A Project Report on

Reactivation of silica gel using solar thermal system

Submitted in the partial fulfillment of the requirements for the award of the degree of Master of Engineering in Electrical Engineering of Gauhati University (Session: 2015-2017)

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This is to certify that the project entitled REACTIVATION OF SILICA GEL USING SOLAR THERMAL SYSTEM has been submitted by the M.E. fourth semester student: Bipasha Sarma (E-15/07) in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Electrical Engineering of the Gauhati University.

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Further, the report has not been submitted in any form for the award of any other degree.

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Abstract

This work deals with the reactivation process of a solid desiccant (silica gel) using a flat plate solar collector. Instead of using conventional fuel for the reactivation process, solar energy is used for the removal of the moisture from the silica gel. In this work a small silica gel drier is fabricated which is almost similar to a solar drier used for the drying process of agricultural commodities. Different modified form of solar flat plate collector is used to improve the performance of the basic model so that maximum solar heat is absorbed. Maximum regeneration temperature attained is 67^oC with aluminium as absorbing material and glass as glazing material with a collector tilt angle of about 30^o. A mathematical model of the system is also designed and simulated to compare to the practical designed system. Carbon saving during the experiment is also evaluated. It is expected that the same model can also be used for drying of food product.

Contents

List of Figures

List of Tables

Chapter 1

INTRODUCTION

Dry air (which is free of water vapour) is widely used for operating a vortex tube, spot cooling in precision equipment manufactories, drug manufacturing, pneumatic control systems, chemical industries and many others and most importantly in power transformers. Dehumidification of moist air using a refrigeration coil is an expensive method, whereas dehumidifying by a sorbent material (also called desiccant) often economically more attractive. One of the most commonly used sorbent material called silica gel is also widely used as a drying agent in power transformers. It is very difficult to reactivate absorbent materials, but adsorbents can be reactivated easily by heating the bed to a certain temperature. For continuous operation, an absorbent bed must be reactivated for reuse. The reactivation temperature depends upon the type of the sorbent material, bed length, air mass velocity through the bed (if hot air is used), time of the heating cycle, etc. In this work, reactivation of moisturized common silica gel by solar heating using a conventional type flat plate solar collector has been studied. Atmospheric air was heated by the solar collector to about 67^oC (max temperature obtained) with aluminium as absorbing material and glass as glazing material with the collector tilt angle of 30^o before forcing it through the gel bed. The model is a one time investment which further reduces the cost of buying silica gel, cost of burning conventional fuel and cost of manufacturing of a different model for drying of food products. The model also reduces the carbon released to the environment produced during burning of conventional fuel.

The mass flow rate, temperature, and humidity of air are the most important parameters that determine the quality of the dried product. Temperature of the drying air must be kept below some maximum value that depends on the intended use of the product. In fact, deleterious effects on grain are determined by a combination of temperature and humidity of drying air and the duration of exposure rather than by temperature alone. Thus, high temperature can be used for a short time. Along with the temperature of the drying air, the air flow rate also determines the drying time. Increasing of air flow rate will reduce drying time but it relate with other factors too. At the same temperature, the air with low relative humidity has more capacity to dry than that with higher humidity. Therefore, the objectives of this work are to design, construct and test the solar dryer with dehumidification system to develop solar dryer for saving energy.

1.1 MOTIVATION BEHIND THE WORK

- As the throwing the used solid desiccant (silica gel) to the environment can cause environment hazard, uses of this model is very much eco-friendly.
- Use of this model will eliminate the cost of buying silica gel every time. It also saves the time to go to the market for buying the silica gel again and again.
- The model is a application of non-conventional solar energy which is maintenance and cost free. Thus it reduces the cost of burning fuel.
- The same model can be used for other drying purposes like drying of agricultural commodities.
- Although this type of work on non-conventional energy is very important but there are very less research has been performed. So there is a huge scope of research in future.

Chapter 2

REVIEW OF LITERATURE

In dehumidification process air passes through desiccants and it will humidify the desiccants. After some time desiccants will get saturated. Due to saturation, the colour of desiccants changes; for example in case of silica gel, its colour changes from dark blue to purplish pink after saturation. A desiccant can be of two type-solid and liquid. For reuse of desiccants it must be regenerated or reactivated. This can be done by driving of the moisture from desiccant. For this process source of energy is required. This source can be electricity, waste heat, natural energy or solar energy.

During the past few decades, researchers have studied the dehumidification of air and other gases by using various sorbent materials as an alternative to cooling and simultaneously the research of the regeneration of desiccants have also been developed. Regeneration of the solid and liquid desiccants have been done by different researcher in the following manner

2.1 REGENERATION OF SOLID DESICCANT

Sukhmeet Singh and Parm Pal Singh (1998) have performed an experiment on multi -self regenerator and packed bed regenerator simultaneously [1]. The experimental set up for both the regenerator were almost same but the packed bed one had a single self whereas another one had four selves. A solar collector was used to preheat the air, which was used to regenerate the desiccant ,whereas an electric heater having twelve strips of total 1KW capacity was used as the main heating system. They used silica gel to regenerate. How regeneration of silica gel was effected by the temperature of the air, velocity of air and number of selves used, was investigated in the experiment.

Sutavadee Techajunta (1999) studied how insolation and airflow rate had effected on the regeneration process of desiccant [2]. He used a solar simulator. It was found that insolation effects more on regeneration process rather than airflow rate. He also proposed a mathematical model to measure the temperature and humidity of the air leaving the panel.

Lounici et al. (2000) published a paper where they proposed a different method for regeneration of solid desiccant using electrochemical cell [3]. The system composed of two cell. The first cell contained two electrodes and a potential was applied across them. The two electrodes produced a electric field. The second cell was used to compare between the first cell and current activated column. A solution of distilled water, synthetic sodium fluoride and sodium hydroxide were used in the column. A constant temperature of 25^{o}C was maintained during the experiment. Alumina ball saturated by fluoride ions was used as the solid desiccant during the experiment.

Mohammed et al. (2003) studied the energy stored while a substance changes its phase [4]. One of the most common phase change energy storage is the latent heat storage. They also studied the phase change materials and their applications. A study of the previous work on latent heat and its application in different field was also included in this paper.

A. K. M. Iqbal Hussain have suggested a method for the reactivation of silica gel using a flat plate solar collector [5]. The plate was composed of eighteen gauge galvanized sheet of iron painted black paint to increase the absorptivity of the collector. Two glass cover was used as glazing material. Air from the environment was forced to pass through the collector with the help of a centrifugal fan, where they were heated upto 70^{o}C. The reactivation process was performed in a cylinder of inner diameter of 10cm. Heated air from the collector was allowed to enter to the cylinder. Another centrifugal fan was used at the outlet of the cylinder. The changing weight of the silica gel against the time of exposer to the sun light was studied in this paper.

Kodama et al. (2005) have done an experiment where they performed the regeneration process using low grade energy like solar energy [6]. The regenerated temperature was 60^{o}C and desiccants like activated alumina, silica gel, activated charcoal and zeolite etc can be reactivated at this low temperature.

V.Shanmugam, E.Natarajan (2005) published a paper where they carried out the regeneration using a flat plate solar collector [7]. The experimental set up composed of a dryer that combined the desiccant and forced convection. The whole experiment set up was tested in Chennai, India.

Pramuang et al. (2007) studied the regeneration of solid desiccant using solar collector [8]. The collector used was a parabolic dish collector having aperture area of 1.4m^2 and receiver area 0.48m^2 . The receiver was made of aluminum foil of 0.2mm thick. The receiver was painted matt black to increase the absorptivity of the receiver. Solid desiccant silica gel was used as regenerating substance. The regeneration process was performed in a container of dimension 1.2m x 0.6m x 0.6m. The temperature at which the regeneration process was started was as low as 40^oC. Environmental air was used as the circulating fluid which collects heat from the collector to perform the regenerating process. The whole set up was insulated by using fibre glass of thickness 50mm. It was observed that the regeneration process of silica gel was highly effected by the amount of solar radiation incident on the parabolic collector, the initial moisture present on the silica gel ,the humidity of air and the number of silica gel bed used during the experiment.

Qi et al. (2010) published a paper where they used electro-osmosis regeneration method for regeneration of solid desiccant [9]. An electric field was applied to realize the electro osmosis process. The solid desiccant used in this method was zeolite powder. The maximum moisture removal rate per unit strength of electric field was found to be $1.1*10^7$kg/msV. It was found that using a filter cloth near cathode improve the operation of the system. The advantage of this system is that the regeneration is possible with very low amount of energy and also in a very low temperature. The paper discussed the future application of the electro-osmosis process as one of the most important methods in regeneration of solid desiccant.

Polaert et al. (2010) proposed a method by using microwave irradiation [10]. In the experiment, a no of solid as well as liquid desiccants such as silica, activated alumina, NaX and NaY zeolites etc were regenerated.

Ronghui et al. (2011) investigated a method for the regeneration of solid desiccant using electro-osmotic regeneration method [11]. The advantage of this method is that no energy is required, thus saves energy and construction is very simple. Four different improvement in the electro-osmosis process was discussed by the author in this paper. It was found that platinum-plated titanium anode improved the regenerative process.

Isabelle et al. (2011) have experimentally investigated an regeneration method using a very high frequency microwave [12]. Zeolite NaX was used for regenerating purpose during the experiment. The heating system of the microwave assisted regeneration process was composed of a magnetron having a frequency of 2.45GHz and a power output of 1950W. Microwave were applied in a continuous mode or in a sequence of pulses and thus, their output power also vary in between 30W to 250W. The experiment showed a graphical representation of the decrease weight of the bed vs time and the power consumption during the experiment vs time.

B. Li et al. (2012) carried out an experiment where they used electro-osmosis regeneration process to regenerate a solid desiccant called zeolite [13]. 20V dc supply was used across the electrodes during the experiment. The feasibility of electro-osmosis process to regenerate a solid desiccant was evaluated in the experiment. A case study was also performed with conventional air conditioning systems and the EO integrated system.

Wisut et al. (2012) carried out a experiment to realize a solar drying system [14]. The drying system consisted of a silica gel bed where the drying process was carrier out using silica gel desiccant. The silica gel bed had a dimension of 0.95m length, 0.55m width and 0.01m thickness. Green chilly was used as the substance to be dried. From the experiment it was found that the silica gel that were placed at the top had more adsorption rate .

Yadav et al. (2012) investigated a process of regeneration where they used a evacuated tube solar heater [15]. The collector area was 4.44m^2. The reactivation rate for three desiccant silica gel, activated alumina and activated charcoal was investigated. The set up had a heat exchanger having a square dimension of 190mm x 190mm. A blower of 0.335 kW capacity was used to circulate the air inside the solar heater. A regulator was also used to control the air flow rate. The regeneration process was performed in a chamber of dimension 450mm x 450mm x 600mm made of wood, which provided a good insulation to the heat loss. It was found that silica gel have a better absorption and regeneration rate as compared to other two desiccants.

Sagar et al. (2013) used a parabolic dish collector of area 0.58 m^2 to perform the regeneration process [16]. Aluminum foil was used as the collector material and tracking process was performed manually. A glass chamber was placed at the middle of the parabolic collector where regeneration process was performed. Silica gel was used as the required solid desiccant in the regeneration process. The temperature inside the chamber was found to be around 38°C during the experiment. The change in the weight of the silica gel with time and variation of solar radiation intensity was studied in this experiment.

