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GHG Tank : for Heat Storage and Utilization

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***Abstract*— The concept of GHG tank is utilization of solar energy for heating purpose. Trapping of solar radiation by greenhouse gases (GHGs), leads to greenhouse effect, best known for its contribution to global warming. The concept here consists of trapping of heat due to greenhouse effect and its utilization for various applications.**

Greenhouse gases like CO_2, SO_2 and CFC have the inbuilt characteristic of trapping heat. This property can be utilized to trap and store heat, which can be transferred through a suitable medium for various applications. The industries which give out GHGs as a residue / flue gases can make use of such systems for low or medium or high temperature applications, as per the temperatures obtained, which depends primarily upon the heat storage capacity of different GHGs and relevant parameters like size of the tank, gas pressure, flow rate of thermic fluid inside the heat exchanger, etc.

The system is developed, based on the principle of heat trapping by GHGs, and it consists of an insulated GHG storage tank with a simple helical, spiral heat exchanger embedded in it for transfer of heat trapped in the tank to the thermic fluid flowing in it from an insulated thermic fluid tank. The GHG Tank has a transparent cover and a reflective inner surface to enable maximum absorption of incident solar radiations by the GHG contained in it. The heat stored in the thermic fluid can be utilized for suitable applications. It will use CO_2 as the GHG. An experimental prototype model of the system is developed and fabricated. The model is tested and preliminary experiments are carried out to validate the working of the concept.

Keywords*— *Greenhouse effect, Greenhouse gases, GHG Heat Storage Tank, GHG Heat Utilization

I. INTRODUCTION

In today's climate of growing energy needs and increasing environmental concern, alternatives to the use of non-renewable and polluting fossil fuels have to be investigated. One such alternative is solar energy. Solar energy is quite simply the energy produced directly by the sun and collected elsewhere, normally the Earth. The sun creates its energy through a thermonuclear process that converts about 650,000,000 tons of hydrogen to helium every second. The process creates heat and electromagnetic radiation. The heat remains in the sun and is instrumental in maintaining the thermonuclear reaction. The electromagnetic radiation (including visible light, infra-red light, and ultra-violet radiation) streams out into space in all directions. Only a very small fraction of the total radiation produced reaches the Earth. The radiation that does reach the Earth is the indirect source of nearly every type of energy used today. The exceptions are geothermal energy, and nuclear fission and fusion. Even fossil fuels owe their origins to the sun; they were once living plants and animals whose life was dependent upon the sun [1].

Greenhouse gases like CO_2, SO_2 and CFC have the inbuilt characteristic of trapping heat. This property can be utilized to trap and store heat, which can be transferred through a suitable medium for various applications. The industries which give out GHGs as a residue / flue gases can make use of such systems for low or medium or high temperature applications, as per the temperatures obtained, which depends upon the heat storage capacity of different GHGs and relevant parameters like size of the tank, gas pressure, flow rate of thermic fluid inside the heat exchanger, etc. [2].

The system is developed, based on the principle of heat trapping by GHGs, and it consists of an insulated GHG storage tank with a simple helical, spiral heat exchanger embedded in it for transfer of heat trapped in the tank to the thermic fluid flowing in it from an insulated thermic fluid tank. The GHG Tank has a transparent cover and a reflective inner surface to enable maximum absorption of incident solar radiations by the GHG contained in it. The heat stored in the thermic fluid can be utilized for suitable applications. It will use CO_2 as the GHG. An experimental prototype model of the system is developed and fabricated. The model is tested and preliminary experiments are carried out to validate the working of the concept. [2] The temperatures and heat gain obtained have been recorded and analyzed to give conclusions leading to the validation of the concept for utilization in low and medium temperature ranges.

II. THE CONCEPT

The idea for this work has been taken from an article in the September, 2006 edition of the Gujarati Science magazine titled “Safari” [2, 3] which attributes the discovery of this idea to British inventor, David E. Jones.

