Design and fabrication of multi-functional equipment to produce gaseous nitrogen/oxygen and water from ambient air

Debdutta Chatterjee*, Krishnasamy Karunamurthy, Nimmagadda Sree Nigam Aditya, Deepak Dalal
School of Mechanical Engineering, VIT Chennai, India
*Corresponding Author: debdutta.chatterjee2017@vitstudent.ac.in

Abstract. Mother earth provides all the necessary resources for the existence of life. Despite the rich resources of water on our planet, majority of world’s total population experiences water shortage annually. Studies have shown that with the increase of global warming, the average humidity of ambient air is rising annually. Due to the decrease of water table on land, alternative sources of acquiring potable water can be of great utility. Out of the several methods available to tap potable water, this paper aims to achieve an alternate source of receiving fresh water directly from ambient air. This process is completely different from distillation. The ambient air also comprises a majority of Nitrogen, and this N2 is used for the purpose of creating an inert environment in packaging industries and for the purpose of extinguishing fire, a multi-functional equipment has been fabricated in order to extract water, along with pure Nitrogen gas from the residual dry air. A Pressure Swing Adsorption (PSA) system is used to separate the Nitrogen from remaining air molecules based on their relative molecular size. In the current industrial sectors, the valves required to actuate the flow of air in PSA system are controlled by PLC circuits and Cam followers. These electro-mechanical components are overpriced. In this work electronic timers are used to actuate the valve timing, which resulted in economical. The system fabricated is simple in construction and it is easy to replace the Carbon Molecular Sieves (CMS) with Zeolite Molecular Sieves in order to obtain Oxygen gas as the pure product that can be used to help Covid-19 patients using medical grade filters. The system can be scaled up with larger mass of CMS, bigger PSA towers and greater compressor power in order to increase productivity.

Keywords: Water from air; N2 and O2 production; Pressure Swing Adsorption; Carbon Molecular Sieves; Covid-19

1. Introduction
Earth has uneven distribution of resources and that includes potable water. We live in a thirsty world. According to WHO every person needs approximately 50 liters of water every day for basic needs like drinking, preparing food, personal hygiene and sanitation [1]. Despite the rich resources of water of our planet more than half of world’s total population (about 4 billion individuals) face water shortage for at least one month every year. A study conducted on the major Indian metro cities found that the water samples failed in 19 out of the 28 parameters. We see that the majority of water on earth (about 96.5%) is in the oceans which is unfit to consume [2]. About 1.7% is in the streams, lakes and soil, approximately 1.7% is found in glacial ice caps, and just 0.001% in our earth’s atmosphere. Compared to the general sources of potable water, the atmospheric water the numbers may look small but it turns out that about 1.29x10^16 L is in the form of clouds, water vapor and fog [3]. About one square-kilometer of atmospheric air contains 10,000 m³ - 30,000 m³ of pure water, in most regions around the globe. Also, studies shows that the amount of water in air has risen over the years and decades. So, if we can extract this moisture in the air, it can potentially help us to a certain extent.
Figure 1: The change in Specific Humidity from year 1971-2010.

From [Figure 1] we can interpret that there is a rising trend in the humidity which we would like to encase. For one thing, humidity is everywhere, even in the desert. We could provide a sensible supply of water in many arid regions, like nations from the southern Mediterranean regions as well as those suffering from water pollution, together with tropical countries, and places where long channel or pipe systems for water transport are not available.

After air has been utilized to extract the water, we shouldn’t let the residual dry air go to waste. We can use it to obtain the major individual component gases in the air mixture specifically nitrogen and oxygen. Pressure Swing Adsorption (PSA) is a technique using which we can trap different gaseous states based on the difference in their molecular sizes.

Carbon Molecular Sieves (CMS), consist of pores or cavities present on the surface of molecular sieves which adsorb Oxygen molecules on its surface due to the minute difference in molecular sizes (Nitrogen has a size of 4.2 Å and Oxygen has a size of 3.9 Å while the size of the hole is 4.0 Å). The separated N2 gas can be used for various applications. It can be used to displace oxygen in food packaging and creating an inert atmosphere to prevent contamination. Eliminating oxygen makes food fresh and long-lasting. It also can provide a bolster the food to avoid its breaking during transportation. Another application can be to inflate tyres, making them durable by reducing oxidation. It improves tire pressure-holding capacity giving improved mileage. It can also be used in soldering or for electroplating steel during manufacturing. It has numerous applications in pharmaceuticals and chemical plants.