Amit et al. (2013) published a research paper where they performed a comparative study of regeneration rate of three different solid desiccant silica gel , activated alumina and activated charcoal [17]. A parabolic dish collector was used to heat the desiccant. The collector was made up of fourty segments of aluminum foil. The sun ray tracking process was done manually with the help of tracking screw. A wire mesh container with dimension 0.2m x 0.2m x 0.2m , was placed at the centre of the collector where the reactivation process was performed. The container made up of mild steel rod and wire mesh. Total three no of beds of dimensions 0.2m x 0.2m x 0.025m were there inside the chamber. After the experiment it was found that silica gel have highest regenerating capacity among all three.

Atul Mehla et al. (2014) performed an experiment on the regeneration of activated alumina where a parabolic dish collector was used to reflect the sun rays [18]. Fourty pieces of aluminum foil joined together was used as the collector material. The desiccant was placed at the middle of the collector. A screw and wheel arrangement was there to performed the sun ray tracking process. The workability of the solid desiccant with a parabolic collector was investigated in the experiment. The maximum regeneration rate of the desiccant was found to be 0.24kg/hr at 10:38am for both days in which the experiment was done.

Yao et al. (2014) have studied the regeneration of solid desiccant using a ultrasonic assisted regenerating system [19]. Theoretically a study was performed regarding the behaviour of silica gel while absorbing and releasing moisture. The study was performed in two stage, without and with the ultrasonic-assisted regeneration. A sequence of experiment was performed with the ultrasonic-assisted regenerating method by considering different environmental condition. On the basis of the theoretical model a simulation model was designed and a number of conclusion was extracted like how additional moisture removal capacity and dehumidification coefficient of performance was effected by the increased regenerating temperature, by the ambient temperature, by the humidity of the environment, by the initial moisture contents of the silica gel etc.

Suris el al. (2014) have carried out an experiment where they used microwave electromagnetic field to regenerate solid desiccant [20]. Silica gel was used as the solid desiccant. The theory behind the microwave regeneration is that the polar dielectric substance posses dipole moment which try to orient along the direction of the external electric field. When they are subjected to a very high frequency microwave electromagnetic field of around 0.4GHz-10GHz , the dipoles oscillates in a very high frequency. As a result, the temperature of the substance increases due to the increase of the kinetic energy. This increase temperature is used in the regeneration process of the solid desiccant. In this paper, the silica gel was placed in resonator chamber where they were subjected to 2450MHz microwave electromagnetic field. A study of the impact of different parameters on the regeneration of solid desiccant under microwave electromagnetic field was performed in this paper.

Zouaoui et al. (2016) published a paper on regeneration process where they used silica gel as solid desiccant [21]. The heating arrangement consisted of ten heating resistances made of stainless steel fins. Nine resistance had a output power of 250W and one had a output power of 2kW. Air was used as the regenerating fluid. The reactivation process was performed in a cylinder of dimension 50cm diameter. The cylinder made of iron and it had a fixed and a movable partition. The experiment concluded that the air velocity highly effects the regeneration rate of silica gel.

2.2 REGENERATION OF LIQUID DESICCANT

S. C. Mullick and M. C. Gupta (1974) carried out an experiment where they used solar energy to regenerate the liquid desiccant [22]. The solar collector used in the experiment was made of galvanised iron sheet. Calcium chloride was regenerated in this experiment. The system suffers from the disadvantage that solar energy was available during the day time. So for continuous operation of the system a backup system should also be used.

Kakabayev et al. (1976) in their research paper suggested the regeneration of lithium chloride in a flat surface [23]. He described a method to calculate the mass of moisture evaporated and the initial moisture condition of the desiccant.

C.S.P. Peng, and J. R. Howell (1984) published a paper where they regenerate the liquid desiccant by using a Spray chamber and a finned tube heat exchanger [24]. The heat exchanger was placed horizontally and hot water was allowed to flow. The liquid desiccant was sprayed in the spray chamber. A blower was used to passed the process air through the liquid desiccant. This system have a advantage of having low pressure drop towards the air side. But it also suffers from a disadvantage of high cost during spraying of the liquid desiccant. The same author also discussed another method for the regeneration of liquid desiccant using solar energy. A sloped surface was used as the solar collector and a transparent film was used as the glazing surface. Weak liquid desiccants can be regenerated using this method. The desiccant was allowed to flow through the inclined surface where the regeneration process was performed.

Peterson et al. (1990) described a hybrid air condition system with vapour compression system [25]. In the same paper they described a regeneration process for liquid desiccant by spraying the desiccant on the condenser of the refrigeration system. This process suffers from a disadvantage of corrosion of condenser coil .

Martin et al. (1999) described a method for regeneration of liquid desiccant in packed bed [26]. In this method, the liquid desiccant was spread over a wide surface by spray had. Process air was allowed to pass above the desiccant. Due to the difference in the partial pressure in between the process air and the liquid desiccant, the moisture from the desiccant was removed. This method suffers from a disadvantage that the liquid desiccant may get transferred along with the high speed process air.

RU Yang and Pai-Lu Wang (2001) studied how singly and doubly glazed collectors/regenerators performed in open cycle cooling system driven by solar energy [27]. A simulation of the model was designed and the system was tested at Kaohsiung, Taiwan. The simulation results was used to determine the seasonal solar fraction of that place.

Alizadeh and W. Y. Saman (2002) described another method for regeneration of weak liquid desiccant using solar energy [28,29]. A black solar collector with transparent lazing was used and the liquid was allowed to flow through the collector. Air was allowed to flow forcefully either along the direction of the liquid flow or in the opposite to the liquid flow. Air took away the moisture from the desiccant and the regenerating process was completed. Calcium chloride was used as the desiccant in this experiment.

A.E. Kabeel (2005) proposed a method for regeneration of liquid desiccant using solar energy [30]. The liquid desiccant was allowed to flow through the upper portion of the solar collector. Air flowing crosswise was used and these air took away the moisture from the desiccant. To test the performance of the system two similar system was constructed and tested. First one used a air blower while the second one without a blower. The absorber was made of thick black cloth. The results showed that the first model had more regenerating capacity compared to others.

Donggen Peng and Xiaosong Zhang (2009) described a model of air pre-treatment using solar energy [31]. The system consisted of two cycle- air cycle and solution cycle . The air cycle had blower, air pretreatment unit and solar collector/re- generator. The outside air was allowed to enter to the system with the help of a blower. The solution cycle comprised of antisepsis solution pump, air pretreatment unit, collector/re- generator and liquid heat exchanger. In the paper they study the performance analysis of the air pre-treatment collector/regenerator.

Ayman et al. (2010) suggested a completely new method in regeneration of liquid desiccant [32]. For the regenerating process they used artificial neural network method. From the data obtained from the previous experiment they constructed the neural network model. In the experiment, lithium chloride was used as the liquid desiccant.

A.S. Alosaimy and Ahmed M. Hamed (2011) carried out an experiment with flat plate solar collector for regeneration of the liquid desiccant [33]. The system consist of a solar heater and a storage tank and a heat exchanger. Hot water from the storage tank was allowed to flow to the heat exchanger where the heat was exchanged to the air in the exchanger. These air was passed through the liquid desiccant solution for regeneration. Calcium chloride solution was used as a liquid desiccant in this experiment for regeneration.

Ahmed et al. (2012) proposed a method for regeneration of liquid desiccant using a tilted wick [34]. The wick was movable and made of black cotton clothes in a double layer form. The wick was placed between two rotating pulleys inclined at about 20^o. A motor was used to rotate the upper pulley while the lower pulley was placed inside a huge chamber where the liquid desiccant was collected. The complete set up was a closed cycle process. Calcium chloride solution was used as the liquid desiccant which was regenerated during the experiment. During the experiment the concentration of the desiccant was measured in the collector chamber as well as in the wick. A mathematical model was also evaluated describing the whole system and for the measurement of intensity of the solar irradiance.

Reddy et al. (2013) proposed a different method for regeneration of liquid desiccant [35]. Strong liquid desiccants can be regenerated using this method. The desiccant was first cooled in the condenser after the refrigeration process was completed and after that the desiccant was sprayed to lose the moisture to the environment. They constructed a regenerating chamber made of acrylic rods and netlon mesh. Acrylic rods were made from acrylic sheets and then they were bind together with the help of super glue and silicon glue. The rods were given a shape of cube. The nelson mesh was used in the outer part of the rod. Twenty one similar boxes were made. The outer most box had a dimension of 50cm x 50cm and each inner box dimension was reduced by 5mm. The whole box was placed in a box made of fibre having dimension 51cm x 51cm. The regeneration process was performed inside this chamber.

Qing Cheng and Xiaosong Zhang (2013) performed a comparative study on two liquid desiccant regeneration method using solar energy [36]. First one was solar TH (Thermal energy) regeneration system and another one was PVED (Photovoltaic-electrodialysis) regeneration method . Lithium chloride solution was used as liquid desiccant for regeneration. In solar TH regeneration system, it is possible to regenerate only weak desiccants. The weak desiccant was allowed to flow through the solar regenerator where it took away the heat from the solar collector and its temperature was increased. The desiccant was then allowed to pass through environmental air and the air removed the moisture from the desiccant. In PVED regeneration method electrodialysis was used. It is a improved method compared to the previous one. An alternate cation and anion exchange membrane was placed in between the cathode and anode. Due to the difference in concentration of the desiccant , the regeneration was completed. It was found that PVED regeneration method is more efficient compared to the other one. But have high cost.

Chapter 3

THEORY BEHIND THE PROJECT

3.1 THE SUN AS A SOURCE OF ENERGY

The sun ,which is the largest member of the solar system, is a sphere of intensely hot gaseous matter having a diameter of 1.39x10^{11}m. The temperature of its innermost region is estimated between 8x10^6K to 40x10^6K. The core has a density of about 100 times that of water and a pressure of 10^9 atm. This high inner temperature is maintained by enormous energy released because of continuous fusion reaction taking placed at the inner portion of the sun. Thus, the sun can be considered as a big natural fusion reactor. The source of this fusion reaction have been suggested by different scientist in different way. The most common one is the reaction of four hydrogen atoms (protons) that combines to release one helium atom (equation 3.1). The atomic mass of the helium atom is less than that of four protons, and this extra mass is converted to energy released during the fusion reaction.

$$4_1^1H =_2^4 He + 2_{+1}^0e(\beta^+) \tag{3.1}$$

3.1.1 The physics of radiative heat transfer

The physical laws that governs the transfer of energy in the form of radiation are:

- The radiative heat transfer process is independent of the presence of matter. The heat even can move through empty space.
- All heated bodies can emit radiation. The wavelength (or frequency) and the spectrum of that radiation are governed by the temperature of the heated body.

- The energy flux drops as the square of distance from the radiating body.
- The radiation emitted by the hot body undergoes transformation while heating other objects whether it is solid, gas or liquid. The physical properties of the object determines the degree of transformation and during the process heat is transferred from the hot body to that object.

