl number for water at 37^0,

Pr = 4.3561, Ra = Gr x Pr = 1.713×10^6

$$NuL = 0.68 + \frac{0.67 \, Ra_L^{1/4}}{[1 + (0.492/Pr)^{9/16}]^{4/9}}$$

Nu = 32.9507

From property table, thermal conductivity for water at 37^0 is

K = 0.6287 W/m.K, hence h_0= 3262.488 $W/m^2.K$

From P-h table for refrigerant R134a

Temp of condenser = 52^0 C, Outlet to compressor = 60^0 C

Inlet to compressor = 21^0 C, Suction pressure = 6.0 bar

Discharge pressure =14.0 bar absolute pressure.

From P-h chart,

h1 = 410 kJ/kg, h4 = 275 kJ/kg

Cooling capacity = $m_r (h_1-h_4)$ 107 x 10^{-3} = m_r (410 - 275) (from LG electronics)

$m_r = 7.92 \times 10^{-4}$ kg/sec

$Q = m_r/\varrho = 7.27 \times 10^{-7}$ m^3/sec

From property table of R134a at 52^0 C

ϱ = Density of refrigerant in liquid state = 1092.7 kg/m^3

μ= Dynamic Viscosity = 138.9×10^{-6} Pa.s

C_p = 1.5832 KJ/Kg K, K = 70.11×10^{-3} W/m.K

Q = A x V, Velocity = 0.0229 m/sec.

We have, Reynolds number (Re) = ϱ V D/ μ

= 1144.73 < 2000 Therefore flow is laminar ,

For laminar flow, Nu = 4.363

$Nu = \frac{h_i L_c}{K}$ $(h_i)_{liquid}$ = 68.9 W/m^2 K

$m_r = 7.92 \times 10^{-4}$ kg/sec $Q = m_r/\varrho = 1.12 \times 10^{-5}$

From property table of R134a at 52^0 C

ϱ = Density of refrigerant in vapour state = 70.204 kg/m^3

μ= Dynamic Viscosity = 13.59×10^{-6} Pa.s

C_p = 1.2716 KJ/Kg K, K = 0.017844 W/m.K

Q = A X V, Velocity V = 0.3566 m/sec.

We have,

Reynolds number (Re) = $\frac{\varrho V D}{\mu}$ = 11700.04 > 2000

Therefore flow is turbulent, For turbulent flow,

$Nu = 0.023 Re^{4/5} Pr^{0.3}$, Also equation, $Nu = \frac{h_i L_c}{K}$

$(h_i)_{gas}$ = 1686.922 W/m^2 K

$(h_i)_{average}$ = (363.82 + 1686.922)/2= 1025.371 W/m^2 K

We have, $1/U = 1/h_i + 1/h_0$, hence, U = 780.64 W/m^2 K

Tank/shell dimensions is taken as 25.5 x 25.5 x 30 (L x B x H in cm); Consider water is filled up to 22 cm height, thus mass of water, Mw = ϱ x Volume = 14.3055 kg.

This 14.3055 kg of water is heated for one hour for temperature rise of 26 to 48^0C. We know that,

Heat absorbed by water = Heat rejected by refrigerant

$M_w \times C_{pw} \times (T_2-T_1) = U A \Delta T$

A = 0.058 m^2

Hence a condenser coil of about 0.058 m^2 is manufactured

$d = 6.35 \times 10^{-3}$ m

Deciding the length and turns of coil

A= 0.058 m^2; 0.14 = π d L

Therefore L = 2.93 m, Approximately L=3.0 m. Consider coil diameter D = 22cm

π D x N = L; N = 4.25, Approximately N = 5 For condenser,

O.D of tube (d_0) = 6.35×10^{-3} m

I.D of tube (d_i) = 3.64×10^{-3} m

Coil diameter D = 22 cm; Length of coil = 3.0 m.

III. RESULTS OF DESIGN OF SYSTEM:

From the above design calculations we have selected the standard components as a result of Refrigeration system available easily in market whose specifications approaches the calculated values in above section for the ease of experiments. The following components of the Vapor Compression system as a result which are tabulated below,

A. COMPRESSOR:

TABLE II- SELECTION ON THE BASE OF DESIGN OF COMPRESSOR

Product	Compressor
Model	MA42LPJG-Hermatically sealed.
Net weight	8.1 kg
Input wattage	96W
Voltage/Frequency	220V/50HZ,1PH
Manufactured By	LG Electronics India Pvt. Ltd.
Cooling Capacity(HP)	1/7
EER(Btu/W.h)	3.8
Suction pressure	0.5bar
Discharge pressure	12-14bar

B. EXPANSION VALVE:

TABLE III SELECTION ON THE BASE OF DESIGN OF EXPANSION VALVE

Product	Expansion device
Type of Expansion device	Constant restriction type-Capillary tube
Capillary length	1.59m
Capillary diameter(ID)	0.80mm
Capillary material	Copper