The concept of the present work involves a combination of the principle of heat trapping by GHGs, using huge quantities of GHG emissions from various industries requiring proper handling, with the potential of ample incident solar thermal energy available to be tapped and utilized in an environment friendly manner.

A. Heat trapping by GHG

The earth is constantly being bathed in radiation of many sorts from the sun – visible light, ultraviolet, infrared, and so on. Around 30% of this radiation is immediately reflected back into space, but the rest of the 70% radiation is absorbed by the earth. This absorbed radiation is changed to infrared radiation, which is then radiated back into space (this absorption / radiation is a different mechanism from simple reflection). Most of the gases in the earth's atmosphere - O_2, N_2, etc. do not interact with this infrared radiation. But the "greenhouse gasses" (CO_2, CH_4, SO_2, etc.) do absorb the IR radiation, and then pass it on to neighbouring molecules as heat (molecular vibration). By doing this, they prevent the Infrared radiations from being radiated back into space, trapping the energy in the atmosphere, and heating up the earth.

The important thing to remember here is that "heat" can mean two things – kinetic energy (vibration of molecules) or electromagnetic energy (infrared). The electromagnetic energy can be released by the earth, but the vibration energy cannot. Greenhouse gasses change the electromagnetic energy into vibration energy, and therefore stop it from escaping. So, this vibration energy is the characteristic property of all Greenhouse gases and that's why they increase temperature. Earth's natural greenhouse effect makes life as we know it possible. However, human activities, primarily the burning of fossil fuels and clearing of forests, have intensified the natural greenhouse effect, causing global warming.

Figure 1 shows the natural global warming taking place in the Earth's atmosphere, which is necessary for maintaining life on the Earth.

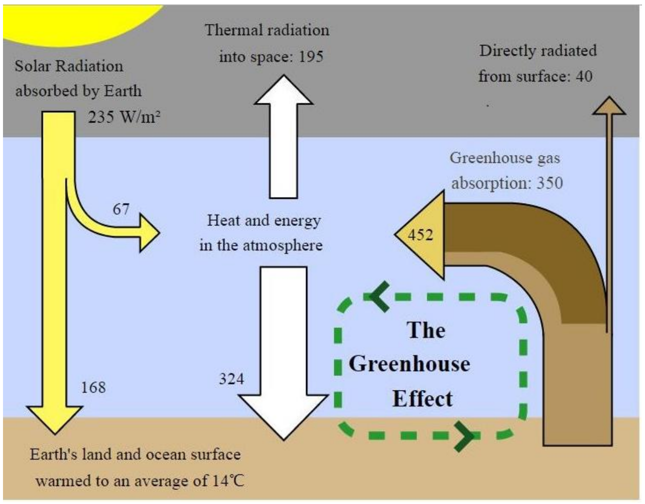

Fig. 1. Energy Exchange due to Greenhouse Effect in the Earth's atmosphere.

Figure 2 shows the relative fraction of man-made greenhouse gases coming from each of eight categories of sources, as estimated by the Emission Database for Global Atmospheric Research version 3.2, fast track 2000 project [4]. These values were intended to provide a snapshot of global annual greenhouse gas emissions in the year 2000. The top panel shows the sum over all man-made greenhouse gases, weighted by their global warming potential over the next 100 years. This consists of 72% carbon dioxide, 18% methane, 8% nitrous oxide and 1% other gases. Lower panels show the comparable information for each of these three primary greenhouse gases, with the same coloring of sectors as used in the top chart. Segments with less than 1% fraction are not labeled [5].

It is evident from the figure 2 that CO_2 accounts for maximum GHG emissions, viz. 72% and more than half of it comes from industrial process heating and power stations. Thus, there is a wide scope of utilization of the system developed. It will help save the fuel required to be used for heating applications that are likely to be carried out by the system. Also, there will be an added advantage of environmental protection due to utilization of GHG pollutants for some useful applications, rather than causing global warming.