3.1.2 Radiation transfer from Sun to Earth

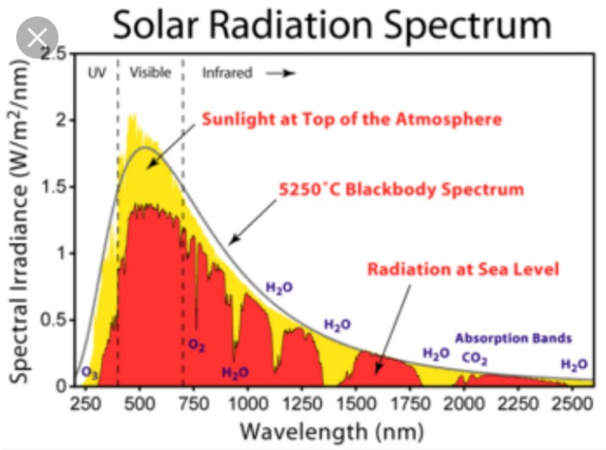

Figure 3.1: *Solar radiation geometry spectrum*

Solar radiation on Earth: The energy transmitted from sun to earth is invariant in spectral characteristics as there is no interfering matters present in the free space. However the energy flux of the radiation decreases because of the high distance between the earth and the sun. This drop of energy is directly proportional to the square of the distance from the Sun. Thus, after travelling several kilometres over the free space the radiation reaches the earth and the radiative flux is approximately 1360W/m^2 in the outer periphery of the earth. Solar radiation incident on the outer atmosphere of the earth is known as extraterrestrial radiation. It can be expressed as,

$$I_{ext} = I_{sc}[1 + 0.033cos(\frac{360n}{365})] \tag{3.2}$$

where I_{sc} in equation 3.2, is the solar constant defined as the energy received from the sun per unit time, on a unit area of surface perpendicular to the direction of propagation of the radiation at the top of the atmosphere and at the earth's mean distance from the sun. I_{ext} is the extraterrestrial radiation. The solar radiation that reaches the earth surface after passing through the earth's atmosphere is known as terrestrial radiation.The variation of solar radiation with respect to different wavelength and earth's distance is illustrated in figure 3.1.

Effect of orbit's shape: The radiation at the top of the atmosphere varies by about 3.5% over the year because of the Earth spins around the Sun. The Earth's orbit is elliptical, where the Sun is located at one of the foci of the ellipse. The Earth remain closer to the sun at one time of year (referred as perihelion) and situated at a very far distance at another time of the year (referred as aphelion). The time-of-year when the Earth is at perihelion moves continuously around the calendar year with a period of 21,000-years. At present perihelion occurs in the middle of the Northern Hemisphere during winter. The annual average radiative solar flux at the top of the Earth's atmosphere has almost remained constant for few hundred years and thus called as Solar Constant. There are however important variations in this flux over longer, so-called "geological", time scales, to which the Earth glaciations cycles are attributed.

Effect of Earth's spherical shape: The earths spherical shape has considerable effect on the received energy from the sun. If the Earth had a shape of a disk and the incoming sunlight had fallen on its surface at perpendicular direction, then each point of the Earth would have received equal amount of radiation equal to the solar constant value. But as the Earth have a shape of a sphere its surface near to the sun receives maximum energy perpendicular to the ground. The two poles of the earth are at the maximum distance from the sun so receives parallel radiation or no energy. The other portion of the earth receives energy that varies between this two maximum and minimum value depending upon its tilt with respect to the sun.

The tilt of the Earth's axis and the seasons: If the axis of Earth was perpendicular to its orbit plane and also to the direction of incoming rays of sunlight then the radiative energy flux would drop as the cosine of latitude from equator to pole. However, the Earth axis tilts at an angle of 23.5^o with respect to its plane of orbit, pointing towards a fix point in space as it travels around the sun. Once a year, on the Summer Solstice (on or about the 21st of June), the North Pole points directly towards the

Sun and the South Pole is entirely hidden from the incoming radiation. Half a year from that day, on the Winter Solstice (on or about the 21st of December) the North Pole points away from the Sun and does not receive any sunlight while the South Pole receives 24 hours of continued sunlight. During Solstices, incoming radiation is perpendicular to the Earth surface on either the latitude of Cancer or the latitude of Capricorn,23.5^o north or south of the equator, depending on whether it is summer or winter in the Northern Hemisphere, respectively. During the spring and fall (on the Equinox days, the 21st of March and 23rd of September) the Earth's axis tilts in parallel to the Sun and both Polar Regions get the same amount of light. At that time the radiation is largest at the true equator. Averaged over a full 24-hour period, the amount of incoming radiation varies with latitude and season. At the poles, during solstice, the earth is either exposed to sunlight over the entire (24-hours) day or is completely hidden from the Sun throughout the entire day. This is why the poles get no incoming radiation during their respective winter or more than the maximum radiation at the equator during their respective summer.

3.2 ENERY FROM EARTH AND EARTHS TEMPERATURE

Solar radiation is divided into two category: Radiation propagating in a straight line and received at the earth surface without change of direction is called direct or beam radiation. Solar radiation scattered by aerosols, dust and molecules is known as diffused radiation. The total radiation at any location on the surface of the earth is the sum of the beam and diffuse radiation and is known as global radiation.

3.2.1 The Earth's albedo

The Earth's surface is not a perfect absorber. It reflects a part of the total solar energy receives. This makes the Earth visible from space although it do not have any internal source of light. The other member of the solar system also shows the same phenomena and are visible because of the sunlight. The most obvious aspect is the brightness of the Earth's cloud cover. A significant part of the Earth's reflectivity can be attributed to clouds. In general, albedo signifies reflectivity. In the context of climate, the reflectivity of a planet is known as albedo. It is just a fractional number. The value of albedo of earth depends upon the geographical location, surface properties, and the weather condition. The Earth's albedo has an average value of about 0.3. It means, the 0.3 part of the total radiation received by the earth from the sun is reflected back by the earth and the other 0.7 part is absorbed by the earth surface.

3.2.2 Effective temperature

The earth can be considered as a big black body. It absorbs the incoming radiation and its temperature increases. The present temperature experienced by the earth is very much effected by the presence of its atmosphere and ocean. Without earths atmosphere and ocean the temperature of its lighted portion would have increased to a very high value, while the darken portion would have much colder.

All heated objects must emit electromagnetic radiation, particularly so if they are surrounded by empty space. This radiation is referred to as outgoing. As long as the incoming radiative flux is larger than the outgoing, the radiated object will continue to warm, and its temperature will continue to increase. This in turn will result in an increase in the outgoing radiation. According to the a law by Stefan and Boltzman, the outgoing radiation increases faster than the temperature. At some point the object will emit as much radiation as the amount incoming and a radiative equilibrium (or balance) will be reached. Using about radiative heat transfer equilibrium temperature of an object can be calculated if the amount of incoming energy is known. Here is how it can be done in the case of a planet rotating around the Sun:

lets the solar radiative flux at the top of the planets atmosphere is S_o (for solar constant) and the albedo of the planet by a. To overcome the difficulty posed by the fact that the planets are spherical and their surface tilts with respect to the incoming radiation, the planet is assumed as a disk placed perpendicular to the incoming radiation having the same radius as the sphere and receiving the same amount of radiation that would have been received by the sphere. If the planet's radius is R the area of that disk is πR^2. Thus:

heat absorbed by planet =

$$(1-a)R^2S_o \tag{3.3}$$

The total heat radiated from the planet is equal to the energy flux implied by its temperature, $T_e$times the entire surface of the planet (from the Stefan-Boltzman law) or:

heat radiated from planet =

$$(4\pi R^2)\sigma T^4 \tag{3.4}$$

In radiative balance we thus have:

$$(4\pi R^2)\sigma T_e^4 = (1 - a)\pi R^2 S_o \tag{3.5}$$

Solving this equation for temperature we obtain:

$$T_e = [(1 - Aa)S_o/4\sigma]^{1/4} \tag{3.6}$$

The subscript e in equation 3.6, is used to the temperature to emphasize that this would be the temperature at the surface of the planet if it had no atmosphere. It is referred to as the effective temperature of the planet. According to this calculation, the effective temperature of Earth is about 255K (or -18 ^{o}C). With this temperature the Earth radiation will be centred on a wavelength of about 11m, well within the range of infrared (IR) radiation. Because of the spectral properties of the Sun and Earth radiation it tend to refer as "shortwave" and "longwave" radiation, respectively.

3.2.3 The greenhouse effect

The effective temperature of Earth is much lower than what is experienced. The average temperature of earth is 288K (or 15^{o}C) over all seasons and considering the entire earth which is much higher than its effective temperature i.e. 255K. This difference of temperature arises because of the presence of some heat absorbing component present in the atmosphere of the earth. This effect of rise in temperature of earth because of the presence of absorbing external particle in the environment is known as the greenhouse effect. This effect is similar to the farming practice of warming garden plots by covering them with a glass (or plastic) enclosure. The Earth's atmosphere contains many trace (or minor)components. While the major atmospheric components (Nitrogen and Oxygen) absorb little or no radiation, some of the minor components are effective absorbers. Particularly effective is water vapour, which absorb effectively in the IR wavelength range. Because the atmosphere is almost transparent to sunlight, all that is absorbed at the surface results in warming and the emission of IR radiation. This radiation cannot freely escape into space because of absorption in the atmosphere by trace gases such as water vapour and carbon dioxide (CO_2). These absorbing gases and their surrounding air warm up, emitting radiation downward, towards the Earth's surface, as well as upward, towards space. This effectively traps part of the IR radiation between ground and the lower 10km of the atmosphere. This reduction in the efficiency of the Earth to lose heat causes the surface temperature to rise above the effective temperature calculated above (T_e) until finally, enough heat is able to escape to space to balance the incoming solar radiation. Because of the IR absorbing gases the heat reflected by the earth cant escape to the space fully instead it is trapped in the earth atmosphere. However, all the heat energy reflected by the earth is not trapped as a portion of it is thrown back to the space by these gases. The green house gases allows the temperature of the earth to rise till the amount of heat radiated from the top of the absorbing layer is equal to the solar radiation at the top of the atmosphere. It is at the top of the absorbing layer that the effective temperature is reached, while down at the surface of the Earth it is much warmer.

3.3 MEASUREMENT OF SOLAR RADIATION

Solar radiation data are measured mainly by the following instruments:

- (i) Pyranometer: A pyranometer is a type of actinometer used for measuring solar irradiance on a planar surface. It can measure the solar radiation flux density in W/m^2. It contains a hemisphere which works within a wavelength range of 0.3m to 3m. Three types of pyranometers can be recognized and grouped in two different technologies: thermopile technology and silicon semiconductor technology.

  - (a)Thermopile pyranometers: It contains a thermopile sensor having a black coating. This sensor absorbs all the solar radiation giving a output spectrum in 300 to 50,000 nanometers range. It also contains a glass dome which provides a spectral response from 300 to 2,800 nanometers. In the modern thermopile pyranometers the active (hot) junctions of the thermopile are located beneath the black coating surface and are heated by the radiation absorbed from the black coating. The passive (cold) junctions of the thermopile are fully protected from solar radiation and in thermal contact with the pyranometer housing, which serves as a heat-sink. This prevents any alteration from yellowing or decay when measuring the temperature in the shade, thus impairing the measure of the solar irradiance.

