Experimental Analysis of Potable Water Generation using Humidified Air

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ABSTRACT
Overcoming the problem of water scarcity is the need of hour. Although desalination process and other sustainable methods are in pipeline for overcoming this problem still, they are in a budding stage as of now. Hence an alternate solution in overcoming this problem is the utilization of atmospheric dew water. Atmospheric dew water has humongous potential in developing the potable water. This source still remains untapped to a large extent. Hence, in this work it is aimed at extracting potable water by utilising the atmospheric dew water. An experimental set up was made consisting of the compressor, condenser, expansion valve and evaporator through which water is collected. This water is collected on daily basis for a period of 7-month tenure and the yield and purity of water is examined experimentally. The monthly average water yield on a daily basis is calculated and the cost analysis for the generation of per litre of water is performed. The outcomes of this work showed the water generation of 20 litres a day on average and the average cost for its generation for a litre was calculated to be INR 14.12 /- which is less than a dollar. At humidified geographical locations this method proves to be a consistent and sustainable solution to overcome the gigantic problem of water scarcity.

Keywords:*-Atmospheric dew water, Potable water yield, Cost analysis.*

Nomenclature:-

ADWG	: Atmospheric Dew Water Generator
HP	: Horse Power
R-22	: Refrigerant 22
mph	: miles per hour,
Kms	: Kilometres
RH	: Relative Humidity
Evap	: Evaporator
m_r	: Mass of the refrigerant inside the pipe
Q_{absb}	: Heat Absorbed
$Q_{rej.}$	: Heat Rejected
$W_{comp.}$	: Compressor work

INTRODUCTION

World population is increasing at a steeper rate and it is currently 7.7 billion and it will reach to 9.7 billion with in no time [1]. With the drastic increase in population the utilization of resources for improving standard of living is also increasing. In recent times the scarcity of water is also increasing due to rapid consumption and increase in population. Mesfin et al. [2] revealed approximately 4 billion people will suffer from water scarcity at least for a month during a year and half a billion people are suffering throughout the year globally [3]. These statics shows the significance of fresh water. Although, 73%

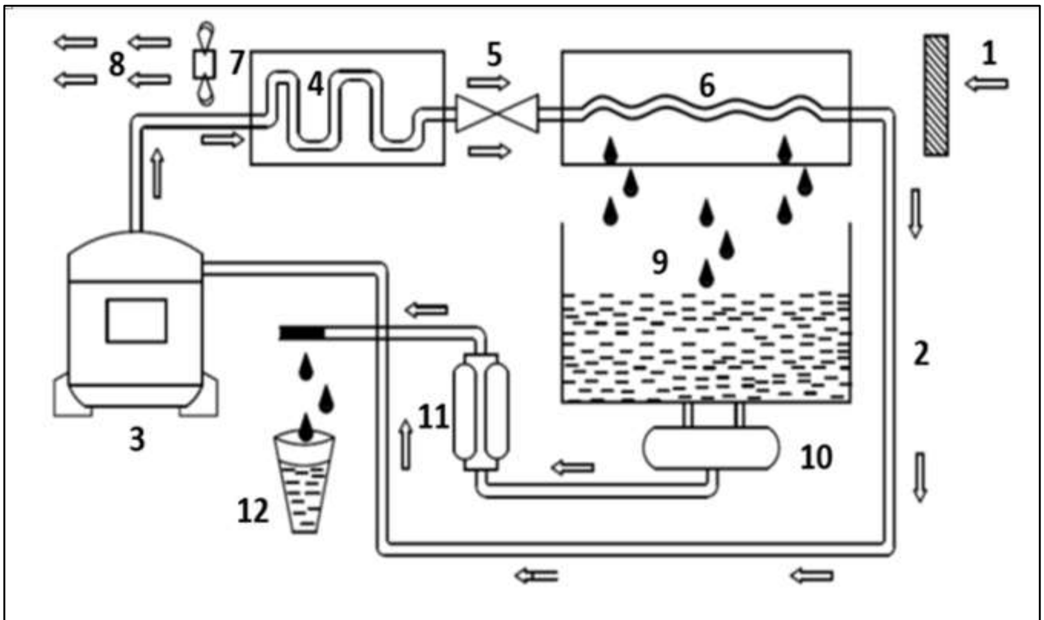
of the earth is surrounded with water but unable to meet the requirement due to the presence of dissolved salts [4]. To mitigate the challenge of water scarcity: seawater desalination process, rain water harvesting and atmospheric water vapour processing etc can be used [5]. Seawater desalination techniques involves high cost and it may not be affordable for under developed or developing countries whereas rain water harvesting is dependent on climate and also more space is required for installation and maintenance. Now atmospheric water vapour processing technique completely rely on humid air and it can be installed with low cost compared to other two methods. These features made the atmospheric dew water generator (ADWG) a popular solution for solving the water scarcity problems. The ADWG is most suitable for coastal regions where the presence of humid air is surplus with an estimated amount of 12.9 $\times 10^{12}$ m^3 of renewable water. Literature reveal that: ADWG technique is a reliable technique to harvest water from the atmosphere [4]. Wei He et al. [5] used thermoelectric coolers for extracting water from atmospheric vapour. For this purpose, two models were designed and experimentally studied under varying flow rates. Results reported that water yield increases with the increased humidity and flow rate i.e. at 90% humidity air, 30 m^3/h flow rate the total water yield of 43.4% was increases. Bahram Asiabanpour et al. [6] compared the cost of water generated through the atmospheric water generator (ADWG) to the regular bottled water and reveal that ADWG technique is cost effective. The other advantages of ADWG system it can make use of solar energy via photovoltaics or solar thermal to harvest the moisture from air. From the above discussions it is clear that the possible and economic way to combat with the water crisis is by utilizing the ADWG. Therefore, in the present endeavour a potable atmosphere water generator was designed and fabricated to extract water from the humid air or atmospheric dew. The detailed experimental procedure with calculations is discussed in methodology and results.

