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Adsorption Refrigeration using Zeolite-Water pair on Pro-e and MATLAB

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Abstract: The methods of production of cold by mechanical processes are quite recent. Long back in 1748, William Coolen of Glosgow University produced refrigeration by creating a partial vacuum over ethyl ether. The first development took place in 1834 when Perkins proposed a hand operated compressor machine working on ether. Then in 1851 came Gorrie's air refrigeration machine, and in 1856 Linde developed a machine working on ammonia. The pace of development was slow in the beginning when steam engines were the only prime movers known to run the compressors. With the advent of electric motors and consequent higher speed of compressors, the scope of refrigeration widened. The pace of development was considerably quickened in 1920 decade when du Pont put in the market the family of new working substances, the fluoro-chloro- derivates of methane, ethane, etc.- popularly known as choloro fluoro carbons or CFCs under the of Freons. Recent developments involve finding alternatives or substitutes of Freons, since it has been found that chlorine atoms in Freons are responsible for the depletion of ozone layer in the upper atmosphere. Another noteworthy development was that of ammonia- water vapour absorption machine by Carre. These developments account for the major commercial and industrial applications in the field of refrigeration.

A phenomenon called Peltier effect was discovered in 1834 which is still not commercialized. Advances in cryogenics, a field of very low-temperature refrigeration, were registered with the liquefaction of oxygen by Pictet in 1877. Dewar made the famous Dewar flask in 1898 to store liquids at cryogenic temperatures. Then followed the liquefaction of other permanent gases including helium in 1908 by Onnes which led to the discovery of the phenomenon of superconductivity. Finally, in 1926, Giaque and Debye independently proposed adiabatic demagnetization of paramagnetic salt to reach temperatures near absolute zero.

Here the main focus is on Zeolite-Water Solar Adsorption Refrigeration, Environmental protection initiates by environmental agencies are necessitating the replacement of chlorofluorocarbons with benign working fluids. One of the sensitive areas affected is refrigeration and heat pump technology, where new working pairs are being developed as an alternative to the traditional CFCs. This will have less impact of the destruction of the ozone layer. In the design of adsorption refrigeration and heat pump systems, it is important to analyse precisely the performance of the cycle. This is based on an accurate determination off the adsorbent-adsorbate performance. Therefore, the thermodynamics behaviour of adsorbent materials has to be studied in details using a number of physical models, which are widely accepted. Various kinds of sorption systems have been developed, mostly of activated carbon-ammonia, activated carbon-methanol, silica gel-water and Zeolite-Water pairs.

Nowadays, the refrigeration sector is one of the most important in the process industry. It was realised in the mid- 1970s that CFCs allow ultraviolet radiation into the earth's atmosphere by destroying the protective ozone layer, while preventing infrared radiation from escaping the earth, and thus contributing to the greenhouse effect. The discovery of the ozone-depleting properties of CFCs and HCFCs refrigerants, and of their global warming potential, led to the Montreal Protocol, which scheduled the end of 1995, and of HCFCs by 2030.

The production of these refrigerants has fallen dramatically in recent years. Researchers have recently focused on the development of new refrigerants to replace CFCs and HCFCs. These new working fluids are synthetic compounds namely hydro fluorocarbons (HFCs). Although the ozone depletion potential of some of them is zero, their global warming potential related to the greenhouse effect- can be large. An alternative to HCFCs in the use of naturally occurring substances (refrigerants) like ammonia, carbon dioxide, methanol, water, and air. Consequently, from the 1970s interest in solid-vapour adsorption systems was rekindled in view of their energy saving potential in air conditioning and heat pump applications. Along with a consideration for energy efficiency, increasing attention was given to the use of waste heat and solar energy.

Adsorption technologies have been used also extensively for separation and purification of gases for the past few decades but their exploitation for refrigeration is still limited. This has led to sorption technology receiving renewed attention due to environmental concerns. New classes of adsorbent-adsorbate pairs, like zeolite, silica gel or activated carbon, are gaining importance because they can replace CFC refrigerants. The advantages of such systems in comparison with conventional compression systems are-

- ***Adsorption systems are environmentally friendly***
- ***They can use heat rather than electricity as the primary energy source.***
- ***No moving parts***
- ***No solution pumps***
- ***Silent and easy to maintain***

Keywords: Adsorption System; Zeolite-Water Pair; Pro-e Designing; MATLAB Calculation; Adsorption Isotherm.

1. INTRODUCTION

About 10 to 20% of the electric power produced worldwide is consumed in cooling applications including air-conditioning and refrigeration applications. This highlights the fact that an energy efficient cooling is very important. Many adsorption cycles have been proposed and investigated by researchers. The integration of solar energy to power these cycles are also reviewed. It is concluded that solar adsorption cooling systems are the most promising technology in solar cooling applications with respect to low cost, the moderate coefficient of performance, ease of manufacture and low maintenance. The major challenge facing the researchers now is a better enhancement of heat and mass transfer in the system in favor of higher performance. In general, solar adsorption systems are not yet in the stage of world-wide commercialization but it is expected it will have a potential market with further development.

Adsorption phenomenon was discovered and employed a long time ago. Historically, Egyptians were the pioneers to explore and to use this phenomenon. Around 3750 BC Egyptians used charcoal for reduction of copper, zinc and tin ores for the manufacture of bronze. Later 1550 BC they used charcoal for medicinal purposes (Da Browski 2001). Adsorption phenomenon has been used for a wide variety of applications since then. These applications include drying of gases, desiccant in packing, dew point control of natural gas, water purification, separation processes, pollution control and refining of mineral oils (Thomas 1998), as well as refrigeration and heat pumping applications. Adsorption refrigeration and heat pumping have recently received more attention (Sumathy, Yeung et al. 2003). In addition to their simple configuration, no moving parts, environmentally friendly, noiseless and simple operation, they can be powered with low-grade energy such as waste heat and solar energy.

The use of solar energy as an energy source to power cooling systems is an attractive goal that is of growing interest among both researchers and energy planners (Henning 2004). Solar radiation is a free natural resource, the running costs of developed solar cooling systems can be expected to be low once the initial costs for their construction and installation have been met. Moreover, cooling load is generally high when solar radiation is high. Solar cooling potentially offers an excellent model of a clean, sustainable. Technology, which is consistent with the international commitment to sustainable development. Many solar cooling systems have been researched such as solar absorption, adsorption, vapor compression, thermoelectric and ejector systems.