The thermopile generates a small voltage in proportion to the temperature difference between the black coating surface and the instrument housing. This is of the order of 10μV per W/m^2 radiation. Typically, on a sunny day the output is around 10 mV. Each pyranometer has a unique sensitivity, unless otherwise equipped with a board for signal calibration.

- (b)Photodiode-based pyranometer:A photodiode-based pyranometer mainly contains a housing dome, a photodiode, and a diffuser or optical filters. The surface area of the photodiode is small which acts as a sensor. A current is generated by the photodiode and its value is proportional to solar irradiance. Another circuit called an output circuit (like transimpedance amplifier), produce a voltage directly proportional to the photocurrent. The output is usually on the order of millivolts, the same order of magnitude of thermopile-type pyranometers.

- (c)Photovoltaic pyranometer: A photovoltaic pyranometer have three essential part- a metallic container with a fixing staff, a small photovoltaic cell and a signal conditioning electronics equipments. Silicon sensors such as the photodiode and the photovoltaic cell vary the output in function of temperature. In the more recent models, the electronics equipments used compensate the signal with the temperature. It removes the influence of temperature out of the values of solar irradiance. In several models, the inside of the case contains a board for the amplification purpose and conditioning of the signal.

• (ii)PYRHELIOMETER:A pyrheliometer is an instrument used for the measurement of direct beam irradiance. A transparent window is there to allow the sunlight to enter inside the main instrument. This sunlight fall on a thermopile and the thermopile converts the incoming heat to an electrical signal like voltage current etc. Another formula is used to convert the voltage or current signal to equivalent energy in watts per square meter. Another system with solar tracker is also used to track the sun at each moment during the day so that maximum radiation can be achieved. A pyrheliometer is often used in the same setup with a pyranometer.

- (iii)SUNSHINE RECORDER:A sunshine recorder records the amount of solar radiation at a perticular location. The output of the sunshine recorder is the weather, climate and the reperature of a defined geographical area. This information is useful in meteorology, science, agriculture, tourism and other different field. It is also known as heliograph. There are two basic types of sunshine recorders. One type uses the sun itself as a time-scale for the sunshine readings. The other type uses some form of clock for the time scale.

3.4 SOLAR TIME

Solar time is a calculation of the passage of time based on the sun's position in the sky. The fundamental unit of solar time is the day. Two types of solar time are apparent solar time (sundial time) and mean solar time (clock time).

- Apparent solar time: The apparent sun is the true sun as seen by an observer on Earth. Apparent solar time or true solar time is based on the apparent motion of the actual sun. It is based on the apparent solar day, the interval between two successive returns of the Sun to the local meridian. Solar time can be measured by using a sundial. The equivalent on other planets is termed as local true solar time.

- Mean Solar Time: Mean solar time is the hour angle of the mean Sun plus 12 hours

In general, solar time,

$$solartime = standardtime + 4(L_{st} - L_{loc}) + E \tag{3.7}$$

where L_{st} and L_{loc} in equation 3.7,are the standard longitude used or measuring standard time of the country and the longitude of the observer's location respectively. E is a correction factor.

3.5 SOLAR RADIATION GEOMETRY

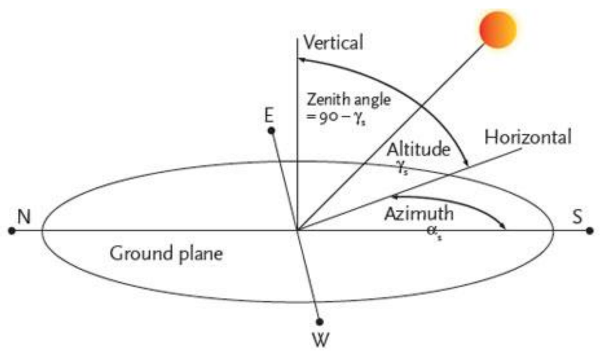

Figure 3.2: *Solar radiation geometry 1*

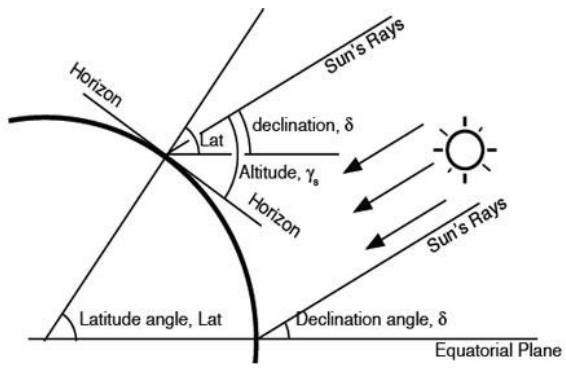

Figure 3.3: *Solar radiation geometry 2*

The Earths daily rotation about the axis through its two celestial poles (North and South) is perpendicular to the equator, but it is not perpendicular to the plane of the Earths orbit. In fact, the measure of tilt or obliquity of the Earths axis to a line perpendicular to the plane of its orbit is currently about 23.5^o. Different solar radiation geometrys are illustrated in figure 3.2 and 3.3.

- (a)Latitude: The latitude of a location on the earth's surface is the angle made by a radial line joining the given location to the centre of the earth with its projection on the equator plane.

- (b) Declination: The Sun declination angle, δ, is defined to be that angle made between a ray of the Sun, when extended to the centre of the earth and the equatorial plane. The Sun declination angle, δ, has the range: -23.5^o $< \delta < +$ 23.5^o during its yearly cycle .

$$\delta = 23.45sin((360/365)(284 + n)) \tag{3.8}$$

  Equation 3.8 is the expression for declination angle in degree, where n is day of the year counted from 1st January.

- (c)Solar Noon : Solar Noon is defined to be that time of day at which the Suns rays are directed perpendicular to a given line of longitude. Thus, solar noon occurs at the same instant for all locations along any common line of longitude. Solar Noon will occur one hour earlier for every 15 degrees of longitude to the east of a given line and one hour later for every 15 degrees west.

- (d)The hour angle: The hour angle, , is the angular distance between the meridian of the observer and the meridian whose plane contains the sun. Thus, the hour angle is zero at local noon (when the sun reaches its highest point in the sky). At this time the sun is said to be due south (or due north, in the Southern Hemisphere) since the meridian plane of the observer contains the sun. The hour angle increases by 15 degrees every hour.

$$\omega = 15(t_o - 12)^o \tag{3.9}$$

  Equation 3.9 is the expression for hour angle ω at time t_o.

- (e)Inclination angle: It is the angle between the sun's ray and its projection on a horizontal surface.

- (f) Zenith angle: It is the angle between the sun's ray and the perpendicular to the horizontal plane.
- (g)Solar azimuth angle: It is the angle on a horizontal plane, between the line due south and the projection of the sun's ray on the horizontal plane. It is taken as +ve when measured from south towards west.
- (h) Slope: It is the angle between the inclined plane surface (collector), under consideration and the horizontal. It is taken to be positive or the surface sloping towards south.
- (i)Surface azimuth angle: It is the angle in the horizontal plane, between the line due south and the horizontal projection of the normal o the inclined plane surface(collector). It is taken as +ve when measured from south towards west.
- (j) Angle of incidence: It is the angle between the sun's ray incident on the plane surface (collector) and the normal to that surface.

3.6 SOLAR COLLECTOR

Intensity of solar radiation is very low. Its density per unit area is also very low. So, it is required to collect it in large scale. For this purpose solar collector is used. It is the first basic unit of solar thermal system. It absorbs solar energy as heat and then transfer it to the heat transport fluid efficiently. The heat-transport fluid delivers this heat to a thermal storage tank/boiler/heat exchanger to be utilized in the subsequent stages of the system.

3.6.1 Classification

Solar collector are mainly classified into two category:

- (1)Flat plate collector: It basically consists of a flat surface with high absorptivity for solar radiation called the absorbing surface. Typically a metal plate, usually of copper, steel or aluminium material are used as the absorbing material. Sometimes along with the collector a tubing of copper in thermal contact with the plates are also used. The absorber plate is usually made from a metal sheet 1mm to 2mm in thickness, while the tubes, which are also of metal, range in diameter from 1 to 1.5cm. They are soldered, brazed or clamped to the bottom of the absorber plate with the pitch ranging from 5cm to 15cm. In some designs, the tubes are also in line and integral with the absorber plate. Figure 3.4 shows a complete flat plate collector.

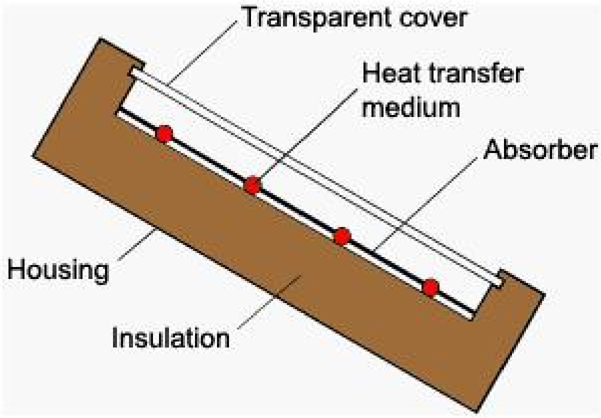

Figure 3.4: *Flat plate solar collector*

The main function of a absorber is to collect maximum solar radiation passing through the glazing. A glazing is another important component of a collector. It is a transparent material like glass, glazing etc. The function of the glazing is to transmit maximum radiation to the solar collector. The glass is transparent to incoming solar radiation and opaque to the infra-red re-radiation from the absorber. The glass covers act as a convection shield to reduce the losses from the absorber plate beneath. The glass thickness of 3mm and 4mm are commonly used. The usual practice is to have 2 covers with specific ranging from 1.5cm to 3cm.

The collector plate is coated with black color to absorb the maximum radiation.Heat is transferred from the absorber plate to a point of use by circulation of fluid across the solar heated surface. The fluid used is generally air or water. Thermal insulation of 5cm to 10cm thickness is usually placed behind the absorber plate to prevent the heat losses from the rear surface. Insulation materials is generally mineral wool or glass wool or fibre glass.

The flat plate solar collector is further divided into two category:

- (a) Liquid flat plate collector: Here a liquid, most commonly water is used as heat transport medium from the collector to the next stage of the system. Sometime, a mixture of water and ethylene glycol is also used.
- (b)Flat plate air heating collector: A solar air-heating collector is similar to a liquid flat plate collector with a change in the configuration of the absorber and tube. The surface are sometime roughened and longitudinal fins are provided in the air flow passage. Corrugated, V-shaped, matrix etc are some of the other variations of shapes of the absorber plate.

- (2) Concentrating type: In concentrating type solar collector, high intensity solar radiation is focus to a point in the collector with the help of a concave or convex shaped collector. The whole system is a optical system which uses the principle of refraction and reflection. The optical system is placed in between the solar radiation and the absorber. In these collectors radiation falling on a relatively large area is focused on to a receiver or absorber of considerably smaller area (figure 3.5). As a result of the energy concentration, fluids can be heated to temperatures of 5000^{o}C or more.