Similarly, oxygen can be used in oxy-acetylene torches for cutting and fusing metals or to remove impurities such as carbon from the steel throughout manufacturing or it can be used in medicine. We can also create an oxygen enriched atmosphere in offices and malls.

For mining moisture from ambient air, there can’t be the only technology serving for all the areas. In foggy zones, the solution may be setting up systems that can cause suspended water droplets in the air to coalesce. In humid environments, with thick water vapor in air but without nucleation into droplets, devices that can condense the vapor and collect it might be best. And in arid regions, specialized machineries that can excavate the slight moisture that’s around will need to be designed and developed.

1.1 Review Of Literature

A wide variety of research papers, reviews and patents were studied in order to understand the behavior of different CMS structures and PSA systems along with molecular behaviors that lead to the separation of Nitrogen and Oxygen from ambient air.

According to the paper published by Teresa A. Centeno and Antonio B. Fuertes based on supported CMS membranes that were based on a phenolic resin, the diffusivity parameter for granular carbon molecular
sieves changes with molecular size. The gas separation was not applied to the separation of CO2 gas because it is an absorbable gas at 298 K [4].

From the study conducted by R. V. Jasra, N. V. Choudary & S. G. T. Bhat about the separation of gases using PSA, it has been understood that the attractive forces that are accountable for adsorption are the van der Waals forces. Desorption can be attained either by raising the temperature in the system, or by dropping the adsorbate pressure. The phase dealing with desorption also results in regeneration of the adsorbent surface for reuse throughout the following adsorption step. The CMS contain pores that are in a narrow range of approximately 5 and 10 and with a maximum pore volume of 0.25 cm$^3$/g [5].

The researches T. A. Braymer, C. G. Coe, T. S. Farris, T. R. Gaffney, J. M. Schork, J. N. Armor also expressed their findings about Granular CMS, that any CMS for production of N2 in the commercial should have a greater volumetric O2-equilibrium capacity. Commercial O2 selective CMS are of bimodal porous materials that separate the O2 from N2 on a kinetic basis. They are used broadly for the production of 95-99.7% pure N2, by the PSA process.

Similarly, according to S. J. Bhadra and S. Farooq it can be understood that N2 productivity progressively rises as the pressure of adsorption is increased [6].

We confirmed about the types of processes inside the PSA beds by studying that the efficient two-fold PSA process designed consists of two cycles with the same steps:

- Adsorption
- 2 de-pressurizing equalizations
- Evacuation
- 2 pressurizing equalizations
- Backfilling

This data was collected from the research conducted by José Antonio Delgado Dobladez, about the prototyping and simulation of the effective separation of NH3/N2 mixtures with [Ni3(HCOO)6] MOF by PSA [7].

We studied about the physical properties of CMS like strength and the stability with pressure changes from the paper by Mohamed Saffdar Allie Baksh and Frank Notaro, that adsorbents that are CMS based have neither adequately high density nor crush strength. Subsequently, in faster PSA cycles, the abrupt changes in pressure can cause the CMS type adsorbent to drift and pulverize due to the grinding action amongst the granules. To minimize crushing, the flow rate of the moving gas is reduced, with associated increase in cycle time period, namely, lower product makes rate and greater bed size factor [8].

According to the paper by S. J. Bhadra and S. Farooq in order to separate NH3/N2 mixture by PSA process in order to upgrade Natural gas, it has been found that N2 productivity progressively improves as the pressure of adsorption is increased. [9]

The most important factor that leads to the separation is the relative size of the molecules as compared to the sieve. We collected the fact that the kinetic diametrometer sequence of the gas molecules in air is He $<$ H2 $<$ CO2 $<$ O2 $<$ N2 from the paper about permeation of gasses through micropores of CMS Membranes Derived from Kapton Polyimide, and published by Hiroyuki Suda, Kenji Haraya [10].

From a review on the different water-extraction methods from atmosphere in arid zones by Ahmed M. Hamed, A. E. Kabeel, the most common methods are cooling saturated ambient air to a temperature which is lower than the dew point temperature of the air, and absorbing the vapor from humid air by using a solid/liquid desiccant, with following retrieval of the removed water by heating the desiccant and condensing the water that was evaporated [11].
2. Methodology

The above flowchart in figure 2 represents the strategy employed while building the prototype. Once, the idea was formed, much time was spent on carrying out the literature survey required for the components, calculations and processes involved. Taking points from the survey, a layout was proposed and only then the material and the machinery required were bought. Then the prototype was fabricated and experimented on before finalizing as a product.