C. EVAPORATOR:

TABLE IV- SELECTION ON THE BASE OF DESIGN OF EVAPORATOR

Product	Evaporator
Type	Fin and tube type
Tube material	Copper
Tube diameter (OD)	3/8"
Tube arrangement	Non-staggered
Type of fin	Plate type
Fin material	Aluminum
Number of fins/inch	9
Number of tubes	9
Face area (L x H) sq.cm	23 x 24
Number of rows	2
Overall dimensions in cm(Lx H x D)	23 x 24 x 9.5

D. CONDENSER:

TABLE V SELECTION ON THE BASE OF DESIGN OF CONDENSER (WATER COOLED CONDENSER)

Product	Condenser
Type	Shell and coil
Shell material	Stainless steel
Shell Dimensions (L x B x H) in cm	25.5 x 25.5 x 30
Number of turns of coil	9
Tube material	Copper
Coolant in shell	Water
Tube diameter (OD)	1/4"
Coil diameter	22cm

IV. EXPERIMENTAL SET UP:

Fig 2 Experimental Set up of Evaporative Water Generation.

Experimental set up consisting of 1. Compressor 2. Water cool condenser for sub cooling 3. Evaporator 4.Expansion valve.

V. RESULTS AND DISCUSSION:

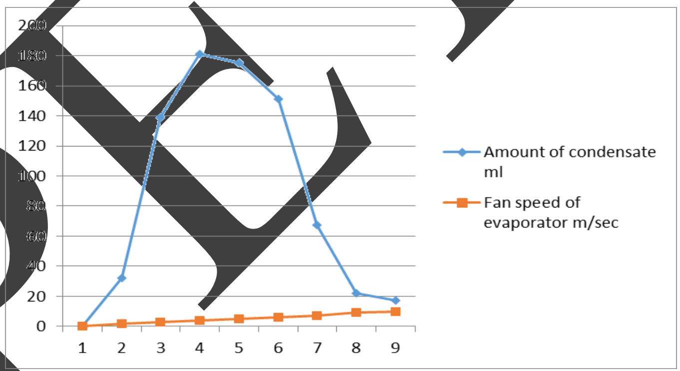

Figure 3 Effect of evaporator fan speed on condensate collection

Graph shows that rate of condensate and flow rate of air. Graph shows that rate of condensation is increases with flow rate up to 4 m/s and after that it will be slight decrement is shows in it. When flow rate is 0 m/s then no condensate is collected it means the surrounding moisture in air formed the ice around the evaporator tube. But as the flow rate increases beyond 2 m/s water condensation starts gradually. From the above graph it is observed that the maximum condensate is collected at the flow rate of 3.8 m/s. Hence all the trials of the system carried out on 3.0 m/s of flow rate.

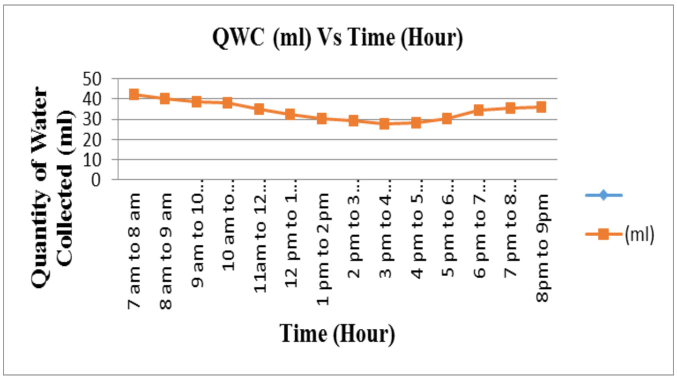

Figure 4 Variation of condensate collection for the span of entire day (System without Subcooling)

Experiment was conducted for the complete month of January 2017. Reading of the water condensate collected for every hour from 7:00 hour to 21:00 hour was noted. The amount of condensate collected shown in details as sample in above graphs. The experimental hourly rates of condensate extraction for typical dry days of January. It is observed that the condensate yield is more during the morning, then falls down in afternoon and again increases in evening. It is also observed that the maximum hourly condensate yield occurs during 7.00

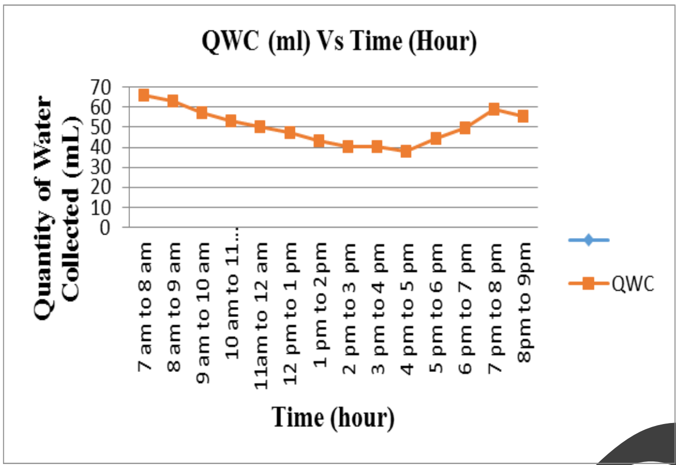

Figure 5 Variation of condensate collection for the span of entire day (With Sub cooling)