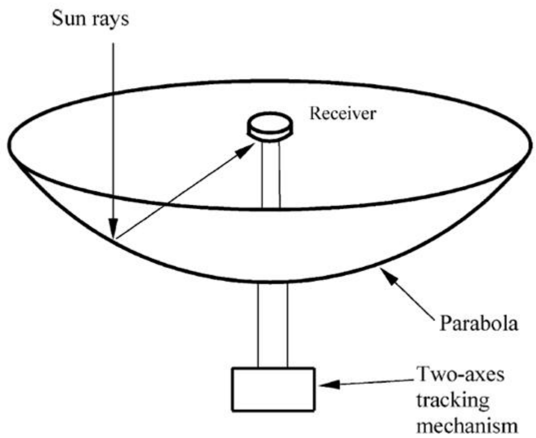

Figure 3.5: *Concentrating type solar collector*

The collector consists of a concentrator and a receiver. The concentrator shown is a mirror reflector having the shape of a cylindrical parabola. It focuses the sunlight on to its axis where it is absorbed on the surface of the absorber tube and transferred to the fluid flow through it.

A concentric glass cover around the absorber is also used to reduce the heat losses to the surrounding during the process. In order that the suns rays should always be focussed on to the absorber tube, the concentrator has to be rotated. This movement is called tracking system. In this system, the axis of the collector is rotated according to the suns position.

3.6.2 Overall Classification

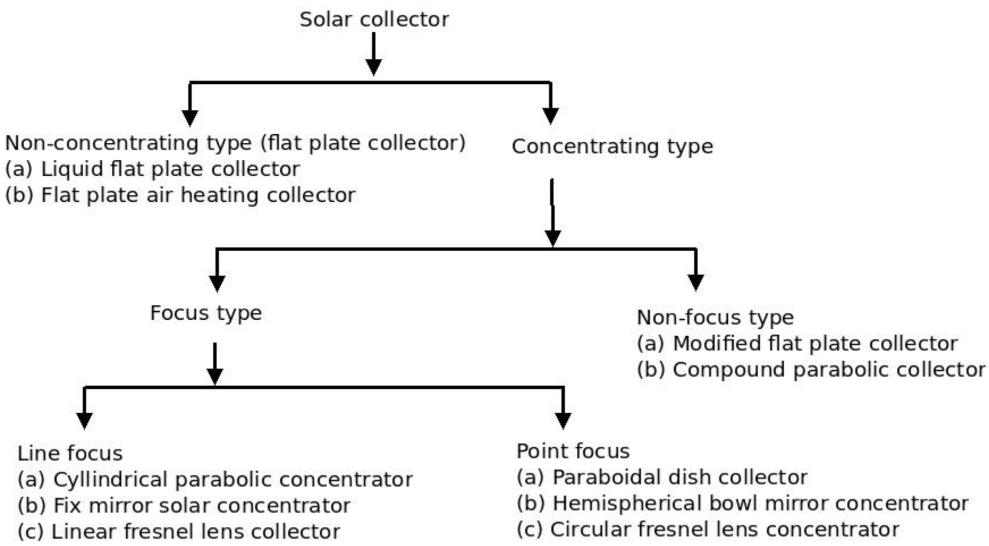

Figure 3.6: *Flow chart*

3.7 WHAT IS A DESICCANT?

A desiccant is a substance that have high affinity towards water molecules. They may be solid desiccant or liquid desiccant. Desiccants absorbs the moisture from other substance making them dry. They are used to create dry environment inside the industries, to prevent the medicines from damage, to increase the longevity of the electrical equipments etc. One of the most commonly used solid desiccant is silica gel. It is used in power transformers to create dry atmosphere inside it. A desiccant after absorbing moisture from the environment around it get saturated. It shows some indication while absorbing moisture. These changes may be some physical changes or chemical changes. For example silica gel have deep blue colour in unsaturated form.

After getting saturated it change its colour to dark pink. Once get saturated it is not possible to use the desiccant again.

Most of the desiccant after getting saturated are thrown to the environment. But this process is not a environment friendly process and can cause many environmental hazard. For this reason regeneration of desiccant is required. In the regeneration process the moisture contents on the desiccants are removed by means of some external processes so that the used desiccants can be used again and again. It also reduces the cost of buying the desiccants.

Different methods are used separately for the regeneration of solid and liquid desiccants. One of the most commonly used method is regeneration using low grade energy like solar energy. Solar energy is cost free and pollution free. It can be easily collected by using a solar collector. A working fluid is heated with this solar power which is used in the regeneration process. Apart from using solar energy sometime electric resistances are also used to increase the temperature. Two new and efficient method for the regeneration for desiccant is electro-osmosis regeneration and microwave electro-magnetic field regeneration. Regeneration of liquid desiccant includes regeneration through spraying and regeneration by passing forced air.

3.7.1 Types of desiccants

- Solid desiccants: Solid desiccants are also called adsorbents.They are the desiccants which do not changes its any physical or chemical properties during regeneration process. Example of solid desiccant is silica gel, activated charcoal, activated alumina, zeolite etc.

  Solid desiccants have more surface area per unit mass. They absorbs water molecules due to existence of a electric field at the surface. The electric field is not uniformly charged. So they can attract polarized water molecules due to the instability in terms of charges. The solid desiccant absorbs the water molecule due to the difference in vapour pressure in between the molecule and the environmental air.

- Liquid desiccants: Liquid desiccants are also called absorbents. They are the desiccants which changes either chemically or physically during the regeneration process. They are generally some strong ionic solution like lithium chloride and calcium chloride. The absorption capacity of liquid desiccants can be changed by changing its concentration and temperature. Temperature is controlled by using heater and cooler. Concentration is changed by changing the moisture contents in it. This is done by heating or spraying.

3.8 SILICA GEL

Silica gel is a form of silicon dioxide which is granular, vitreous and porous. It is derived from sodium silicate synthetically. Silica gel contains a nano-porous silica micro-structure, suspended inside a liquid. It is mainly used as a drying substance in many applications. It shows a peculiar phenomena of absorbing moisture even in room temperature. Silica gel used as a drying substance is known as silica xerogel. It is a naturally obtained mineral and needed to be purified for application purpose. As a desiccant it has an average pore size of 2.4 nanometers and has a strong affinity for water molecules.

Silica gel is commonly available in small packet of size typically 2x3cm for everyday use. It is most commonly used as desiccant for control of local humidity or degradation of some goods. It has a added advantage of showing physical and chemical indication of amount of moisture absorption.

3.8.1 Silica gel as desiccants

Presence of moisture can be dangerous in many cases. Presence of moisture may help in growing mold and spoilage. It may also damage electrical and electronic equipments and can speed up the decomposition process of chemical, medical products etc. So small packet of silica gels are very much helpful for all these purpose.

Silica gels are also used to maintain relative humidity inside very high frequency radio or satellite transmission system. In case of waveguide also, presence of moisture can cause arcing, which can cause the damage of power amplifier. Also, the beads of water that form and condense inside the waveguide change the characteristic impedance and frequency, degrading the signal. It is common for a small compressed air system to be employed to circulate the air inside the waveguide over a jar of silica gel.

Silica gel is also used to create dry environment inside the industrial compressed air systems. Air that flows from the compressor is allowed to flow through a silica gel beds. The bed absorbs the moisture from the air which may cause damage to the compressor. The similar system is used in railway locomotives also. The condensed air and ice in the brake air pipe can lead to the failure of brake failure. So the air inside the locomotive is subjected to silica gel before using.

Silica gel is also used for controlling relative humidity in different places like museum, library exhibitions, storage etc. Other applications include diagnostic test strips, inhalation devices, syringes, drug test kits and hospital sanitation kits.

3.8.2 Breathing Process of Transformers

Breathing is the process where the transformer Breather-in or Breather out the air from its body due to thermal contraction and expansion of oil mass. When the transformer is loaded or unloaded,the oil temperature inside the transformer tank rises or falls accordingly the air pressure inside the tank changes by either breathing in or breathing out the air. This phenomenon is called "Breathing" of the transformer. The air which is being breathed in contains either dust particles and/or humidity that change the dielectric strength of the oil. For proper functioning of transformer, it is absolutely necessary that dielectric strength of transformer oil remains unimpaired. Hence, it is necessary that, the air entering into the transformer is free from moisture and dust particles.

3.8.3 Function of Silica gel as Breather

The sole function of Silica Gel Breather is to dehydrate the air and to remove dust particles of the air breathed in by the transformer.

OPERATION AND WORKING OF SILICA GEL BREATHER : Silica gel brather are some hollow cylindrical tubes which are transparent. The tubes contain chemically pure silicium salt (Silica Gel) with cobalt as indicator. This grade of Silica Gel is called as indicating grade of Silica Gel.

The indicating grade of Silica Gel, which is filled in the breather, is hard blue crystals, which has considerable absorption power for moisture. Silica Gel absorbs moisture signalling the saturation degree by changing colour. Deep blue silica gel means the gel contains no moisture. Light blue colour of silica gel means the silica gel contains some moisture but not fully saturated (absorbed water for about 15% of its weight). Pink colour of silica gel means the silica gel is completely saturated with moisture (absorbed water for about 30 - 40% of its weight) and can not be used further.

For proper functioning of transformer dehumidification of Silica Gel crystals and removal of dust particles from breathed air is necessary. Moisture is removed from Silica Gel crystals by heating it inside a ventilated oven at to 150^o C, until the colour becomes deep blue again. Dusts particles are filtered by the oil in the oil cup. Pressure value for air passage into the breather are: 0.003 Kg/cm inlet or 0.005 Kg/cm outlet.

3.8.4 Need for Reactivation

Once used silica gel get saturated. After that it is thrown to the environment which is not at all an environment friendly process. Also reactivation reduces the cost of buying new silica gel. For all these reason silica gel is reactivated. A number of different methods are used for the reactivation process. They include uses of burning of easily available fuel, uses of non-conventional energy, uses of electric arc heating, uses of microwave, uses of electro-osmosis process etc.

3.9 CARBON FOOTPRINT

The common definition of carbon footprint is the total set of greenhouse gas emissions caused by an individual, event, organisation, or product, expressed as carbon dioxide equivalent. In day to day life different activity of human being cause carbon emission. When a car is driving , the burning of fuel cause emission of carbon dioxide, depending on its fuel consumption and the driving distance. When a house is heated with fuel ,with coal , with gas, carbon is emitted. Even the use of electricity also releases carbon dioxide as there is some emission of carbon dioxide at the time of generation of electricity. The production of foods and goods also emitted some quantities of carbon dioxide. Carbon footprint is calculated as the sum of all these carbon dioxide emission induced by a huan activity in a given time frame. This time frame is generally one year.

The best way is to calculate the carbon dioxide emissions based on the fuel consumption. Each of the following activities add 1kg of carbon dioxide to carbon footprint:

- Travel by public transportation (train or bus) a distance of 10 to 12km (6.5 to 7 miles).
- Drive with a car a distance of 6 km or 3.75 miles (assuming 7.3 litres petrol per 100km).
- Fly with a plane a distance of 2.2km or 1.375miles.
- Operate a computer for 32hours (60Watt consumption assumed).
- Production of 5 plastic bags.
- Production of 2 plastic bottles.
- Production of 1/3 of an American cheeseburger.

Carbon dioxide is one of the most important gas of green house which causes global warming. Other important gases to study under green house effect are methane and ozone. Sometime while calculating the carbon footprint emission of all these gases are also included. In that case these gases are converted to the equivalent amount of carbon dioxide which may cause the same effect of global warming.