3. Process Diagram of the System

The above flowchart in figure 2 represents the strategy employed while building the prototype. Once, the idea was formed, much time was spent on carrying out the literature survey required for the components, calculations and processes involved. Taking points from the survey, a layout was proposed and only then the material and the machinery required were bought. Then the prototype was fabricated and experimented on before finalizing as a product.

Figure 2. Flowchart explaining the methodology followed.

Figure 3. Layout of the system.
The layout consists of a reciprocating air compressor, a 9L compressor tank, a refrigerant type air dryer, 2 Pressure Swing Adsorber (PSA) beds and 1 surge tank.

The purpose of a compressor is to collect greater quantity of humidity in a smaller volume of ambient air, so that a greater quantity of water gets condensed per unit volume when dew point temperature of air is reached at 6 bar(g) to 8 bar(g) pressure. The compressor used was a 550W, 220V/50Hz, 3.73 cfm (110 lpm), 1440 rpm reciprocating compressor, working pressure 6.5 bar(g) with the cut-off pressure as 8 bar(g). The reason for choosing this model is that the compressor is compact, which makes it portable, quite economic, easily available in the market and the greatest advantage is that it is oil-free. When compared to a screw compressor as an alternative, a screw compressor would require 3 types of filters: a pre-filter, a coarse filter and a fine filter in order to remove the oil present in them up to 0.003 ppm. Hence an oil-free reciprocating compressor was chosen for this project. A compressor tank was used to adjust small changes in the pressure and for storing the compressed air. The relatively cooler walls of the compressor tank will be an advantage to initially condense a small quantity of water vapor present in the air.

The refrigerant type air dryer was used as a cooler and dehumidifier. The model used for the dryer is ELRD20 and the makers are ELGI. It is the lowest available air dryer in the market. It is quite economic and compact with capacity up to 20cfm air-flow and 16 kg/cm2 air pressure with a +2°C pressure dew point.

The dryer consists of a refrigeration system, where the evaporator is a tube in tube type heat exchanger made of copper, where the outer tube is for the air to flow and the inner tube for refrigerant R134a to flow. It is puff insulated to reduce heat loss.
The PSA beds, as shown in the figure 4, is filled with small cylindrical black solids called Carbon Molecular Sieves (CMS), of Grade- 1.5 GN-H, Purity- 99.5% minimum. There is a pack of coconut fiber attached in order to tighten the packing and to prevent opposite forces that may crush the CMS during pressure changes. The complete bed is welded using Metal Inert Gas Welding using CO2 gas in order to prevent blowholes. There is a 5 mm thick mild steel plate with 5 mm diameter holes at pitch of 10 mm. Ambient air comprises of 78% Nitrogen, 21% Oxygen and 1% of other gas molecules. The purpose of the CMS is to adsorb the Oxygen molecules into the pores at a minimum pressure range of 6-6.5 bar(g). Since Oxygen molecules are smaller than Nitrogen molecules, the oxygen molecules get trapped inside the pores, leaving behind the nitrogen molecules. The PSA consists of 2 beds, one undergoing adsorption and the other undergoing regeneration. The total cycle time is 2 minutes. There is a 2 second gap after every minute for pressure equalization. During adsorption in one of the beds (1 minute duration), the oxygen is adsorbed at 6.5 bar(g) pressure and 99-99.5% pure Nitrogen is collected and stored into the surge tank. During the same 1 minute, the other bed is undergoing regeneration, where the reduction in pressure (caused after 2 seconds of pressure equalization) back flushes the trapped oxygen from another outlet. This oxygen is not as pure as compared to the nitrogen product. The PSA system consists of eight ¼” solenoid-controlled gate valves (denoted as V in the figure) that are used to control the flow of dry air from the dryer to the PSA system. It also regulates the flow of air by reversing the flow for pressure swing during adsorption and regeneration.