Sorption solar cooling has proven to be technically feasible (Meunier 1994). Adsorption refrigeration has received much attention in recent years (both for ice making and heat pump); various types of adsorption refrigerators and heat pumps were developed (Saha, Koyama et al. 2003; Alam, Akahira et al. 2004; Luo, Dai et al. 2006), mostly of activated carbon-methanol, zeolite-water, silica gel-water and calcium chloride-ammonia pairs.

Due to the poor performance of the basic intermittent adsorption cycle, many modifications were suggested and analyzed in the literature. These modifications include implementing a multi-bed system with heat recovery, mass recovery, thermal wave, convective thermal wave and cascade system. Those systems are reviewed regarding recent development trends and their integration with solar energy.

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being too cool some product or space to the required temperature. One of the most important applications of refrigeration has been the preservation of perishable food products by storing them at low temperatures. Refrigeration systems are also used extensively for providing thermal comfort to human beings by means of air conditioning. Air Conditioning refers to the treatment of air so as to simultaneously control its temperature, moisture content, cleanliness, odour and circulation, as required by occupants, a process, or products in the space.

2. A ZEOLITE-WATER SOLAR ADSORPTION REFRIGERATOR

Refrigeration is an interesting application of solar energy because the incident radiation and the need for cold production both reach maximum levels in the same period. In developing countries, solar refrigeration is an increasingly acknowledged priority in view of the needs for food and vaccine preservation and due to the fact that solar energy is generally widely available in these countries. Different solar refrigeration systems using sorption processes have been proposed and tested with success. In relation to the solar adsorptive refrigeration systems, different types of solid-gas were considered. The zeolite-water and silica gel-water pairs were chosen for cold storage, while the activated carbon-methanol pair was chosen for ice production.

The given system operates under an intermittent cycle, without heat recovering, and is aimed to regenerate the adsorber with solar energy, the choice for the working fluid – the adsorbate – depends on the evaporator temperature and must have the high latent heat of evaporation and small molecular dimensions to allow an easy adsorption. With water as adsorbate, the zeolite is a very suitable adsorbent. This material is basically porous aluminum silicate that can be found raw or synthesized, is innocuous, well available and is cheap.

The solar powered absorption refrigerator was designed to achieve cooling by operating on adsorption – desorption principle. The system has no moving parts. Water is used as working fluid and synthesized highly porous silicon compound (Zeolite 4A) is used as an adsorbent. The operation concept is based on the fact that when cool (at night) the Zeolite acts like a sponge soaking up or adsorbing the water vapour and when heated during the sunning day the water vapour is desorbed or released. The system operates under a partial vacuum, the water vapour moves with high efficiency under low pressure. At the desorption temperature of water, water vapour begins to desorb from the Zeolite. Thus the receiver act as a boiler and the water vapour leaves through the perforated holes on the duct to the condenser. This water vapour is condensed into water droplet as heat is given off by the heat exchanger (condenser). The resulting water runs down due to gravity into a sealed storage tank inside the refrigerator compartment. During the night, Zeolite is cooled close to ambient temperature and start adsorbing water vapour. The liquid water in the storage tank (an evaporator) adsorbs heat from the space to be cooled and is converted into water vapour. Since the system is sealed under very low pressure the remaining water in the storage tank freeze's ice. This ice will melt slowly during the next day thus providing sustained cooling at reasonable constant temperature.

2.1 ANALYSIS

First, we take the system in which water is put in the condenser. So first we take that from heating, temperature of water reaches up to 80°C then
Assumption
Mass of water = 100 kg
Maximum temperature of water reached = 80°C
Initial temperature of water is = 30°C
We know that
$Q = mC\Delta T$
$Q = 2.09 \times 10^4$ KJ
Now if water is replaced by palm oil than to find maximum temperature of palm oil we equate
Q =m CΔT for palm oil. But C (heat capacity) of palm oil varies with temperature as shown in table

Table 1 Variation of temperature and heat capacity

Temperature X (°C)	Heat capacity Y (KJ/kg·K)
20	1.848
30	1.875
40	1.902
50	1.93
60	1.959
70	1.988
80	2.018
90	2.049
100	2.081

Table 2 To find the relation between heat capacity and temperature we apply Regression line method

Temperature X	Heat capacity Y	XY	X.X
20	1.848	36.96	400
30	1.875	56.25	900
40	1.902	76.08	1600
50	1.93	96.5	2500
60	1.959	117.54	3600
70	1.988	139.16	4900
80	2.018	161.44	6400
90	2.049	184.41	8100
100	2.081	208.1	10000
ΣX=540	ΣY=17.65	ΣXY=1076.44	ΣX.X=38400

Form of regression line is equal to
Y = A+ BX
Where

$$A = \frac{[\Sigma Y \cdot \Sigma(X \cdot X) - \Sigma X \cdot \Sigma(XY)]}{[n \cdot \Sigma(X \cdot X) - (\Sigma X) \cdot (\Sigma X)]}$$

$$B = \frac{[n\Sigma(XY)) - \Sigma X \cdot \Sigma Y]}{[n\Sigma(X \cdot X)) - (\Sigma X) \cdot (\Sigma X)]}$$

So by putting the value of all parameter we find value of A and B that is
A =1.787 B = 0.003

So finally we find regression line equation it is
Y = 1.787 + 0.003X

Where, Y = C = Heat capacity
X = T = Temperature

So now to find the maximum temperature of Palm oil

$$\int_{30°C}^{T} \text{Mpalmoil Cpalm oil } \Delta T = \text{Q water} = 2.09 \times 10^4$$

Where,
Mass of palm oil = 80 kg (because relative density of palm oil with respect to water is 0.8.)
Heat capacity of palm oil **C = 1.787 + 0.003T**
So by solving integral we find maximum temperature reached by palm oil is

T max of palm oil = 156.56°C

	A	B	C	D	E	F	G
1	Temperature (°C) = X	Heat capacity (KJ/kg·K) = Y	X.Y	X.X	A	B	Y
2					1.7867111	0.002907	
3	20	1.848	36.96	400			1.8448444
4	30	1.875	56.25	900			1.8739111
5	40	1.902	76.08	1600			1.9029778
6	50	1.93	96.5	2500			1.9320444
7	60	1.959	117.54	3600			1.9611111
8	70	1.988	139.16	4900			1.9901778
9	80	2.018	161.44	6400			2.0192444
10	90	2.049	184.41	8100			2.0483111
11	100	2.081	208.1	10000			2.0773778
12							
13	540	17.65	1076.44	38400			
14							