AM with a value of 241.25 ml during the morning (7:00–8:00 AM). On the other hand, the minimum hourly condensate yield occurs during the day time with a value of 59.6 ml. Average collection of water condensate is 1590 ml for one day for given time duration in graph.

From figure no 4 it is observed that total water collected is 423.3 and 478.6 ml respectively while figure no 5 it is observed that average total water collected by the system with subcooling is 700 ml per day for the same month of December 2016.

A system with subcooling reduces the temperature at evaporator more than system without subcooling, hence evaporator area is at very much lower temperature and hence the atmospheric air entering in the evaporator becomes cooler because of more temperature difference. This extra temperature difference is average 4 to 5 degree Celsius. Hence extra heat transfer facilitates more condensation in the same time of interval.

Hence performance by the system is increases and more output at same energy consumption occurs in the form of condensate.

VI. CONCLUSION:

From results and discussions it can be concluded that,

1. Average 1600 ml of water is generated from this system with the compressor of capacity 107W, hence if the system is enlarged by its size or capacity it will give about 20-25 litres of water per day which is sufficient for drinking for the family of 4-5 mebers. (it is generally observed that commonly used household air conditioner of 1.2-1.5 tonne with 1200W compressor potential collects 5 liters of moisture to dehumidified the room in 30 minutes after strting it in summer days.)

2. Water condensate collection shows that during morning and evening more exraction of water occurs than in afternoon, hence it is further concluded that during night time it will give more water than day time as the ambient temperature is lower during night than day. Hence system will run more effectively during night time.

3. Simulation results shows that COP of subcooled system is more than without subcooled system by 12.4% hence if subcooling is employed with the commonly used Air Conditioner will increase its capital cost but will decrease its running cost significantly, because heavy tariffs are applied for higher unit of power consumptions now a days.

4. As per results and discussions the cooled air from the evaporator can be used for various purposes effectively because of its lowered temperature than atmospheric temperature. This will save additional cost of cooling

5. Another byproduct of this system is hot water from condenser tank which can be used for making warm water which will again reduce the cost of heating water if needed