| Time (sec) | V1 | V2 | V3 | V4 | V5 | V6 | V7 | V8 |
|------------|----|----|----|----|----|----|----|----|
| 58         | 1  | 0  | 0  | 1  | 1  | 1  | 1  | 0  |
| 60         | 0  | 0  | 1  | 1  | 0  | 0  | 1  | 1  |
| 118        | 0  | 1  | 1  | 0  | 1  | 0  | 1  |    |
| 120        | 0  | 0  | 1  | 1  | 0  | 0  | 1  | 1  |

**Figure 5. Valve Timing Diagram.**

The time period of each cycle is 2 minutes as shown in the above figure 5 and the valve components have been named in figure 6 below. During the first 58 seconds of cycle, the valves V1 (inlet valve), V4
(exhaust valve), V5 (Oxygen exhaust valve), V6 (final product valve) and V7 (product valves) are open to let the adsorption to take place at bed 1. During the next 2 seconds (pressure equalization) the valves V3 and V4 (exhaust valves), V7 and V8 (product valves) are open in order to stabilize the pressure between the two vessels. This causes an intermediate pressure as the remaining gas in adsorber bed 1 flows to the adsorber bed 2. During this step neither air is absorbed, nor is the product gas (nitrogen) produced. During the next 58 seconds, the adsorber bed 1 undergoes depressurization (regeneration) where the trapped gases such as Oxygen, Carbon dioxide and other inert gasses are back flushed. Due to the reduction in pressure, the CMS loses its ability to hold the adsorbed gases and hence releases them as an exhaust. At the same time, the adsorber bed 2 starts operating at 6-6.5 bar(g) pressure. This is again followed by a pressure equalization stage for 2 seconds and the pressure swing cycle is hence repeated.

Figure 6. PSA Valve Layout.

According to current industrial sectors, the solenoid-controlled gate valves are operated by PLC circuits and CAM followers, which is fairly expensive. Our project aims at using simple ways to control valves using 2 simple electronic timers. This is a completely new method of actuation, which is cost effective and needs no knowledge of coding. The electronic timer circuit is briefly shown in the figure 7 shown below. There is a live channel A1 and a neutral channel A2. Each timer consists of two common points shown as 15, 25, two NC points shown as 16, 26, and two NO points shown as 18, 28. The solenoid coil is charged lies between the Live and the common point and is charged by A1. In the first timer, 16 is connected with V1, 24 is connected with V4 and V7. In the timer, 18 is connected with V2, 28 is connected with V3 and V8. We have kept V5 open for all time since the machine is not continuously operated and also V6 is kept open since the surge tank has a manually operated valve used to store the Nitrogen gas. Each valve is connected to the Neutral channel. The connectors between the common points and the NC, NO points act as a Single Pole Double Throw switch (SPDT). Initially when the solenoid is uncharged, the connectors rest on the NC points, keeping V1, V4, and V7 open during the first cycle, in the meantime keeping V2, V3 and V8 closed. During the next cycle V2, V3 and V8 are open, whereas V1, V4, V7 are closed.
4. Materials and Equipment
The components used in this project and their specifications have been listed below:

- The Reciprocating Air Compressor used for this system as shown in figure 8 has a power rating of 550 w, maximum pressure of 8 bar(g), tank volume of 9 liters, voltage specification of 220v/50hz, speed of 1440 rpm and flow-capacity: 110l/min.
- The refrigerant type air dryer as shown in figure 9 had the working pressure of 16 kg/cm^2, a Flow Capacity of 20 cfm, Voltage requirements of 220 V AC /50 Hz, Power rating of 0.24 KW, and the pipeline diameter of the heat exchanger was 12mm.
- The PSA system as shown in figure 10 had the bed inner diameter of 76.2 mm, bed height of 660.4 mm, bed wall thickness of 4mm, tower to tower gap of 203.2 mm, flange diameter of 177.8 mm, flange thickness of 10mm, surge tank height of 559mm, surge tank inner diameter of 152.4 mm, 2 Minilec electronic timers. body parts of each bed were MIG welded with a 0-wire mesh, 5mm thick MS plate, 5mm hole at 10 pitch (dist. bet 2 holes), 0.5mm tight ss perforated sheet. bed was tightened by coconut fibers, in order to prevent crushing effect of the CMS due to rapid pressure changes.
- CMS used as shown in figure 11 was made in Kuraray, Japan, of grade 1.5 GN-H, with purity: 99.5%, CMS quantity of 4kg (2kg each bed).
- The Valves used as shown in figure 10 were Solenoid Controlled Gate valves, 2 way- 1 in 1 out, with a nominal diameter of ¼" (one-fourths inch), Voltage rating of 220 V.
5. Results and Analysis

5.1 Psychrometric Calculations of The Process – ‘Cooling and Dehumidification’

From the initial experimentation stage of the project, certain data values are recorded -
Outlet dry bulb temperature (Tdb2) = 25.12 °C
In figure 12 the red slanting line represents the psychrometric process and the end points of the slanting line are plotted using the inlet dry bulb temperature (DBT), the relative humidity (RH) at that point and the Apparatus Dew Point (ADP) specified for the cooling coil.