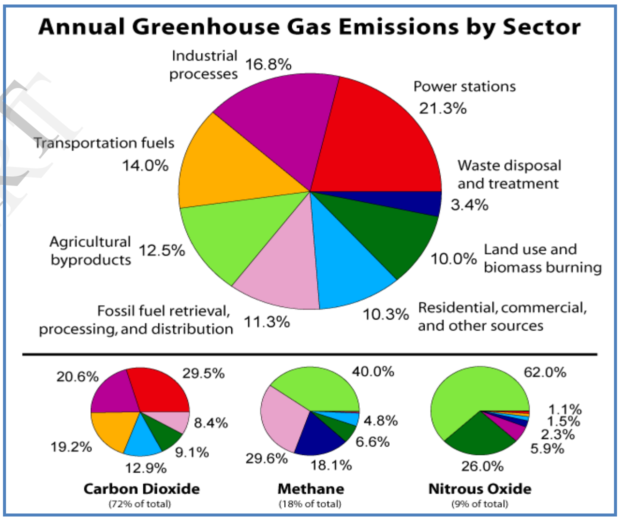

Fig. 2. Annual GHG Emissions by Sector.

B. Tapping Solar Thermal Energy

With about 300 clear, sunny days in a year, India's theoretical solar power reception, on only its land area, is about 5 Peta Watt-hour per year or PWh/year (i.e. 5 trillion kWh/year ~ 600 TW). The daily average solar energy incident over India varies from 4 to 7kWh/m^2 with about 1500–2000 sunshine hours per year, depending upon location. This is far more than current total energy consumption [6], as shown in figure 3. These facts give a fair indication of the potential of solar energy utilization in India.

The major drawback of the intermittence of availability of solar thermal energy can be overcome by thermal storage of the heat tapped in an insulated thermic fluid tank, from which the thermic fluid is circulated for transferring and storing heat from the GHG storage tank to the thermic fluid storage tank [2].

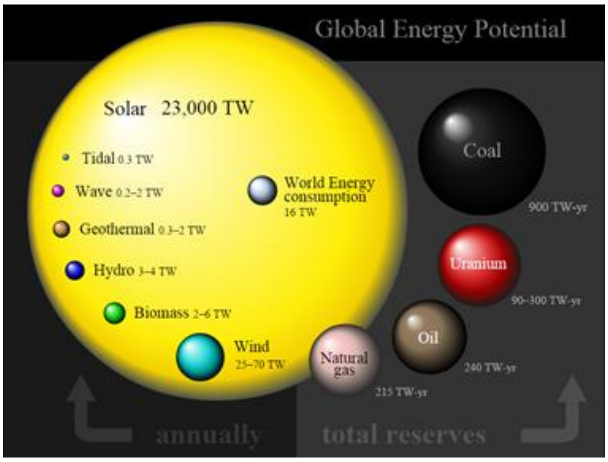

Fig. 3. Most abundant global energy potential of Solar Energy [6].

Figure 4 shows the schematic diagram of the system. An additional water tank is shown to demonstrate a possible, common use of the heat stored in the thermic fluid tank. The water piping can be directly embedded in the GHG tank to get hot water / steam for utilization during day time. A separate thermic fluid storage tanks makes utilization during night time also possible.

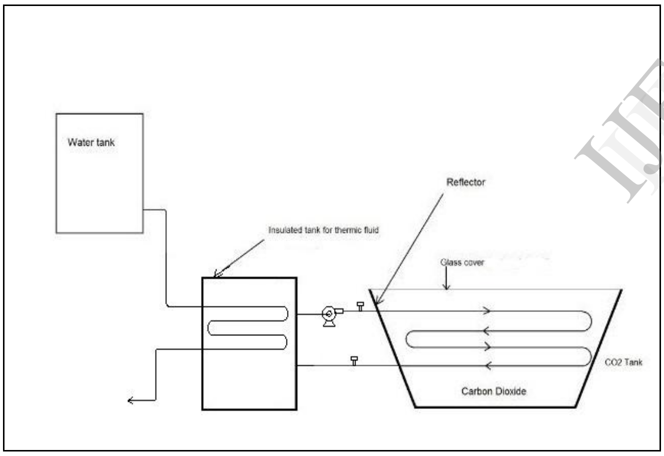

Fig. 4. Schematic diagram of the GHG Tank and Thermic fluid Tank.