MATERIALS AND METHOD

The atmospheric dew water generator (ADWG) unit is designed and fabricated at the campus of Department of Mechanical Engineering, Raghu Engineering College, Visakhapatnam, India located at 17°59'41.6"N 83°24'52.9"E, and elevation above sea level is 24 m. The campus is located 21.3 km from Bheemili Beach as shown in Figure 1. The average wind velocity in normal days in this loaction is 9.4 mph and the experimentation was carried out at different climatic conditions from October 2019 to April 2020 to collect the water.

Fig.1:-*Location site of the experimental set up,*
(Courtesy: Google map taken on February 2020)

The ADWG unit consists of hermitically sealed reciprocating compressor of 1/3 H.P, condenser and an evaporator. The overall dimensions of the unit are 55 cm x 55 cm length and 30 cm x 30 cm breadth. The schematic view of the experimental setup is present in Figure 2a and photographic view of the unit is shown in Figure 2b. Refrigerant R-22 is used in the present investigation as a coolant and a draft fan of forced type is installed to cool the condenser. A hygrometer is utilized to measure the humidity levels (10% to 99% relative humidity) and dry bulb temperature (DBT) from -10^{0}C to 50^{0}C with a battery capacity of 1.5 V. A storage tank of 25 litres is fitted to the unit to collect the water generated during the process. Along with these equipments the accessories such as thermocouples, hygrometer and psychrometer are connected to the equipment at various locations required for the calculations purpose.



Parts: 1. Moist air In 2. Refrigerant fluid line (R-22) 3. Compressor 4. Condenser 5. Capillary tube 6. Evaporator 7. Draft Fan 8. Warm air out 9. Storage tank 10. Ozone generator 11. Water filter 12. Glass of water.

Fig.2(a):-*Schematic view of the experimental set up*

Fig.2(b):-*Pictorial representation of the experimental set up*

METHODOLOGY

The working of ADWG is relied on vapour compression refrigeration cycle and the refrigerant used in this present endeavour is R-22 which is used to absorb the moisture. The ADWG units comprises of three main circuits which are known as refrigeration cycle, psychometric cycle and water generation cycle. Initially the moist air enters into the electrostatic air filter as shown in the Figure 2a then it passes over the evaporator where dehumidification takes place. During this process the dry air and water vapour gets separated results in formation of water droplets which are collected in the storage tank as shown in Figure 2a The refrigerant R-22 is filled inside the pipe of evaporator (cooling), from there the refrigerant flows to the compressor where it is converted to vapour in the compressor. The hot refrigerant vapour enters into the condenser (heat rejected) and gets condensed to liquid. The refrigerant expands to low pressure inside the capillary tube. The low-pressure liquid refrigerant enters into the evaporator and gets evaporated by absorbing the heat from humid air and this gets dehumidified and gets collected in the storage tank.As the superheated vapor particles enters the evaporator where the tempperature is less they gets condensed and water droplets are stored.These stored water droplets in the final cycle gets collected in the storage tank and is processed to remove impurities by ozone generator and filtered with carbon filters. The finally obtained water samples were used for further analysis.