Fig 1: Excel sheet

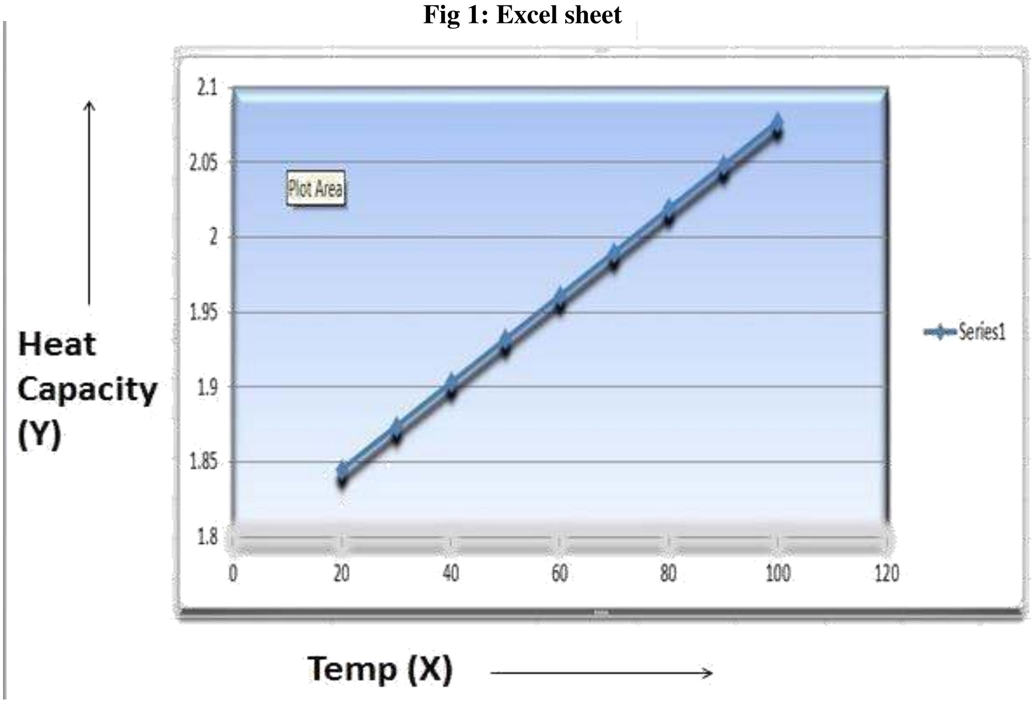


Fig 2- Regression line graph

In adsorption process, the pressure is kept constant at P_{eva}. The refrigerant vapour evaporates in the evaporator picking up its latent heat from the chilled water then, adsorbed by the adsorbent packed in the adsorber. The refrigerant concentration in the adsorber increases from Wmin to Wmax. In pre-heating process, the sorption element is isolated and heated at constant concentration using a high-temperature heat source and hence the pressure increases from P_{eva} to P_{con}. In desorption process, the refrigerant regenerates and goes to the condenser at pressure Pcon. The refrigerant concentration on the sorption element decreases from Wmax to Wmin. In the pre-cooling process, the adsorbent bed is cooled at a constant concentration which makes the pressure decrease from P_{con} to P_{eva}. The model described here is a thermodynamical equilibrium model. This means, all the thermal contributions are calculated based on heat and mass balance provided by the (P-T-W) di89agrams.

Cooling effect can be estimated as given in Equation

$$Qc = Ms\,(W_{max} - W_{min})[\Delta h_{eva} - \int_{T_{eva}}^{T_{ad}} Cp,ref\ dT]$$

Where Ms is the mass of the sample adsorbent, W_{max} and W_{min} is the maximum and minimum sorption uptake, respectively. Δh_{eva} is the vaporization enthalpy and C_p; *ref* is the specific heat of refrigerant.

Desorption heat can be calculated as given in Equation

$$Q_{des} = Ms\ Q_{st}\ (W_{max} - W_{min})$$

$$Wmax = Wo\ e^{[-\{(\frac{RTad}{E})\ln(\frac{Pads}{Peva})\}^{n}]}$$

$$Wmin = Wo\ \ e^{[-\{(\frac{RTdes}{E})\ln(\frac{Pdes}{Pcond})\}^{n}]}$$

Total sensible heat is the sum of sensible heat during preheating and desorption shown in Equation

$$Q_{sh} = Q_{pre} + Q_{des}$$

Sensible heat during pre-heating can be estimated as in Equation

$$Q_{sh,pr} = Ms\int_{Tb}^{Tc} Cp,s\ dT + MsWmax\int_{Tb}^{Tc} Cp,ref\ dT + Mbed\int_{Tb}^{Tc} Cp,bed\ dT$$

Sensible heat during desorption can be estimated as in Equation

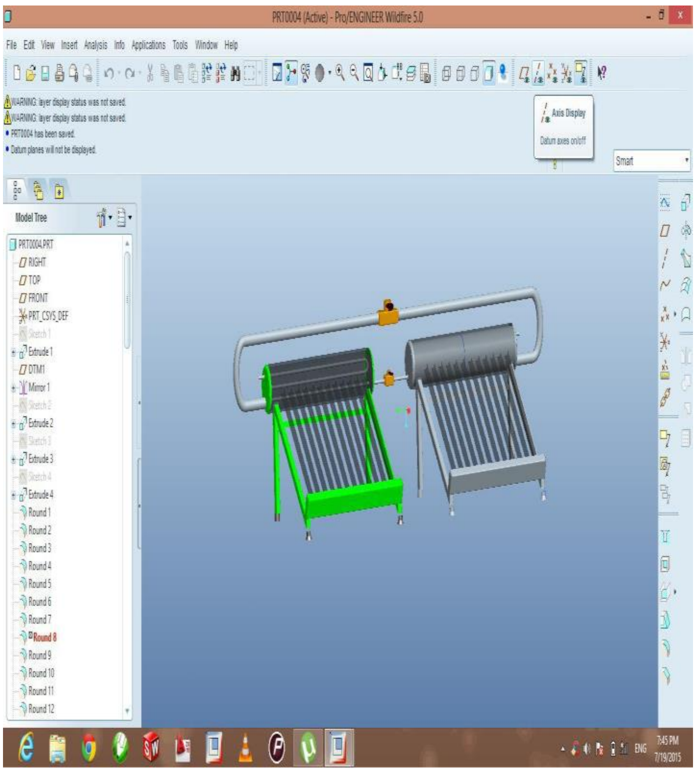
$$Q_{sh,des} = Ms\int_{Tb}^{Tc} Cp,s\ dT + Ms\{(Wmax + Wmin)/2\}\int_{Tb}^{Tc} Cp,ref\ dT + Mbed\int_{Tb}^{Tc} Cp,bed\ dT$$