And, the ADP temperature of the Cooling coil used is specified to be 2° - 3° so, plotting the process on a Psychrometric chart we get,

Here in figure 13, point 1 represents the inlet conditions of the air (average conditions of the place of experimentation is considered) which is - 30°C (Tdb1) and the RH is 35%. Hence, on the line joining
ADP point and Pt1, we can plot Point 2 which is at an intersection of ‘Tdb2’ and the process defining line.

The amount of moisture in the air at Point 1 = 9.4 g/kg of air (from the psychrometric chart);  
The amount of moisture in the air at Point 2 = 8.2 g/kg of air (from the psychrometric chart);  
\[ \text{Moisture abstracted} = 9.4 - 8.2 = 1.2 \text{ g/kg of air} \]

5.1.1 Calculation for amount of water collected with respect to the operational time.

The amount of water collected as per the operational time is also calculated using the flow-rate, the density of air at the specific pressure inside the compressor.

From reliable online tools we were able to find various graphs with different parameters, we chose the below graph in figure 14 as we already have the required data.

Extrapolating from the graph we can interpret the density of air at 6-6.5 bar(g) at the temperature of operation is found to be ‘7.2 kg/m^3’.

Flow rate of Air = 110 lpm = 0.11 m^3;  
Considering, 1 min of operation:  
Mass of Air processed = 7.2 \times 0.11 m^3 = 0.792 kg  
So, water abstracted = 1.2 \times 0.792 = 0.95 grams/minute  
Hence theoretically, for 30 minutes of operation, water abstracted = 28.512 ml,  
which is found to be a close value to the experimental value.
5.2 Nitrogen And Oxygen Output

As per the layout two PSA beds are connected to one surge tank for the gaseous extracts to be collected. Here, the gas collected varies with by the changing the desiccant in the PSA beds. Analytical methods making use of experiments were used to estimate the amount of Nitrogen output.

5.2.1 Steps taken to measure the quantity of nitrogen gas as the output parameter.
1. The amount of Nitrogen output was measured by using a stopwatch to note down the time taken to evacuate the Nitrogen gas from the volume of Surge tank.
2. The stopwatch was started at 4.9 bar(g) pressure (maximum pressure reached in surge tank) and was stopped when the pressure gauge showed a reading of 0 bar(g) (atmospheric pressure).
3. The volume of the surge tank was measured and was divided by the time taken to evacuate the vessel, in order to get the amount (m3/sec) of Nitrogen gas output.
4. In case of Oxygen, when considering the composition of air, there is 21% of Oxygen and 78% Nitrogen. Hence the current readings of Nitrogen output were extrapolated in order to estimate the O2 output. The result obtained will be true if CMS is replaced with ZMS.

5.2.2 Calculations.

According to the steps mentioned above, the volume of the dimension tank was found.

Dimensions of Surge Tank:
Inner Diameter = 0.15 m
Outer Diameter = 0.16 m
Height = 0.53 m
Volume of Surge Tank = 0.00936 m³ = 9.36 L

Then, the Nitrogen output is equal to “Volume of Surge Tank divided by Average time taken to empty the tank”
The average time was found out to be 0.35 minutes. So, the Nitrogen Output becomes 26.74 Lpm.

5.2.3 Energy Analysis

Power rating of Reciprocating Air Compressor = 550 W
Power rating of Refrigerant-type Air Dryer = 240 W
Power rating of 8 Solenoid-controlled Gate Valves and electronic timers = 200 W
Total rated power of electrical appliances = 990 W
Total time of operation = 8640 h
Power consumed = 8553.6 kWh
Annual water production = 1625 l
So, energy consumed per liter of water = 5.26 kW
Annual Nitrogen production = 26.27 * 60 * 8640 = 13862016 l
So, energy consumed per liter of Nitrogen = 0.000617 kW
6. Conclusions

The proposed project has been fabricated in-house and has been experimented on. The following conclusions can be drawn from the experiment.