RESULTS AND DISCUSSIONS

Relative Humidity Measurements

Relative humidity (RH) plays a significant role in extraction of water from the atmosphere. In this current endeavour the relative humidity data for the experimental location is collected from the time and data source [10]. A P-h chart of R 22 is used to get the values of enthalpies used for the calculation purpose. A graphical plot is drawn in Figure 3 in comparison with relative humidity from different metrological cities in the country. The RH data is obtained from Oct-2019 to April 2020 and from the Figure 3 it is evident that experimental location (Visakhapatnam) is having an average RH of 70% which is higher than Chennai, Puri, Kolkatta and Panaji. Therefore, it is evident that the chosen experimental location can be used for ADWG to mitigate the challenge of water scarcity in the city. Table 1, represent the relative humidity and average dew point temperature for the experimental location for the period of 7 months which is obtained from the free source [10]. From the Table 1, it is evident that an average RH and dew point temperature is observed as 70 % and 20.9 ^{0}C for Visakhapatnam. In the similar manner the average relative humidity for various cities are found and plotted which are represented below in Figure.3.

Table 1:*-Monthly report of relative humidity and dew point temperature in Visakhapatnam city.*

	Oct-19	Nov-19	Dec-19	Jan-20	Feb-20	March-20	April-20	Avg
Relative Humidity (RH) %	74	68	67	71	70	69	71	70
Dewpoint temp (^{0}C)	23.2	19.9	17.8	18.1	20.1	22.4	24.8	20.9

Fig.3:-*Relative humidity comparison between different meteorological cities in the country*

WATER YIELD CALCULATIONS

In line with the approach for the dew point temperature, the relative humidity plays a crucial role to extract the amount of moist air and generate water. Here the experiment is made to operate in the campus located in Visakhapatnam, for seven months during October 2019 to April 2020 irrespective of all climatic conditions. Amount of yield water generated for 1m^3 of air is estimated by taking the average relative humidity with fixed dry bulb temperature for seven months as shown in the Table 2. The parameters required for the yield water generation [5,8] were the partial pressure of air taken $P_a = 1.01325$ bar, and saturation pressure P_s obtained from the steam tables @ 30 ^{o}C $P_s = 0.0424$ bar, and specific humidity ratio ω, the Partial pressure of dry air P is obtained by using the Eq. (1)

$$P = P_a - P_w \quad (1)$$

where the partial pressure of the water P_w is calculated using the Eq. 2 & 3 i.e.

$$P_w = \left(\frac{RH}{100}\right) x\ P_S \quad (2)$$

$$RH = \frac{P_w}{P_s} X\ 100 \quad (3)$$

The volume of water present in 1m^3 of air is obtained by using the specific humidity ratio as shown in the Eq. (4)

$$\omega = \frac{0.622\ x\ P_w}{P_a - P_w} \quad (4)$$

Using the above calculation procedure the average specific humidity is found out on monthly basis for the months of October-2019,November 2019,December-2019,January 2020,February-2020,March-2020 and April -2020 and the values are depicted in the Table.2 below.The plot between monthly yield and the month representing the highest yield is shown in Fig.4

Table 2:-*Average yield water generation values during october 2019 to april 2020.*

S.No.	Metrological cities	Average relative humidity (%)	Average dew point temperature (^{0}C)	Fixed dry bulb temperature (^{0}C)	Specific humidity (kg of water / kg of dry air)	Average yield of water generated in liters (ω x 1000)
1	Visakhapatnam (Oct- 2019)	71.8	22.8	30	0.019267	19.26
2	Visakhapatnam (Nov-2019)	74	23.2	28	0.019876	19.87
3	Visakhapatnam (Dec-2019)	68	19.9	26	0.018217	18.21

4	Visakhapatnam (Jan-2020)	67	17.8	27	0.017942	17.94
5	Visakhapatnam (Feb -2020)	71	18.1	29	0.019046	19.04
6	Visakhapatnam (Mar-2020)	70	20.1	30	0.018769	18.76
7	Visakhapatnam (Apr-2020)	69	22.4	32	0.018493	18.49