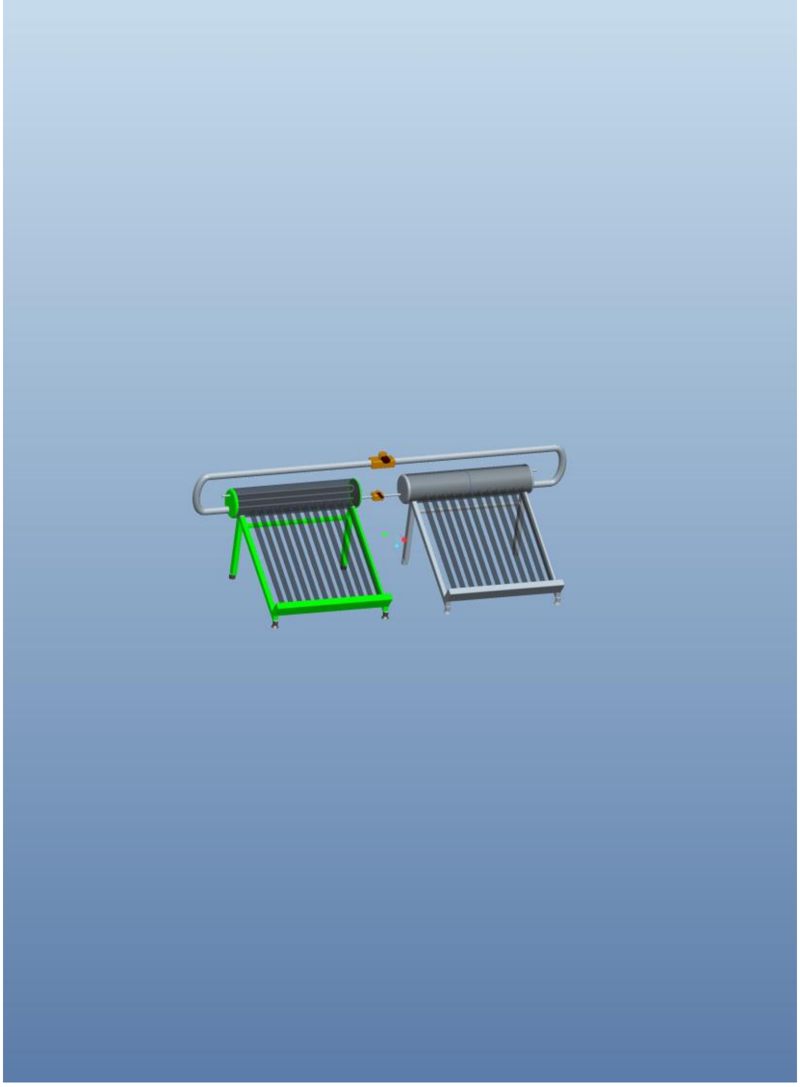
For simplicity, the thermal capacity of the adsorption bed is considered two times that of the thermal capacity of the adsorbent. The specific cooling effect (SCE) and the coefficient of performance (COP) of the time independent ideal adsorption cycle is calculated using the following Equations

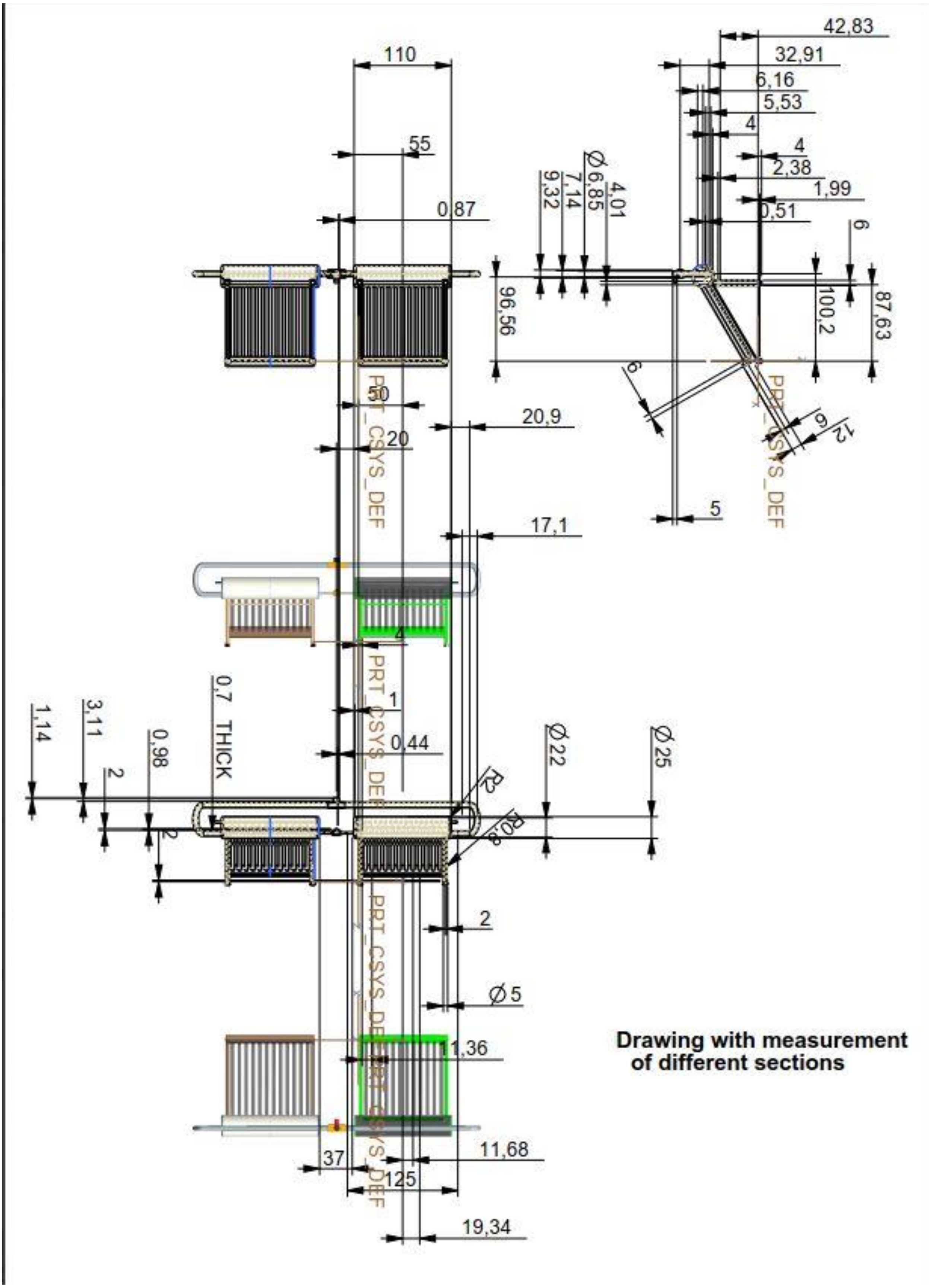
$$SCE = (W_{max} - W_{min}))[\Delta_{heva} - \int_{Teva}^{Tad} Cp,ref\ dT]$$