Few people express their carbon footprint in kg carbon rather than kg carbon dioxide. The kg carbon dioxide can be converted to kg carbon by multiplying with a factor 0.27 (1.000kg CO_2 equals 270kg carbon).

The carbon footprint is a very powerful tool to understand the impact of personal behaviour on global warming. To stop global warming, the calculation and constant monitoring of personal carbon footprint is essential.

For registered users, there are lots of carbon footprint calculator on website, which allows to store individual activities like, e.g. travelling by car, train, bus or air plane, fuel consumptions, electricity bills and so on. The individual contributions is called the "carbon stamps". However, the answers can vary widely between websites depending on the methodology used. For example, one website might focus only on the fuel use involved in flying while another might include an estimate of the climate impact of the vapour trails caused by the plane. Similarly, one website might estimate a person's footprint based only on their home energy and travel, while another might include an estimate of all the goods and services they consume, from clothes and computers to education and healthcare. An off-line carbon footprint and primary energy consumption calculator (Excel sheet) is also available. There are also graphs available for the carbon dioxide emission per capita by a country i.e. average carbon footprint by a country. In the medium- and long term, the carbon footprint must be reduced to less than 2.000 kg carbon dioxide per year and per person. This is the maximum allowance for a sustainable living.

Some formulas are also there to calculate carbon footprint manually. For that purpose an factor called carbon emission factor is defined which is basically a conversion factor. Carbon emission factor provide the equivalency of a particular fuel or electricity or food consumption to the carbon emission. By multiplying with the carbon emission factor with a particular fuel consumption, carbon footprint can be calculated. Another important factor while calculating carbon footprint of a fuel is the calorific value of the fuel. It is defined as the amount of energy generated while burning a particular amount of fuel.

Chapter 4

PROJECT IMPLIMENTATION

The project starts with the literature review of the topic Reactivation of desiccant. After that, the hardware system was implemented first. After the first hardware model, to increase the efficiency of the system another model (only the collector part) is designed with the view to minimize the heat loss due to the first model. After the realization of both the model, both the collectors are exposed to the sunlight for three days -27th, 28th and 29th December, 2016 for approximately two hours each day and temperature rise for both the collector for each day is noted.

A mathematical model is implemented for both the plates by considering all the thermodynamical behaviour of the collector material and the expected temperature rise for the collector material (and thus the air in contact with the collector, which act as the heat transfer fluid) is calculated theoretically. And finally, both the theoretical and practically obtained value is calculated.

After the completion of the hardware model, the experiment with the silica gel is tested. The experiment is performed by using both the hardware model and the results are compared. A simulation model is also designed using MATLAB coding with the help of the mathematical model. At the end, carbon footprint is calculated by considering two method- the regeneration process using wood as fuel and regeneration process using electricity as heating medium. Thus carbon saving during the experiment is estimated.

4.1 HARDWARE IMPLIMENTATION

4.1.1 Design of the first hardware model

The first hardware model consist of two chamber. First one is the heating chamber where the heat transfer fluid is heated. This fluid is transferred to the next chamber where the reactivation process is done. The heated fluid dry the silica gel. And thus the whole reactivation process is completed.

- COLLECTOR:The collector for the first model is 0.5x0.5cm and the material used is black painted aluminium foil as shown in figure 4.1. The collector is placed at a depth of about 8cm from the top of the first chamber. First chamber made up of wood which act as a low heat transfer material. It acts as a insulator. Another insulator used is glass wool and placed at the bottom and side of the chamber. The top of the chamber is covered with glass which act as the glazing material for the collector.

Figure 4.1: *Collector of the first hardware model*

- AIR FLOW MECHANISM: As shown in the figure 4.2, the air in the first chamber will enter from the environment through the entrance provided at the top of the chamber. For the heated air to transfer from the first chamber to the second chamber, another entrance is provided at the top of the another side of the first chamber which releases at the bottom of the second chamber. The heated air from the second chamber will be again released to the environment through a passage at the top of the another side of the second chamber.

Figure 4.2: *Air flow mechanism of the first hardware model*

- SILICA GEL REACTIVATION MECHANISM: This part consist of the second chamber. The heated air enter from the first chamber to the second chamber where the reactivation of the silica gel is performed. The passage for the hot air is at the bottom of the chamber. A perforated tray is placed at the middle of the chamber as shown in figure 4.3. Hot air from the bottom of the chamber passes through the tray and release to the environment from the top passage. The tray is placed in a wooden frame. The whole chamber is made up of aluminium as aluminium itself absorbs sun radiation to heat the chamber which is an additional advantage.

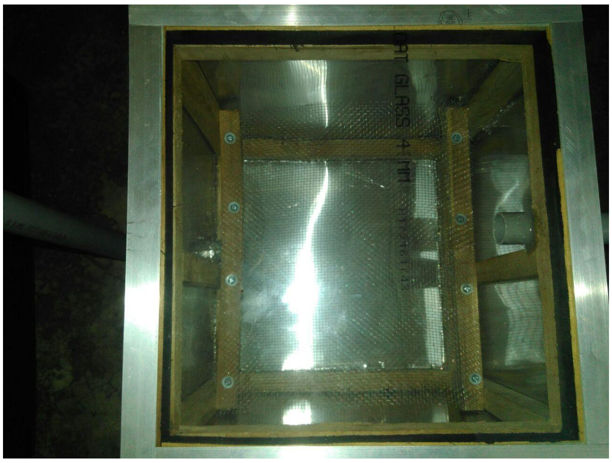

Figure 4.3: *Reactivation chamber of first hardware model*

4.1.2 Design of the second hardware model

As with the first model rise of temperature is not at a satisfactory level, another model for the flat plate collector is designed. The second chamber for both the collector will be same and will tested sepeartly.

Figure 4.4: *Collect part of the second hardware model*

The collector and air flow passage both are designed in this model with a single sheet of aluminium of dimension 2mx1m. As shown in the figure 4.4, a portion of dimension 1mx1m of the sheet is taken and folded from three side with a length of 5cm. This portion will act as the required flat plate collector. Other 1mx1m half is folded in such a way that it form like a triangle. The tip of the triangle is folded to make a passage to enter the air flow to the second chamber. This portion will form a pipette like structure which will form the air flow mechanism. The end of the triangle is again folded with a 5cm gap. The whole sheet is painted with black paint. The glazing material used here is a cling film instead of glass as cling film has more transmisivity of radiation value as compared to glass.

4.2 MATHEMATICAL MODELLING

Assumptions:

- (a)heat loss at the edges of the chamber is neglected

- (b)only average value of the solar radiation is taken while the radiation varies with times

- (c) the average temperature of the collector is taken while different portion of the collector may have different temperature at a particular time

Let, I= average solar radiance (in watt/m^2)

A= area of the collectors

t_o=thickness of the plate

ρ=density of Al

α=absorbtivity of the collector materials

τ=transmisivity of the glazing

t= time for which collector is exposed to sun lighted

T_{in}=initial temperature of the collector

T_{fin}=final temperature of the collector

s= specific heat energy of aluminium

Incident energy (E in watt) on the glazing is given by,

$$E = IA \tag{4.1}$$

As, watt= joule/sec, therefore,heat energy incident on glazing is,

$$Q_{in} = Et \tag{4.2}$$

$$Q_{in} = IAt \tag{4.3}$$

Now, energy fall on the collector

$$Q_c = \tau Q_{in} \tag{4.4}$$

$$Q_c = \tau IAt \tag{4.5}$$

therefore, heat energy absorbed by the collector,

$$Q_{abs} = \tau\alpha I A t \tag{4.6}$$

again,

$$Q_{abs} = ms(T_{fin} - T_{in}) \tag{4.7}$$

so,

$$ms(T_{fin} - T_{in}) = \tau\alpha I A t \tag{4.8}$$

now,

$$m = \rho A t_o \tag{4.9}$$

therefore,

$$\rho A t_o s(T_{fin} - T_{in}) = \tau\alpha I A t \tag{4.10}$$

therefore,

$$\rho t_o s(T_{fin} - T_{in}) = \tau\alpha I t \tag{4.11}$$

therefore,

$$T_{fin} - T_{in} = (\tau\alpha I t)/(\rho t_o s) \tag{4.12}$$

$$T_{fin} = T_{in} + (\tau\alpha I t)/(\rho t_o s) \tag{4.13}$$

Equation 4.13 gives the final temperature rise of the collector

4.3 CONSIDERATION OF HEAT LOSS

There are mainly two types of losses occur in a flat plate collector which are optical and thermal losses, respectively. Optical losses can be shown as $\tau\alpha$, where $\tau\alpha$ is the transmittance- absorbance of the glass cover depending on the material properties. Thermal losses can be divided into three parts which are heat loss from the top of the collector U_{top}, from the back U_{back} and the edge of the collector U_{edge} respectively. During the calculations heat loss through the edges has been ignored. Heat loss from the top of the collector can take place by means of radiation and convection heat transfer mechanism from the glass cover to the atmosphere and from the absorber plate to the cover.

Thus, heat loss from the collector,

$$Q_L = U_L(T_p - T_a) \tag{4.14}$$

Where T_p=mean temperature of the absorber plate

T_a=temperature of the surrounding air

U_L= overall loss coefficient

The heat loss from the collector is the sum of the heat lost from the top and back.

Thus,

$$U_L = U_{top} + U_{back} \tag{4.15}$$

Klein[37] generalized a formula to calculate the top heat loss coefficient which can be shown as,

$$U_{top} = (\frac{N_c}{\frac{C}{T_c}(\frac{T_p - T_a}{N_c + f})^e} + \frac{1}{h_w})^{-1} + \frac{\sigma(T_p + T_a)(T_p^2 + T_a^2)}{(\epsilon_p + 0.00591 N_c h_w)^{-1} + \frac{2N_c + f - 1 + 0.133\epsilon_p}{\epsilon_c} - N_c} \tag{4.16}$$

Where, f=(1+.0889 h_w-0.11 h_w ϵ_p)(1+.076 N_c)

C=520(1-0.000051 β^2) for $0^o < \beta < 70^o$ and if $70^o < \beta < 90^o$, then $\beta = 70^o$

e=0.430(1-100/T_p)

N_c=no of glass cover

h_w=heat transfer coefficient of wind

σ=stefan-boltzman constant

ϵ=emissivity

β=collector tilt angle

now, heat loss from the back of the collector is,

$$U_{back} = K_{ins}/L_{ins} \tag{4.17}$$

Where K_{ins}=thermal conductivity of insulator

L_{ins}=thickness of insulation

Equation 4.16 and 4.17 provide the expression for top heat loss coefficient and back heat loss coefficient respectively.

4.4 MATERIAL SPECIFICATION

τ = 0.87(for glass), 0.9(for cling film)

α = 0.9 (for black painted aluminium foil)

I= 6.29 KWh/m^2/day[38] at a tilted angle 49^o (obtained from the website of the solar electricity handbook for the location Guwahati, India (with latitude 21.45^o north and longitude 91.73^o east) for the month of December)

I=4.08 KWh/m^2/day[38] for a flat surface (obtained from the website of the solar electricity handbook for the location Guwahati ,India (with latitude 21.45^O north and longitude 91.73^o east) for the month of December)

= 2700 kg/m^3(for aluminium foil)

t_o =0.15mm

s = 900 J/gm/^{o}C

4.5 EXPERIMENT1

The experiment is performed in a sunny weather on 27th, 28th and 29th December, 2016. The two collector is exposed to sun radiation for two hours. The temperature rise for each plate is observed and noted with two different thermometer.