III. THE SYSTEM

The system consists of the following components, as shown in figure 5 :

1. GHG Tank
    a. Outer body
    b. Reflective Al foil on inner surface
    c. Transparent cover
    d. CO_2 gas
2. Helical Heat Exchanger
3. Pump & Valves
4. Thermocouples
5. Pressure gauge
6. Thermic Fluid Storage Tank.

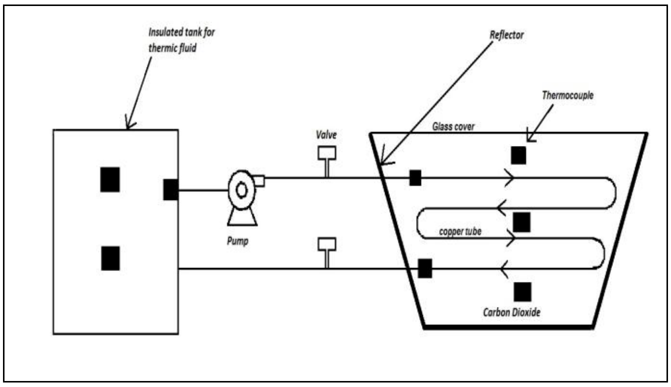

Fig. 5. Schematic of GHG Tank system under study.

A. *GHG Tank*

The GHG Tank is fabricated from 3mm thick IS 229 MS plate, as shown in figure 6. The dimensions of the tank are as follows [2] :

1. Upper diameter: 2 feet
2. Lower diameter: 0.5 feet
3. Height: 0.75 feet (45^0 taper)
4. Thickness: 3 mm.

Thickness of the tank is decided using the theory of circumferential shell under internal pressure.

Fig. 6. GHG Tank Body [2].

The tank is given a 45^o taper and its inner surface is covered with Aluminum foil to enable maximum reflection from its tapered surface into the CO_2 stored in the tank, allowing it to absorb maximum possible heat. The tank is covered with a transparent 6mm thick polycarbonate cover. Polycarbonate is preferred over glass due to less brittleness, higher strength and usability over wider temperature range, better transmissivity than most types of glasses, lighter weight and lower cost (about ½ to1/3 times that of glass) [7, 8].

Both, GHG Tank and Thermic Fluid Tank are insulated from outside using Asbestos Webbing Tape, found best suited as insulator due to properties like durability, low cost, high in water repellence, low water absorption, highly resistant to flame, heat, oil, fungus and mold, non-corrosive to cables, non-sagging and good abrasion resistance [2].

In the present work, CO_2 is used as the heat storage medium. The properties of CO_2 under standard conditions are as follows [9]:

Critical point
Critical temperature: 31 °C
Critical pressure: 73.825 bar
Critical density: 464 kg/m^3

Triple point
Triple point temperature: -56.6 °C
Triple point pressure: 5.185 bar

Gaseous phase
Gas density (1.013 bar at sublimation point 2.814 kg/m^3
Gas density (1.013 bar and 15 °C (59 °F)): 1.87 kg/m^3
Compressibility Factor (Z) (1.013 bar and 15 °C (59 °F)): 0.9942
Specific gravity (air = 1) (1.013 bar and 21 °C (70 °F)): 1.521
Specific volume (1.013 bar and 21 °C (70 °F)): 0.547 m^3/kg
Heat capacity at constant pressure (C_p) (1.013 bar and 25 °C (77 °F)): 0.037 kJ/(mol. K)
Heat capacity at constant volume (C_v) (1.013 bar and 25 °C (77 °F)): 0.028 kJ/(mol. K)
Viscosity (1.013 bar and 0 °C (32 °F)): 0.0001372 poise
Thermal conductivity (1.013 bar and 0 °C (32 °F)): 14.65 mW/(m.K)

The properties of CO_2 under experimental conditions are calculated from first principals, with the help of CO_2 properties calculator available online.