$$COP = Ms[\frac{SCE}{Qdes + Qsh}]$$

2. PRO-E SOLID MODEL







Drawing with measurement of different sections

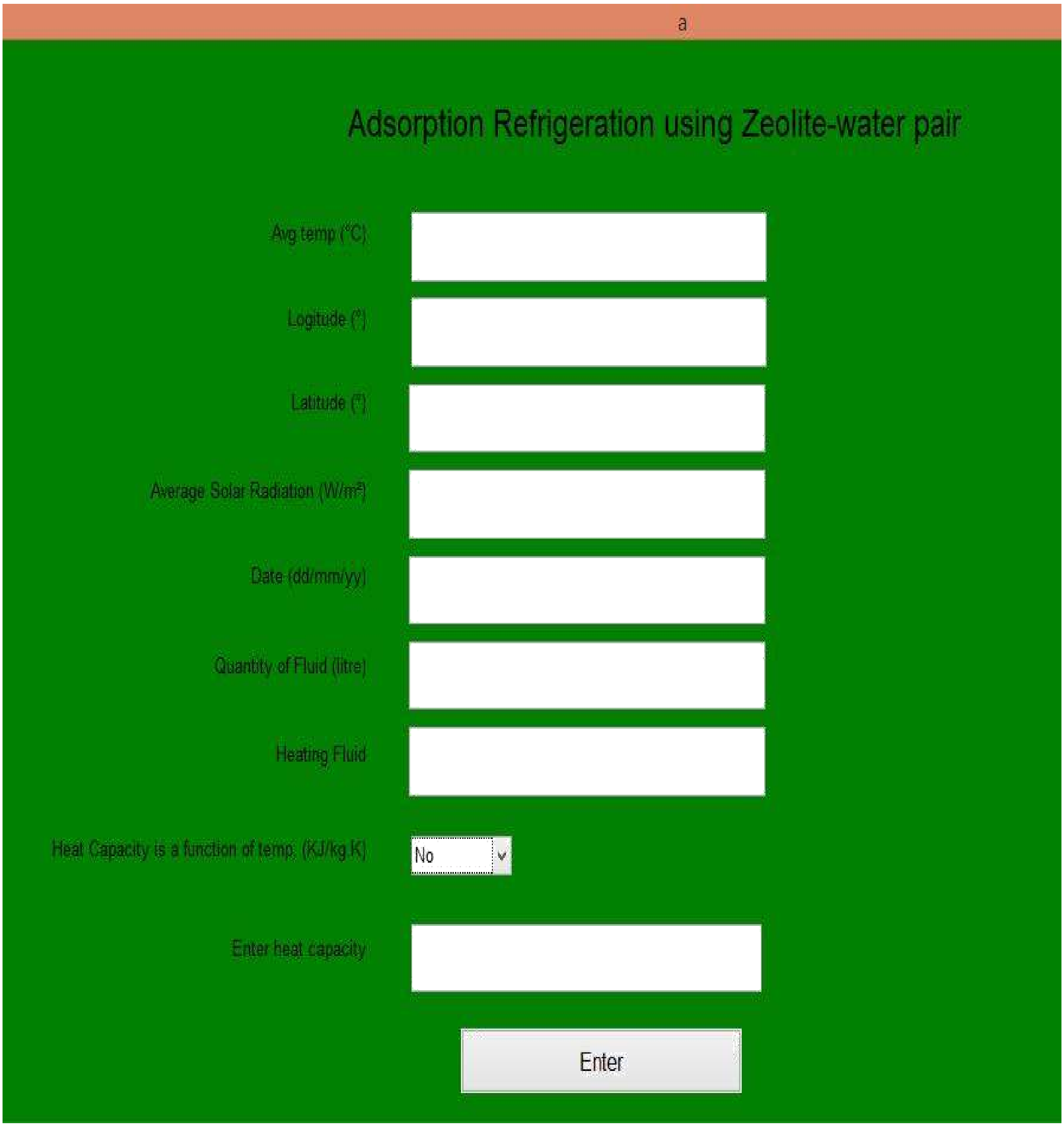
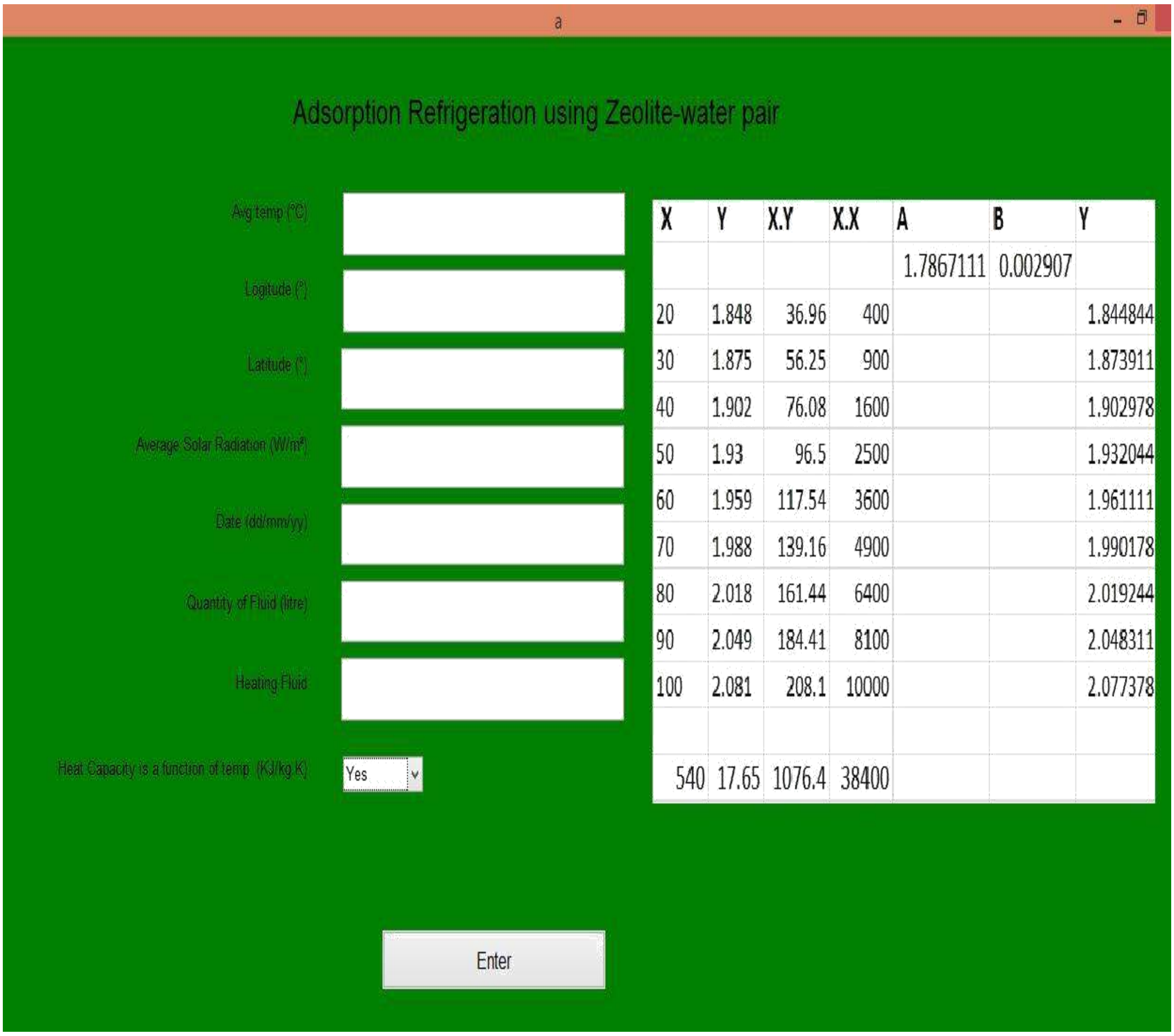