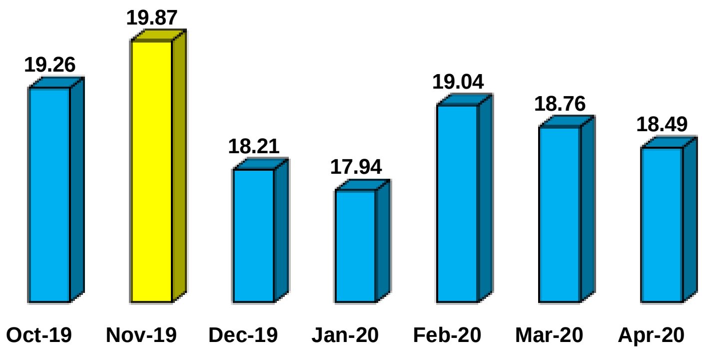


Fig.4:*-Plot for monthly average yield in Visakhapatnam during October 2019 to April 2020.*

COST ANALYSIS

Based on the yield of water generated the cost analysis is done for the generation of litre of a bottle extracted from the set-up. Initially the work done on compressor,heat extracted and heat removed are found out.The cost of generation for each litre of water is found by the analysis of electricity consumption done for the entire month and the average yield generated by the equipment. The cost of energy consumption is taken to be INR 6.11/- per kWh of unit consumption as per the State Governement of India .The analysis stated that for the month of October-2019 the water generated is priced as INR 13.23 /-. In the similar way the price of generation is calculated for the other months also. The values are tabulated and represented below in Table 3 and the plot between water yield and the cost generation per litre of water extracted is plotted and shown in Figure 5.

Table 3:*-Cost analysis for generation of a litre of water from October 2019 – April 2020*

S.No.	Month	$W_{comp.}$ (kW)	$Q_{absb.}$ in the Evap. (kJ/s)	m_r flowing in`side the pipe	Energy consumed in kWh	Running cost per month (INR)	Running cost per day (INR)	Yield (Liters)	Cost per liter (INR)
1	Oct – 19	60	30	0.029	1252	7649	254.9	19.26	13.23
2	Nov - 19	80	36	0.0249	1434	8761	292.4	19.87	14.71
3	Dec – 19	68	32	0.028	1369	8364	278.8	18.21	15.30
4	Jan – 20	67	28	0.032	1512	9238	307.9	17.94	17.16
5	Feb – 20	54	36	0.0249	968	5914	197.1	19.04	10.34
6	Mar – 20	68	32	0.028	1370	8370	279	18.76	14.86
7	Apr – 20	62	33	0.027	1205	7362	245.4	18.49	13.26

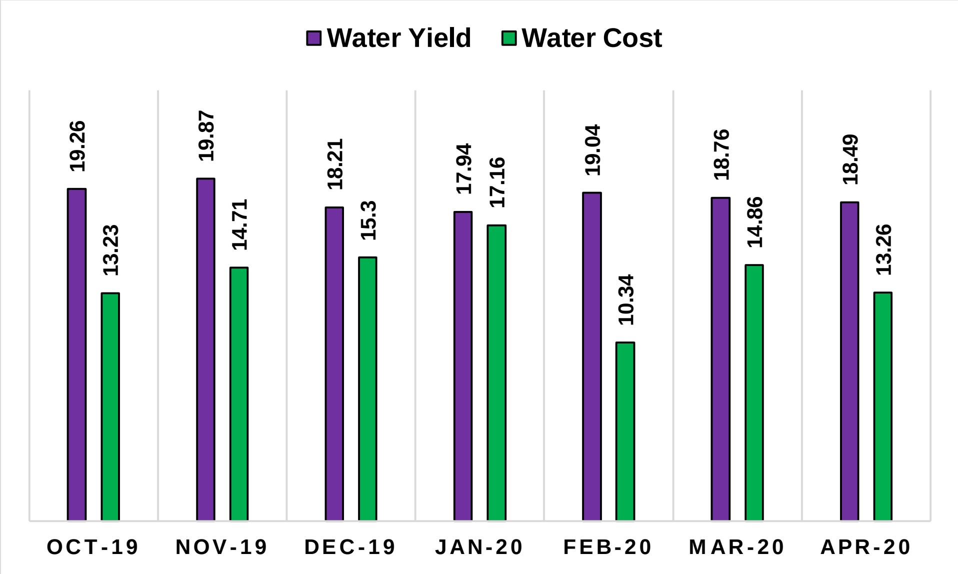


***Fig.5:-**Plot for water yield and water cost for all the months*

Reference calculations for the production of yield water generation and cost estimate for one liter of water in visakhapatnam is found below:

The parameters required to estimate the cost of water genration for 19.26 liters are heat absorbed $Q_{absb.}$, mass flow rate of refrigerant (m_r), heat rejected in the condenser $(Q_{rej.})$, and compressor work $(W_{comp.})$. Equation (5), gives the amount of heat absorbed as, $Q_{absb.} = mCp\ dt + (w\ x\ h_f g) = 1 \text{ x } 1.005 \text{ x } (30 - 22.8) + (0.01923 \text{ x } 2430.7) \quad = 53.978 \text{ kJ/min}$, $Q_{absb.} = 0.8966$ kW, and the mass flow rate (m_r) is calulated by $m_r = \frac{Q_{absb.}}{(h_1 - h_4)}$, $0.8996 = m_r \text{ x } (200 - 170)$, $m_r = 0.030$ kg/sec, Eq. (6), also the amount heat rejected in the condesner is obtained by using the Eq.(7), $Q_{rej.} = m_r + (h_2 - h_3) = 0.030 + (260 - 170) = 2.7$ kJ/s . Finally the compressor work is estimated for the generation of the water potential is $W_{comp.} = m_r x\ (h_2 - h_1)$ Eq.(8), $= 0.030 \text{ x } (260 - 200) = W_{comp.} =$ 1.80 kW.

Using the above values the cost estimation for the amount of water generated is determined by:

Amount of water extracted for the month of october 2019 $=$ 19.26 litres

Power consumed by compressor

$= 1.80$ kW

Total usage $= 30 \text{ x } 24 = 720$ hrs.

Total energy units consumed

$= 30 \text{ x } 24 \text{ x } 1.8$

$= 1296$ kWh

Cost per electricity unit is

$=$ Rs. 6.11 /−

Total running cost is obtained as

$= 1296 \text{ x } 6.11$

$=$ Rs. 7918.56 /−

Cost of the water gneration per day

$= {7918.56}/{30}$

$=$ Rs. 254.9 /−

For 19.266 litres of average yield water, the price obtained is $=$ Rs. 254.9 /−

Cost per litre $=$ Rs. 13.23 /−

Hence the average cost per litre of water generated for 7 months on a daily basis is obtained by the ratio of total sum of cost per liter from October 2019 to April 2020 to the number of months the water is extracted is calculated as follows:

$= {(13.23 + 14.71 + 15.30 + 17.16 + 10.34 + 14.86 + 13.26)}/{7}$

$= 14.12$ /−

WATER PURITY

Degradation of water quality is greatly led to a variety of global issues, including human availability of drinking water and the survival of animals. Hence it is very important to determine the potability of water. Therefore the water collected is being checked in the chemistry lab for finding the alkalinity of water using the pH meter the alkalinity of water is tested which came aroun 7.38 for the month of October - 2019.

CONCLUSIONS

The highest average yield of water was found in November 2019 to be **19.87 litres.** Water scarcity is on rising high which is engulfing the whole world slowly. Hence sustainable development of solutions for generation of water rather than harvesting and recycling is the need of the hour. Hence, devices like ADWG would help a lot in providing long term solutions for lethal problems like water scarcity. The novelty over here is indicated by the inlet of moist air which is the source of water. The problem of overcoming scarcity of water is piling up day by day and techniques like here if followed in a proper manner would yield results to overcome such acute problems in a sustainable manner.Hence, this is a small step in the direction of reducing the water scarcity which is engulfing the whole world in a rapid rate.

FUTURE SCOPE

Although high quality of water is expected from this equipment, presence of volatile organic compounds (VOC's) in air gets dissolved in the condensate and leads to the microbial growth.This microbial growth may question the quality of water generated hence if chemical analysis of elemental presence is done as per the Environmental Protection Agency (EPA) drinking water standards than the generated water can be used for drinking purposes also which is our proposed future work. As an application part this unit generated, if utilised for marine applications will be much benefit and the problem of fresh drinking water availabilty in their voyage can be solved to a larger extent comprising of the fact that within the sea it is highly humidified region.

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BIOGRAPHIES

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