4.6 EXPERIMENTAL RESULTS

Table 4.1 and 4.2 gives a comparision between analytical and practical value using the first hardware model and second hardware model respectively.

Table 4.1: For the first model with glass as glazing material and collector tilted at about 49^o from ground

Day	Temperature rise (analytical) (in degree celcius)	Temperature rise (practical) (in degree celcius)
Day1	65	54
Day2	65	55
Day3	65	53

Table 4.2: For the second model with cling film as glazing material and collector placed in flat ground level

Day	Temperature rise (analytical) (in degree celcius)	Temperature rise (practical) (in degree celcius)
Day1	52	40
Day2	52	37
Day3	52	35

4.7 SIMULATION

The simulation model is designed in MATLAB code. The temperature rise (ideally) inside the regenerating chamber can be calculated for certain conditions using this simulation model.

4.7.1 Simulation without losses

Three different conditions are considered-

- (i) Solar plate placing horizontally in a cloudless weather
- (ii) Solar plate placing horizontally in a cloudy weather
- (iii) Solar plate placing inclined at some angle

The solar intensity value needed while estimating the temperature rise value inside the regenerating chamber can be calculated using the following formulas:

- (1)Solar plate placing horizontally in a cloudy weather:

$$\delta = 23.45sin(\frac{360(284+n)}{365}) \tag{4.18}$$

$$\omega_s = cos^{-1}(-tan\phi tan\delta); \tag{4.19}$$

$$N_{bar} = \frac{2}{15}\omega_s; \tag{4.20}$$

$$a = 0.409 + (0.5016sin(\omega_s - 60)) \tag{4.21}$$

$$b = 0.6609 - (0.4767 * sin(\omega_s - 60)) \tag{4.22}$$

$$\omega = (solartime - 12)15 \tag{4.23}$$

$$I_o = (3600I_{sc}(1 + 0.033cos(\frac{360n}{365}))(cos\phi cos\delta cos\omega)) + (sin\delta sin\phi) \tag{4.24}$$

$$Ho = 3600(\frac{24}{\pi})(Isc(1 + 0.033cos(\frac{360n}{365})))((cos\phi cos\delta * sin\omega_s) + (\omega_s sin\delta sin\phi)) \tag{4.25}$$

$$H_g = H_o(a + (b\frac{n_{bar}}{N_{bar}})) \tag{4.26}$$

$$I = H_g(a + (bcos\omega))(\frac{I_o}{H_o}) \tag{4.27}$$

Equation 4.27 is the expression[39] for solar intensity for a collector placing horizontally on earth's surface in a cloudy weather.

- (2)Solar plate placing horizontally in a cloudless weather:

$$Ibn = Ae^{(-B/(cos\phi cos\delta cos\omega))+(sin\delta sin\phi)} \tag{4.28}$$

$$I_b = I_{bn}((cos\phi cos\delta cos\omega) + (sin\delta sin\phi)) \tag{4.29}$$

$$I_d = CI_{bn} \tag{4.30}$$

$$I = I_b + I_d \tag{4.31}$$

Equation 4.31 is the expression[39] for solar intensity for a collector placing horizontally on earth's surface in a cloudless weather.

- (3) Solar plate placing inclined at some angle:

$$k = H_g/H_o \tag{4.32}$$

$$H_d = (1.354 - (1.57k))H_g \tag{4.33}$$

$$\omega_{st} = cos^{-1}((-1)tan(\phi - \beta)tan\delta) \tag{4.34}$$

$$R_b = ((\omega_{st}sin\delta sin(\phi - \beta)) + (cos\delta sin\omega_{st}cos(\phi - \beta)))/((\omega_s sin\delta sin\phi) + (cos\delta sin\omega_s cos\phi)) \tag{4.35}$$

$$R_d = (1 + cos\beta)/2 \tag{4.36}$$

p=0.2

$$R_r = p(1 - cos\beta)/2 \tag{4.37}$$

$$I = (H_g(((1 - (H_d/H_g))R_b) + ((H_d R_d)/H_g) + R_r)) \tag{4.38}$$

Equation 4.38 is the expression[39] for solar intensity for a collector placing inclined to the earth's surface. The whole simulation model is tested for the month of july in Guwahati city. Following are the parameters considered while testing the simulation system:

τ =0.87(for glass)

α=0.9 (for black painted aluminium foil)

ρ = 2700 kg/m3(for aluminium foil)

t_o =0.15mm

s = 900 J/gm/^{0}C

t_{in}=25

t= 2 hr

n_{bar} = 7 (average time for which solar intensity is available)

ϕ =26.14 (latitude for guwahati)

n =198 (taking the ideal condition for the month of july i.e. 17th july)

solar time =12

I_{sc} = 1367 W/m^2

A =1093

B =0.186

C =0.138

β=30^o

Table 4.3: Results of simulation model

Collector plate condition	Weather condition	Delta (in degree)	Solar intensity (J/sec)	T (final) (in degree celcius)
Placed horizontally	Cloudless	21.2258	285.7457	69.1953
Placed horizontally	Cloudy	21.2258	271.1157	66.9326
Inclined at an angle of 30^0	No condition	21.2258	373.9338	82.8351

Table 4.3 provides the results of the simulation model. The results of the simulation model reveal that the regeneration of silica gel (or any other solid desiccant) is possible with the designed model.

4.7.2 Consideration of heat losses

The system considered under the simulation model is a ideal one. There are two heat losses in a practical system- one is a thermal loss another on is optical loss. The optical losses is considered in the simulation system. As the consideration of the thermal loss makes the system more complicated, so it is ignored in the simulation model. The heat loss terms are considered separately by considering the physical properties of the flat plate collector and using the Kleins formula. The consideration is designed in MATLAB coding.

Data used:

K_{ins}=0.04W/mK

N_c=1

h_w=7 w/m^2 K

ϵ_p=0.09

ϵ_p=0.94

T_a=30^o

σ=5.67 x10^{-8} W/m$^2K^4$

Results:

Figure 4.5 gives the curve for top heat loss coefficient vs plate temperature. Figure 4.6 gives the curve for back heat loss coefficient vs thickness of insulation.

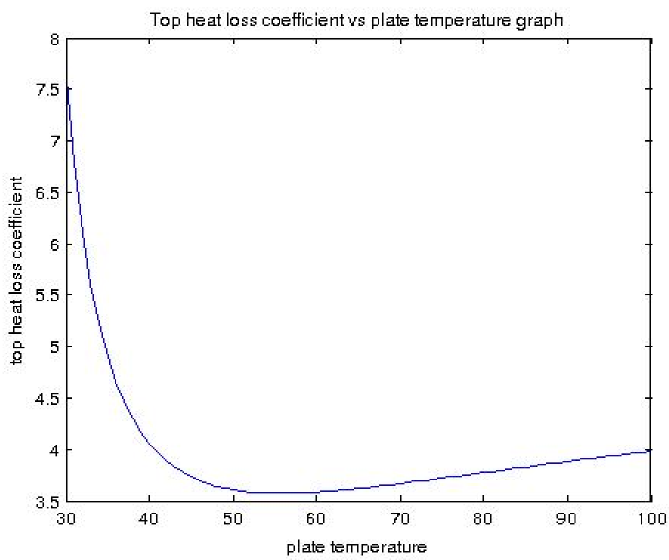

Figure 4.5: *Top heat loss coefficient vs plate temperature graph*

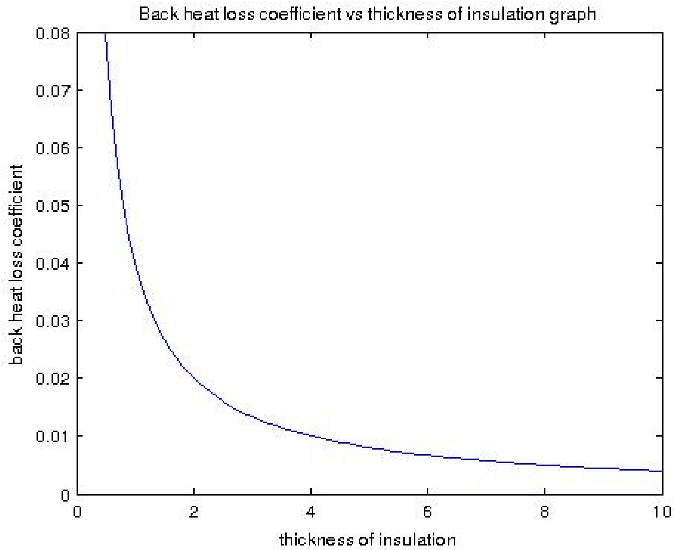

Figure 4.6: *Back heat loss coefficient vs thickness of insulation graph*

4.8 EXPERIMENT 2

The experiment with the silica gel is performed on the sunny weather of 31st of july (with the first hardware model) and the sunny weather of 6th of august (with the second hardware model) .

4.8.1 With the first hardware model

The set up for the experiment is as shown in figure 4.7. The chamber containing the solar collector is first tilted to an angle of approximately 30 and is exposed to the sunlight. Though the passage connected to this chamber cold air will flow to the chamber due to the pressure difference. This air will get heated in the chamber and through the air flow mechanism it will transfer to the regeneration chamber. The silica gel is placed in the regeneration chamber in a perforated tray. The regeneration chamber is placed above the collector chamber so that hot air can easily transfer from the collector chamber to the regeneration chamber due to pressure difference. The hot air after regenerating the silica gel will flow to the environment through the passage at the top of the regenerating chamber. The glazing for the collector used here is glass and glass wool is used as insulation.

The reduced weight of silica gel in every half an hour is calculated and is tabulated

Figure 4.7: *Experiment set up for first hardware model*

in table 4.4. (Amount of silica gel taken initialy=500gm).

Figure 4.8 shows the curve for regeneration rate vs time with first hardware model

Table 4.4: Regeneration of silica gel using first hardware model

Time	Weight of silica gel (in kg)	Regeneration rate (in kg/hr)
10:00:00	0.5	0
10:30:00	0.495	0.01
11:00:00	0.484	0.022
11:30:00	0.479	0.01
12:00:00	0.462	0.034
12:30:00	0.445	0.034
01:00:00	0.423	0.044
01:30:00	0.397	0.052
02:00:00	0.371	0.052
02:30:00	0.368	0.006
03:00:00	0.363	0.01
03:30:00	0.363	0
04:00:00	0.363	0

4.8.2 With the second hardware model

The set up for the experiment is as shown in figure 4.9. The collector plate is placed horizontally and is exposed to sun light. The triangular section attached to the collector work as the air flow mechanism. Through the passage available in the collector cold air enters to the collector and get heated. This hot air is transferred

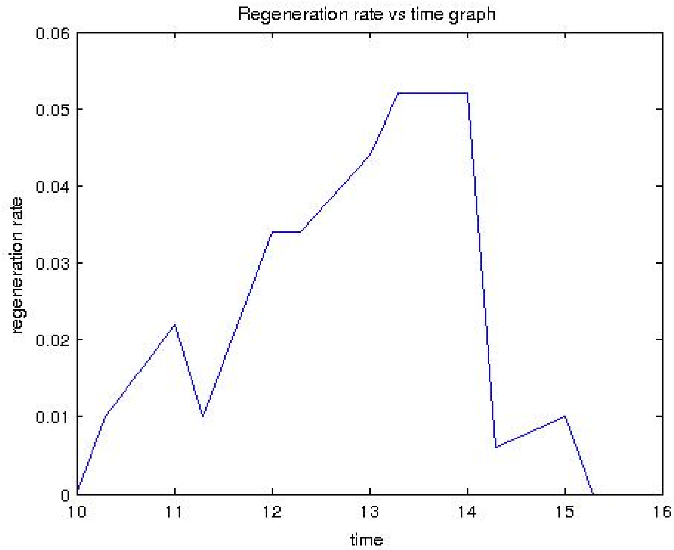

Figure 4.8: *Regeneration rate vs time graph with first hardware model*

to the regenerating chamber and following the same principle as the first hardware model the silica gel will regenerate. The glazing used here is cling film and glass wool is used as insulator.