Fig 6 Input Screen when heat capacity is not the function of temp



X	Y	X.Y	X.X	A	B	Y
				1.7867111	0.002907	
20	1.848	36.96	400			1.844844
30	1.875	56.25	900			1.873911
40	1.902	76.08	1600			1.902978
50	1.93	96.5	2500			1.932044
60	1.959	117.54	3600			1.961111
70	1.988	139.16	4900			1.990178
80	2.018	161.44	6400			2.019244
90	2.049	184.41	8100			2.048311
100	2.081	208.1	10000			2.077378
540	17.65	1076.4	38400			

Fig 7 Input Screen when heat capacity is the function of temp.

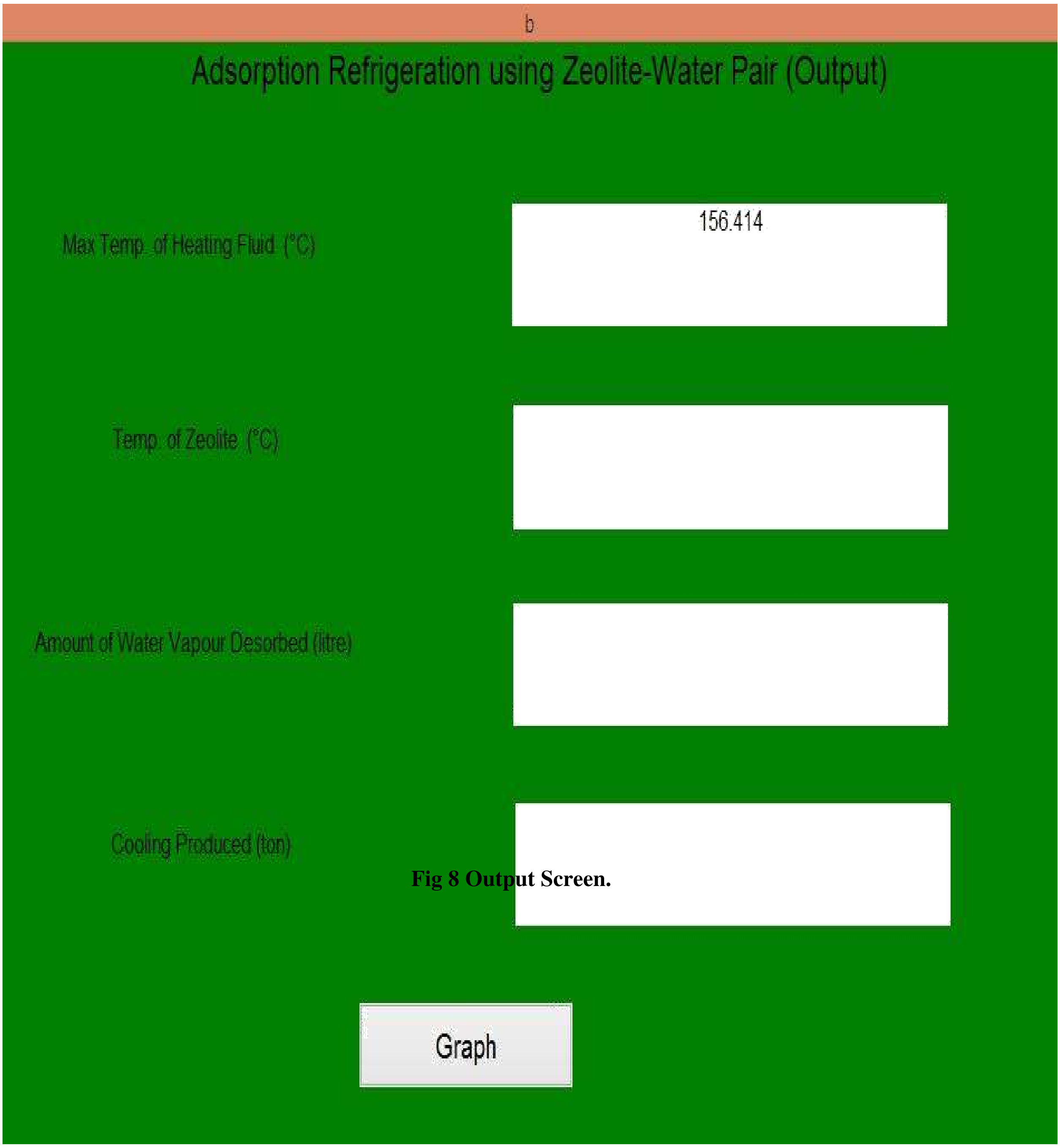


Fig 8 Output Screen.

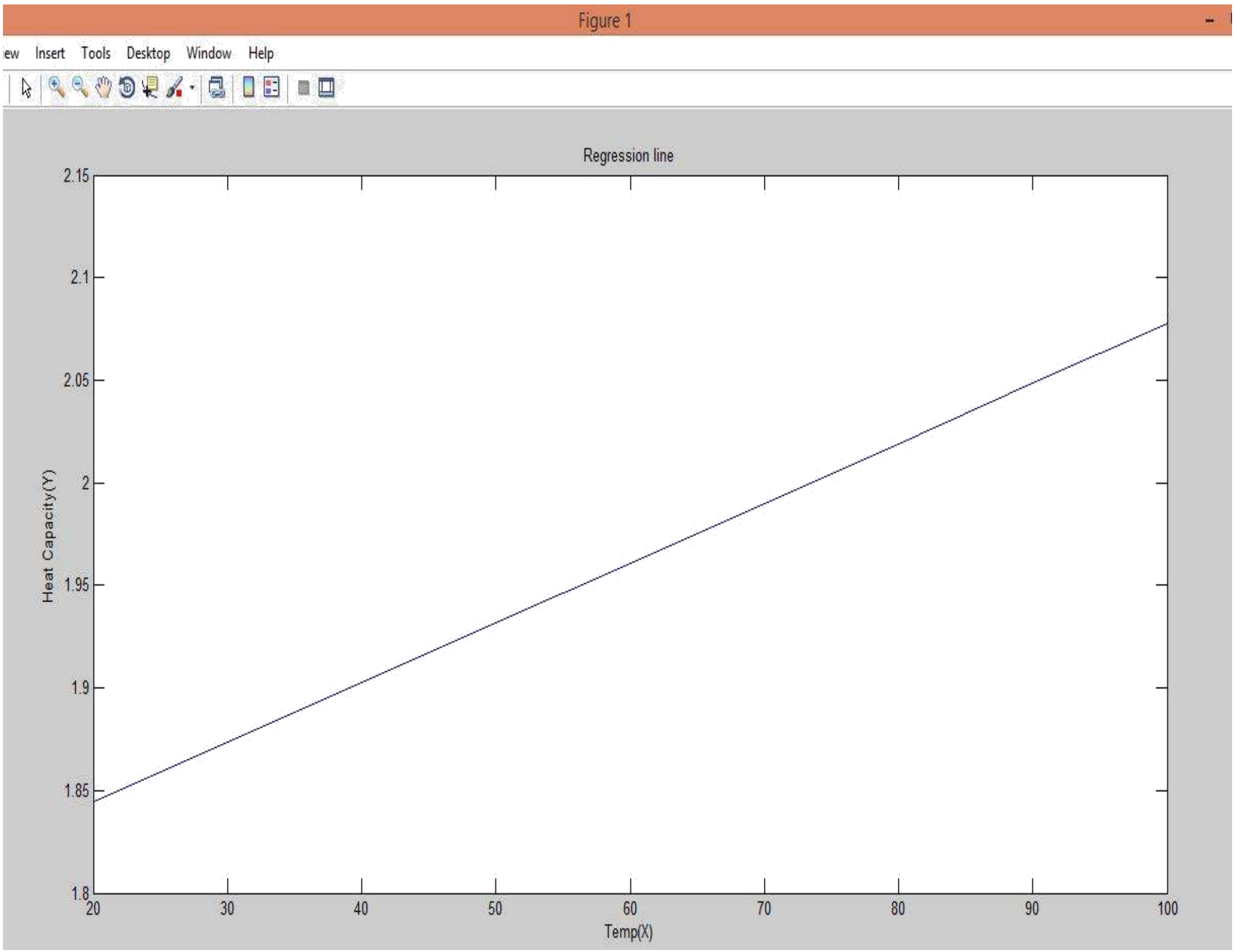


Fig 9 Regression graph in MATLAB

3. RESULTS AND DISCUSSION

The experimental determination of the adsorption refrigeration using synthetic Zeolite A and water pair has been presented in this report. Basically, Adsorption cycle is intermittent because cold production is not continuous: cold production proceeds only during part of the cycle. When all the energy required for heating the adsorbers is supplied by the heat source, the cycle is termed single effect cycle. Typically for domestic refrigeration conditions, the coefficient of performance (COP) for single effect adsorption cycle lies around 0.3-0.4. A minimum of two adsorbers is required to obtain a continuous cooling effect (when the first adsorber is in the adsorption phase, the second adsorber is in desorption phase). These adsorbers will sequentially execute the adsorption-desorption process.

Thus here, a new device has been made which two same kinds of structures have connected by a pipe and a valve. The one device acts as an air conditioner and other gives hot water in cold temperature.

Analysis of A Zeolite-Water Solar Adsorption Refrigerator was done where water was replaced by palm oil. A 3D solid model was prepared on Pro-E while a Graphical User Interface (GUI) was prepared on MATLAB to allow the user to get a predefined input screen to have the desired output by changing various factors.