B. *Helical Heat Exchanger*

A helical heat exchanger consisting of copper tubes is embedded in the GHG Tank. Thermic fluid is circulated in it to carry away the heat stored by the CO_2 filled in the tank. As mentioned earlier, the heat stored by the CO_2 can be also directly utilized for heating applications by circulating required fluid, such as air, water or any other suitable medium to gather and carry away the heat to a desired destination. However, this arrangement will enable the utilization of the heat during day time only. A thermal storage tank containing a fluid which will bring and store the heat for utilization during the time when sunlight is not available, such as a suitable thermic fluid, can be used to overcome this limitation.

Copper tubes are selected the heat exchanger considering the basic function of ensuring maximum heat transfer due to high thermal conductivity. In addition to this, copper tubes are available in drawn (hard) and annealed (soft) tempers, as well as a wide assortment of lengths, diameters, and wall thicknesses to meet the needs of a broad spectrum of conditions. Other parameters which support selection of copper tubes are superior performance at reasonable costs, light weight and compactness, ease of handling and fabrication, smooth inner surfaces allowing easy fluid flow inside the tubes, wide range of types of fittings available, etc. [10]. Figure 7 shows the helical heat exchanger. Outside the GHG Tank, the copper tube of the heat exchanger is insulated to prevent thermal losses.

The size of the copper tubes is decided as per ASME Code for pressure piping ASME B31. It uses the following formula [10] :

$$P = [2S\,(t_{min} - C)] \,/\, [D_{max} - 0.8(t_{min} - C)] \qquad (1)$$

Where,

P = allowable pressure, psi

S = maximum allowable stress in tension, psi

t_{min}= wall thickness (minimum), in.

D_{max}= Outside diameter, in.

C = constant = 0 (As per Code B31, for good corrosion resistance.)

Working out the size of the pipe from (1) and referring to the standard sizes available from the data tables [10], the copper tubes having following dimensions are selected :

D_{max} = 9.52mm

D_{min} = 7.75mm

Thickness = 1.77 mm.

Fig. 7. Helical Heat Exchanger [2].

C. *Thermic Fluid Tank*

Thermic fluid is stored in and circulated from an insulated thermic fluid tank into the helical heat exchanger for carrying the heat stored in the GHG Tank and storing it for utilization. The circulation of the fluid is done with the help of a pump. For the present system, a wiper pump was installed, since the pumping requirement for the small experimental model was less. Figure 8 shows the pump. Valves are mounted at inlet and outlet of the heat exchanger for controlling the flow of thermic fluid.

Fig. 8. Thermic fluid pump [2].

D. Measuring Instruments

Thermocouples, with a digital display are used for measuring temperature of CO_2 in the GHG Tank, temperature of thermic fluid at the inlet and outlet of the Helical Heat Exchanger and inside the Thermic Fluid Tank. J type thermocouples having Iron (+) vs. Constantan (nickel-45% + copper-55%) (-), found to be best suited for the requirements of the present work were selected for installation in it [11]. Suitable configurations of the thermocouple, having required provisions for their seal-proof fitting into the system were acquired and mounted in the system.

A pressure gauge has been mounted in the system to measure the pressure of CO_2 filled in the GHG Tank.

E. Thermic Fluid

Heat transfer fluids and thermal oils vary in terms of thermo-physical properties like, kinematic viscosity, operating temperature range, pour point, boiling point and flash point and therefore there are many factors to be taken into consideration when selecting a thermal oil for a heat transfer system, such as, safety in usage, thermal stability, heat transfer efficiency, cost, disposal, availability and transportation, etc. [12].

Two thermic fluids, viz. Dowtherm A and Hytherm 500 were found suitable for the system, out of which Hytherm 500 was selected as it met all requirements and was readily available. Hytherm 500 is a thermic fluid designed to cover a broad range of heat transfer applications and is recommended in services involving maximum bulk temperatures upto 285°C [13-14]. It has the following favourable properties :

- Excellent oxidation & chemical stability.
- Low volatility, low vapour pressure
- Non corrosive & non toxic
- Excellent thermal conductivity

Figure 9 shows the assembled view of the system.