1. Water can be successfully extracted from the moisture present in the atmosphere.
2. The N2 gas byproduct can be collected, quantified and used for various applications such as fire extinguisher, food packaging, etc.
3. The PSA system is dynamic and can be easily switched to a O2 collection plant by replacing the CMS with Zeolite Molecular Sieves (ZMS).

The current approach is better than the existing approaches since the prototype uses simple electronic timers to actuate the valve opening and closing, that are economical than PLC circuits and cam followers used in current industrial sectors.

The prototype produces 99% pure Nitrogen. Even if the Oxygen is a by-product, using certain medical grade filters the prototype could be used to create an Oxygen-enriched atmosphere inside enclosed spaces such as offices and malls, during the outbreak of Covid-19.

Air separation industries use Alumina gel as the desiccant to adsorb water. Since the refrigerant-type air dryer drops the temperature of the moist air to down to its dew point temperature, the condensed water is pure. If the equipment is cleaned at regular intervals, pure water can be obtained.

References

[1] Bethany Halford, October 14, 2018, Can stripping the air of its moisture quench the world’s thirst?, Retrieved from https://cen.acs.org/environment/water/stripping-air-moisture-quench-worlds/96/i41, Volume 96, Issue 41

[2] 17 November 2019, Only Mumbai meets Drinking Water Quality Standards, The Hindu, Retrieved from https://www.thehindu.com/news/national/only-mumbai-meets-drinking-water-quality-standards/article29992150.ece/amp/

[3] Michael Berger, Yann Kerr, Jordi Font and Jean-Pierre Wigneron, August 2003, Measuring the Moisture in the Earth’s Soil - Advancing the Science with ESA’s SMOS Mission, Earth Observation, Retrieved from https://www.esa.int/esapub/bulletin/bullet115/chapter5_bul115.pdf

[4] Teresa A. Centeno and Antonio B. Fuertes, (1999), Supported carbon molecular sieve membranes based on a phenolic resin, Journal of Membrane Science, vol 160(2), pp. 201-211, https://doi.org/10.1016/S0376-7388(99)00083-6

[5] R.V. Jasra, N.V. Choudary and S.G.T. Bhat, (1991), Separation of Gases by Pressure Swing Adsorption, Separation Science and Technology, vol 26(7), pp.885-930, DOI: 10.1080/01496399108050504

[6] T.A. Braymer, C.G. Coe, T.S. Farris, T.R. Gaffney, J.M. Schork and J.N. Armor, (1994), Granular carbon molecular sieves, Carbon, vol 32(3), pp.445-452, https://doi.org/10.1016/0008-6223(94)90165-1

[7] V. I. Á. Maté, José Antonio Delgado Dobladex, Silvia Álvarez-Torreleras, Marcos Larriba and Ángel Martínez Rodríguez, (2019), Modeling and simulation of the efficient separation of methane/nitrogen mixtures with [Ni3(HCOO)6] MOF by PSA, Chemical Engineering Journal, vol 361, pp. 1007-1018, https://doi.org/10.1016/j.cej.2018.12.154

[8] Mohamed Safdar Allie Baksh and Frank Notaro, (2002), Pressure swing adsorption method for production of an oxygen-enriched gas, US6475265B1

[9] S. J. Bhadra and S. Farooq, (2011), Separation of Methane–Nitrogen Mixture by Pressure Swing Adsorption for Natural Gas Upgrading, Industrial & Engineering Chemistry Research, vol 50(24), pp. 885-930, https://doi.org/10.1021/ie201237x

[10] Hiroaki Suda and Kenji Haraya, (1997), Gas Permeation through Micropores of Carbon Molecular Sieve Membranes Derived from Kapton Polyimide, J. Phys. Chem. B, Vol 101, 3988-3994, https://doi.org/10.1021/jp963997u
[11] Ahmed M. Hamed, A. E. Kabeel, E-Shafei B. Zeidan and Ayman A. Aly, (2010), A Technical Review on The Extraction Of Water From Atmospheric Air In Arid Zones, *JP Journal of Heat and Mass Transfer*, **Volume 4**, Number 3, Pages 213-228