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TABLE X HOURLY CONDENSATE EXTRACTION OF JANUARY 2017

	Time	7am -8am	8am -9am	9am -10am	10am -11am	11am -12am	12am -13am	13am -14am	14am -15am	15am -16am	16am -17am	17am -18am	18am -19am	19am -20am	20am -21am
Date	Water volume collected in mililitre														
01/01/2017		220	192	186	145	100	65	52	59	54	48	52	71	88	105
02/01/2017		221.2	186	187.2	146.2	101.2	66.2	53.2	60.2	55.2	49.2	53.2	72.2	89.2	106.2
03/01/2017		255	187.2	188.4	147.4	102.4	67.4	54.4	61.4	56.4	50.4	54.4	73.4	90.4	107.4
04/01/2017		256.2	188.4	189.6	148.6	103.6	68.6	55.6	62.6	57.6	51.6	55.6	74.6	91.6	108.6
05/01/2017		257.4	189.6	190.8	149.8	104.8	69.8	56.8	63.8	58.8	52.8	56.8	75.8	92.8	109.8
06/01/2017		258.6	190.8	192	151	106	71	58	65	60	54	58	77	94	111
07/01/2017		259.8	192	196	152.2	107.2	72.2	59.2	66.2	61.2	55.2	59.2	78.2	95.2	112.2
08/01/2017		261	193.2	197.2	153.4	108.4	62.5	60.4	67.4	62.4	56.4	60.4	79.4	96.4	113.4
09/01/2017		262.2	194.4	190.4	154.6	109.6	63.7	61.6	60.6	63.6	57.6	61.6	80.6	97.6	114.6
10/01/2017		263.4	195.6	199.6	155.8	110.8	64.9	62.8	69.8	64.8	58.8	62.8	81.8	98.8	115.8
11/01/2017		264.6	201	200.0	157	112	66.1	64	71	66	60	64	[illegible]	100	117
12/01/2017		265.8	202.2	202	158.2	113.2	67.3	65.2	72.2	67.2	61.2	65.2	84.2	101.2	118.2
13/01/2017		267	203.4	203.2	159.4	114.4	68.5	66.4	73.4	68.4	62.4	[illegible]	85.4	102.4	119.4
14/01/2017		222	204.6	204.4	160.6	115.6	69.7	67.6	74.6	69.6	63.6	67.6	86.6	103.6	120.6
15/01/2017		223.2	205.8	205.6	161.8	116.8	70.9	68.8	75.8	70.8	64.8	[illegible]	87.8	104.8	121.8
16/01/2017		224.4	207	189	163	124.9	72.1	55.26	49.56	62.55	54.36	74.36	89	106	123
17/01/2017		225.6	208.2	190.2	164.2	126.1	73.3	56.46	50.76	63.75	55.56	75.56	90.2	107.2	124.2
18/01/2017		226.8	105	191.4	165.4	127.3	74.5	57.66	51.96	64.95	56.76	76.76	91.4	108.4	125.4
19/01/2017		228	106.2	192.6	166.6	128.5	75.7	58.86	53.16	66.15	57.96	77.96	92.6	109.6	126.6
20/01/2017		229.2	107.4	193.8	167.8	129.7	76.9	60.06	62.3	67.35	59.16	79.16	93.8	110.8	127.8
21/01/2017		230.4	108.6	156.8	188	130.9	78.1	61.26	63.5	68.55	60.36	80.36	95	112	129
22/01/2017		231.6	109.8	158	189.2	132.1	79.3	62.46	64.7	69.75	61.56	81.56	96.2	113.2	130.2
23/01/2017		232.8	111	159.2	190.4	133.3	80.5	63.66	65.9	70.95	62.76	82.76	97.4	114.4	131.4
24/01/2017		234	112.2	160.4	191.6	134.5	81.7	64.86	67.1	72.15	63.96	83.96	98.6	115.6	132.6
25/01/2017		235.2	113.4	161.6	192.8	135.7	82.9	66.06	[illegible]	73.35	65.16	85.16	99.8	116.8	133.8
26/01/2017		236.4	114.6	162.8	194	136.9	84.1	67.26	[illegible]	74.55	66.36	86.36	101	118	135
27/01/2017		237.6	115.8	164	195.2	138.1	85.3	68.46	70.7	75.75	67.56	87.56	102.2	119.2	136.2
28/01/2017		238.8	117	165.2	196.4	139.3	86.5	69.66	71.9	76.95	68.76	88.76	103.4	120.4	137.4
29/01/2017		234	118.2	166.4	197.6	140.5	87.7	70.86	73.1	78.15	69.96	89.96	104.6	121.6	138.6
30/01/2017		235.2	119.4	167.6	198.8	141.7	88.9	72.06	74.3	79.35	71.16	91.16	105.8	122.8	139.8

REFERENCES:

1) A. Magrini, L. Cattani, M. Cartesegna, L. Magnani, *Integrated systems for air conditioning and production of drinking water – Preliminary considerations,* Elsevier, Energy Procedia, Volume 75, August 2015, Pages 1659-1665.
2) Abdulghani A. Al-Farayedhi, Nasiru I. Ibrahim, P. Gandhidasan, *Condensate as a water source from vapor compression systems in hot and humid regions*, Elsevier, Desalination, Volume 349, 15 September 2014, Pages 60-67.
3) S. A. Nada, H. F. Elatter, A. Fouda, *Performance analysis of proposed hybrid air conditioning and humidification–dehumidification systems for energy saving and waterproduction in hot and dry climatic regions,* Elsevier, Energy Conversion and Manageent, Volume 96, 15 May 2015, Pages 208-227.
4) Ahmed M. Hamed, A. E. Kabeel, E-Shafei B. Zeidan and Ayman A. Aly, *A technical review on the extraction of water from atmospheric air in arid zones*, JP Journal of Heat and Mass Transfer, Volume 4, 3 November 2010, PP 213-228
5) Xiaohui She, Yonggao Yin, Xiaosong Zhang, *A proposed subcooling method for vapor compression refrigeration cycle based on expansion power recovery*, Elsevier, International Journal of Refrigeration, Volume 43, July 2014, Pages 50-61
6) Gustavo Pottker and PegaHrnjak, *Effect of the condenser subcooling on the performance of vapor compression systems, Elsevier,* International Journal of Refrigeration, Volume 50, February 2015, Pages 156-164.
7) Margarita Castillo-Tellez et all, *Experimental study on the air velocity effect on the efficiency and fresh water production in a forced convective double slope solar still, Elsevier*, International Journal of Applied Thermal Engineering, Volume 75, October 2014, Pages 1192-1200.
8) Justin P. Koeln and Andrew G. Alleyne, *Optimal subcooling in vapor compression systems via extremum seeking control: Theory and experiments,* Elsevier, International Journal of Refrigeration, Volume 43, March 2014, Pages 14-25.
9) Shan K. Wang, "*Handbook of Refrigeration And Air Conditioning,"* Second Edition, McGraw-Hill 2000.