The reduced weight of silica gel in every half an hour is calculated and is tabulated in table 4.5. (Amount of silica gel taken initialy=500gm).

Figure 4.10 shows the curve for regeneration rate vs time with second hardware model

Table 4.5: Regeneration of silica gel using first hardware model

Time	Weight of silica gel (in kg)	Regeneration rate (in kg/hr)
10:00:00	0.5	0
10:30:00	0.498	0.004
11:00:00	0.495	0.006
11:30:00	0.49	0.01
12:00:00	0.485	0.01
12:30:00	0.48	0.01
01:00:00	0.473	0.014
01:30:00	0.469	0.008
02:00:00	0.462	0.014
02:30:00	0.46	0.004
03:00:00	0.455	0.01
03:30:00	0.45	0.01
04:00:00	0.447	0.006

Figure 4.9: *Experiment set up for second hardware model*

4.9 CALCULATION OF CARBON FOOTPRINT

Carbon footprint is calculated considering two other method of regeneration of solid desiccant- one is using wood as heating fuel and the other one is using electric current as heating medium. This two methods are compare with the solar model to determine the amount of carbon saving during the experiment.

For wood as fuel the formula for carbon footprint is:

Carbon emission from wood= Quantity of non-renewable biomass x Net calorific value of wood x Carbon emission factor for wood[40]

Net calorific value of wood = 0.015TJ/tonne

Carbon emission factor for wood = 109.6 $tCO2/TJ$

For electric current as heating medium the formula for carbon footprint is:

Carbon emission from electric heating= Meter unit x Carbon emission factor[40]

Carbon emission factor for electric heating=0.85

Results: Kg of wood required to regenerate 500gm of silica gel = 2kg

No of unit changed in the digital meter which is required to regenerate 500gm of

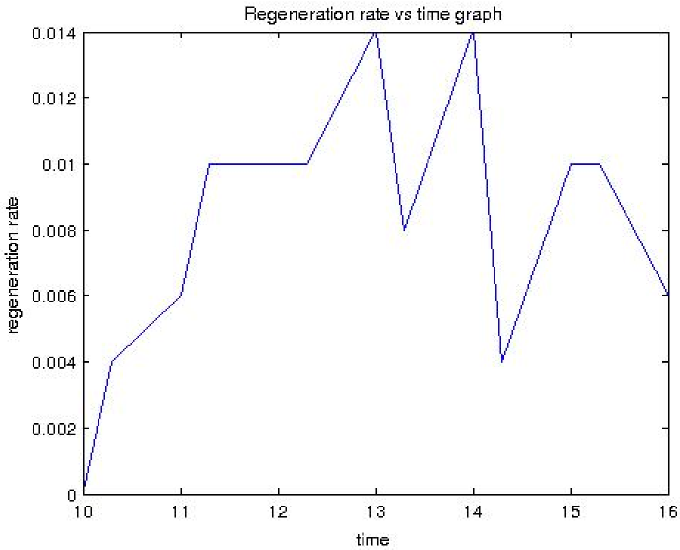

Figure 4.10: *Regeneration rate vs time graph with second hardware model*

silica gel= 2

Figure 4.6 illustrate the results of carbon footprint.

Table 4.6: Carboon footprint

Method of regeneration	Carbon generated (in kg)
Wood as fuel	3.28
Electric heating	1.7

Chapter 5

CONCLUSION AND FUTURE WORK

5.1 CONCLUSION

- (i) From the results it is found that the first hardware model is more efficient than the second one which is also obtained from the simulation model. The collector tilted to some optimal angle always receives more solar intensity than the one placed in a flat surface and hence more efficient.

- (ii) The regeneration rate of the silica gel is first low then increases to a very high value then again decreases. At starting the plate temperature is low so the regeneration rate is also low. As plate temperature increases the regeneration rate also increases. Although plate temperature is maximum after certain time and reach a steady state value, the regeneration rate decreases as the moisture content in the silica gel reduces to a large extend.

- (iii) The simulation model designed is a generalised model which can be used to calculate the expected temperature rise of the collector plate placed at any location on the earth, tilted to any random angle, irrespective of weather condition.

- (iv) The carbon saving during the experiment is 3.28kg as compared to burning of wood and is 1.7kg as compared to electric heating. Also it can be interfered that the carbon generated with fuel is more than the electric heating.

- (v) The top heat loss vs plate temperature curve first decreases reaches a low value than again increases. At starting the heat loss coefficient is high as temperature difference between environment and plate is more. As the plate temperature increases heat loss decreases due to the convection. But after reaching a certain plate temperature the heat loss again starts to increase due to high temperature difference between plate and the environment.

- (vi) The back heat loss vs plate temperature curve decreases very sharply with the thickness of insulation but after certain point the slope of decrease is low as with increase of insulation the heat loss dont have any effect.

5.2 FUTURE WORK

As the research till now in the field of regeneration of solid desiccant is very limited ,there are lot many scopes to research in this field. As the renewable energy is now considered as a great alternative to the conventional energy sources it is an utmost need. The system used in this project can also be modified in different manner. The hardware model designed here are mostly from easily available materials. The collector temperature can be increase by using galvanised steel instead of aluminium sheet. Consideration of thermal losses and humidity while calculating the temperature rise is also under important prospect to be studied in future.

Chapter 6

APPENDIX

6.1 PICTURES TAKEN DURING THE EXPERIMENT

Figure 6.1: *First hardware model exposed to sunlight during experiment-1*

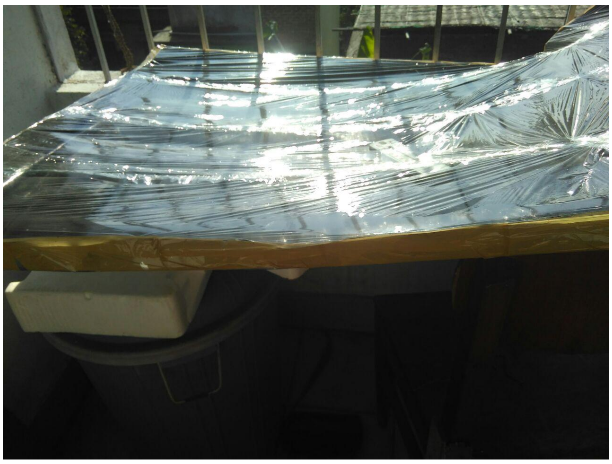

Figure 6.2: *Second hardware model exposed to sunlightduring experiment-1*

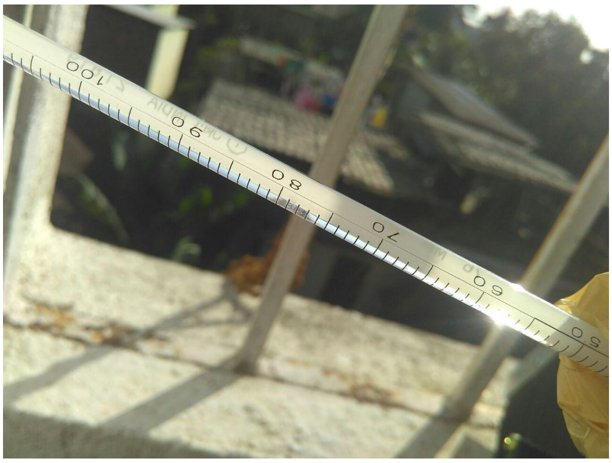

Figure 6.3: *Temperature rise to 55°C with first hardware model during experiment-1*

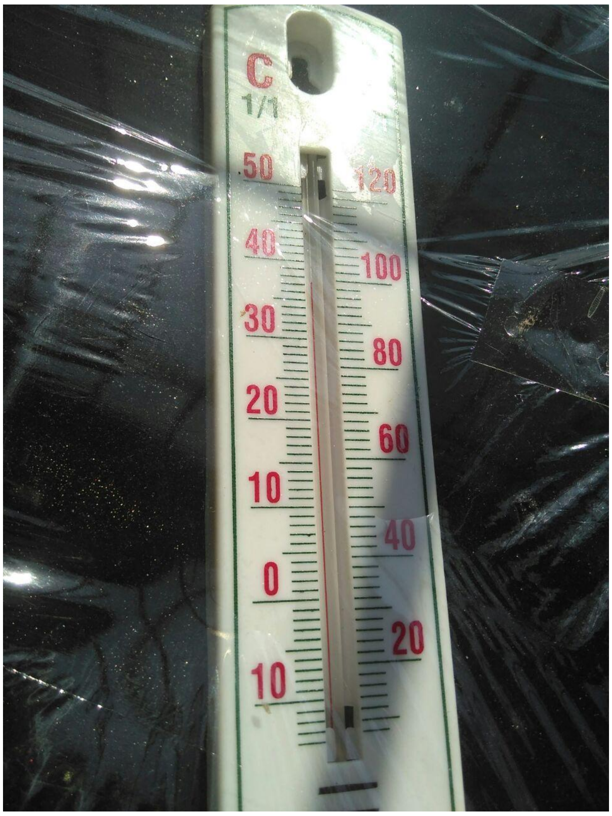

Figure 6.4: *Temperature rise to 40°C with second hardware model during experiment-1*

Figure 6.5: *measurement of thickness of the aluminium sheet with a screw gauge at the physics laboratory of Assam Engineering College*

Figure 6.6: *Temperature rise to* $40^{o}C$ *with second hardware model during experiment-2*

Figure 6.7: *Saturated silica gel placed at the regenerating chamber*

Figure 6.8: *Silica gel started srying in the reactivation chamber*

Figure 6.9: *Silica gel dried copletely with thermometer showing* $67^{o}C$

Figure 6.10: *Saturated silica gel of 500gm*

Figure 6.11: *Silica gel started reducing in weight (484gm)*

Figure 6.12: *Silica gel started reducing in weight (479gm)*

Figure 6.13: *Silica gel started reducing in weight (397gm)*

Figure 6.14: *Silica gel started reducing in weight (371gm)*

Figure 6.15: *Silica gel dried completely (363gm)*

Figure 6.16: *Drying of silica gel in an induction plate (electric heating)*

Figure 6.17: *Drying of silica gel using wood as fuel*