It is found that the idea of sequentially executing the adsorption- desorption processes can be done by this device in a useful and effective manner. Key:

- These systems are environmentally friendly
- They can use heat rather than electricity as the primary energy source.
- No moving parts
- No solution pumps
- Silent and easy to maintain
- Satisfy the Montreal protocol on ozone layer depletion and Kyoto protocol on global warming
- Solar energy - Renewable, abundant, cheap, pollution free
- Large energy saving potential
- Higher reliability
- Zeolite- Water pair has highest driving temperature

- Zeolite- nonpoisonous, non-flammable, naturally available
- Ease of manufacture
- Low maintenance
- Moderate COP
- Low cost
- Minimum looses

4. CONCLUSION AND FUTURE SCOPE

Adsorption solar cooling is a good alternative for traditional cooling and refrigeration systems from both environment and energy conservation perspectives. This report presents an overview of the development of adsorption refrigeration systems. Towards meeting the cooling demand, the conventional mechanical vapour compression systems are often used. This conventional system is popular and advantageous due to its high coefficient of performance, small size, and low weight. However, the system is not without disadvantage such as contributing to global warming, ozone layer depletion coupled with high energy consumption. Reduction of primary energy consumption is strongly required to reduce global warming caused by fossil fuel consumption used in producing the electricity. But its main disadvantage is the refrigerant used, such as a chlorofluorocarbon (CFC), Hydro chlorofluorocarbon (CHFC) which has high global warming and Ozone depletion potential. The criticality in the main disadvantage of the conventional cooling system leads to the regulatory decision reached the convention towards reducing the ozone layer depletion and greenhouse gas emission by the participating countries respectively. The discovery that solar radiation and cooling load reach maximum level in the same season gave impetus to research for solar energy powered refrigeration and air conditioning. That is, demand for cooling (cooling load) is at peak when the solar intensity is optimum.

Thermally activated sorption technology is one of the possible alternatives to electricity is driven vapour compression refrigerator. Adsorption cycles have distinct advantage over other heat drove refrigerating cycles in their ability to be driven by heat at relatively low, near environmental temperatures. A way of decreasing dependence on electricity for cooling is to use environmentally benign, thermally –powered cooling system such as physical adsorption systems. Basically, in an adsorption cooling cycle, the mechanical compressor of conventional vapour compression system powered by electricity is replaced with a thermal compressor driven by low-grade thermal energy like solar energy. The main attraction to the solar adsorption refrigeration is that its working fluids satisfy the Montreal protocol on ozone layer depletion and the Kyoto protocol on global warming. Choosing the most appropriate adsorbent-adsorbate pair is one of the important factors determining the efficiency of the adsorption refrigerator. Since the desirable lowest adsorption temperature for the adsorption refrigerator is room temperature, the boiling point should be preferentially higher than 20^{o}C.

Zeolite – water pair is very suitable to be used in adsorption refrigeration owing to the extremely non-linear pressure dependence of its adsorption isotherms. The isotherms saturate at low partial pressure, after which the amount adsorbed becomes almost independent of pressure. At ambient temperature, the zeolite can adsorb most of the vapour even at high partial pressure, corresponding to high condenser temperature. This unique property of the zeolite is especially important in the case where a high condenser temperature and only a moderate regeneration temperature might be employed. Since water has a high latent heat of vaporization and a convenient boiling point, the

zeolite water pair is one of the most preferred adsorbent – adsorbate pairs. However, water has been shown, in literature to be a potentially excellent working fluid (available in abundance, non-toxic, corrosion free, low cost, ease of handling it, high latent heat and convenient boiling point for adsorption – desorption cycle) for the cooling system. Moreover, its main drawback is the phenomenological volume it presents in the evaporator of the cooling system compared to the volume in the liquid state in the condenser of the system. Also, its extremely low saturation pressure makes it impossible to produce evaporator temperature below 0^{o}C. Powering the system directly with Solar energy is advantageous with the provision of energy grade (renewable, abundant, cheap, pollution free and environmentally friendly) in form of heat. It enhanced the system efficiency with the direct conversion of the solar heat with minimal losses in the system.

Silica gel and chlorides with water pair have the highest COP value. Zeolite with water pair has the minimum value for COP. According to the driving temperature, silica gel and chlorides with methanol pair has the lowest driving temperature. Zeolite and water pair has the highest driving temperature.

Also, the characteristics of the new adsorption pairs are revealing. Many new pairs show a promising future for the cooling application. Finally, it is clear from the study that the adsorption cooling is still needed for more attention and is still have the opportunity to be a traditional device.

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APPENDIX

Adsorption Isotherm

The adsorption equilibrium relates q to C. The equilibrium is a function of the temperature. Therefore, the adsorption equilibrium relationship at a given temperature is typically referred to as adsorption isotherm, i.e.:

$q = f(C)$

Where:

q = mass of species adsorbed/mass of adsorbent (i.e., the equilibrium concentration of adsorbable species in solid adsorbent)

C = equilibrium concentration of adsorbable species in solution

Adsorption Model for Langmuir Isotherm

The assumptions made in the derivation of the Langmuir model are:

- Adsorption is a reversible process
- The adsorbed layer is made up of a single layer of molecules
- The adsorbed molecules do not move on the surface of the adsorbent. However, they can be lost back to the solution
- The enthalpy of adsorption is the same for all molecules independently of how many have been adsorbed

Adsorption data - The adsorption data for the synthetic Zeolite A, at 3 adsorption temperatures (Tad) 40°C to 120°C are given

1. Tad = 120°C

Temp (°C)	P1 (kpa)	P2 (kpa)	m2 (kg)	m3 (kg)	X(kgad/kgw)
5	36.397	36.396	2.60	2.50	0.10
10	36.397	36.396	2.60	2.40	0.20
20	36.397	36.396	2.60	2.35	0.23
30	36.397	36.396	2.60	2.37	0.25
40	36.397	36.396	2.60	2.35	0.25

2. Tad = 100°C

Temp (°C)	P1 (kpa)	P2 (kpa)	m2 (kg)	m3 (kg)	X(kgad/kgw)
5	36.397	36.396	2.60	2.40	0.20
10	36.397	36.396	2.60	2.35	0.25
20	36.397	36.396	2.60	2.35	0.25
30	36.397	36.396	2.60	2.50	0.10
40	36.397	36.396	2.60	2.40	0.20

3. Tad = 40°C

Temp (°C)	P1 (kpa)	P2 (kpa)	m2 (kg)	m3 (kg)	X(kgad/kgw)
5	36.397	36.396	2.60	2.49	0.11
10	36.397	36.396	2.60	2.43	0.17
20	36.397	36.396	2.60	2.40	0.15
30	36.397	36.396	2.60	2.45	0.20
40	36.397	36.396	2.60	2.39	0.21