Fig. 9. The GHG Tank Experimental Set-up [2].

IV. SYSTEM TESTING

The initial testing of the GHG Tank for leak-proof operation was done using water. Further testing was done while filling the CO_2. Also, readings were taken with water filled in the tank as an initial check for the working of various components of the system to fulfill the basic concept of the working of the system.

Testing of tube assembly of the helical heat exchanger is done, as there are various brazing joints made on the assembly, which need to be checked for any leakage(s). It is done by circulating water through the tube structure.

After glass cover is fixed to the tank and CO_2 is filled up, it is tested using detergent water bubble method to ensure leak-proof fitting of the cover.

Table 1 shows the readings obtained during the testing of the system. Here,

T1 = GHG Tank temperature (water-filled for testing).

T2 = Thermic fluid tank temperature.

T3 = Inlet temperature of thermic fluid to GHG Tank

T4 = Outlet temperature of thermic fluid to GHG Tank

Solar Insolation is measured using Solarimeter.

TABLE I. TESTING OF GHG TANK EXPERIMENTAL SET-UP.

Date : 23th April, 2014 (Ambient Temperature ≈ 43°C)
Maximum Solar Insolation : 675watts/m^2

Sr. No.	Time (pm)	Temperature (°C)			
		T1	T2	T3	T4
1	2:30	67	41	44	46
2	3:00	69	44	46	48
3	3:30	73	48	50	50
4	4:00	76	50	50	53
5	4:30	80	51	52	58
6	5:00	83	53	55	64

The system was started around 02:00pm and closed down after taking the last reading at 05:00pm with maximum water temperature reaching 83°C and thermic fluid temperature reaching about 64°C. The system having run successfully during this testing, experiments were done on it with CO_2 filled GHG Tank for two days from morning to evening to assess its working.

V. EXPERIMENT

Experiments were done on 28th and 29th April, 2014, with CO_2 filled in the tank at a pressure of 1.5 bar.

T1 = GHG Tank temperature.

T2 = Thermic fluid tank temperature.

T3 = Inlet temperature of thermic fluid to GHG Tank.

T4 = Outlet temperature of thermic fluid to GHG Tank.

Encouraging results were obtained, with the CO_2 temperature reaching a maximum of about 98°C, around 03:00pm, as shown in Tables II and III.

Figures 10 and 11 show the plot of Time Vs. GHG / CO_2 temperatures for 28th April, 2014 and 29th April, 2014 respectively.

Figures 12 and 13 show Time Vs. Thermic Fluid temperatures for 28th April, 2014 and 29th April, 2014 respectively.

Figures 14 and 15 show the plot of Time Vs. GHG Tank efficiency for 28th April, 2014 and 29th April, 2014 respectively, computed as per the formula :

$$\eta_{GHG\ tank} = [m_{CO2} * C_{pCO2} * (T_{CO2} - Ta)] / [A * I] \quad (2)$$

Where,

m_{CO2} = Mass of CO_2 (kg)

C_{pCO2} = Specific heat of CO_2 (J/kg.K)

T_{CO2} = Temperature of CO_2 = T1 (K)

Ta = Ambient Temperature (K)

A = Area receiving solar insolation

I = Solar Insolation.

TABLE II. EXPERIMENTAL DATA FOR DAY-1.

Date : 28th April, 2014 Maximum Solar Insolation : 687 watts/m²					
Sr. No.	Time	Temperature (°C)			
		T1	T2	T3	T4
1	10:30	65	37	39	45
2	11:00	69	38	41	49
3	11:30	75	50	49	54
4	12:00	78	53	56	59
5	12:30	80	55	57	60
6	13:00	82	58	59	62
7	13:30	85	63	62	64
8	14:00	89	63	64	66
9	14:30	93	64	66	68
10	15:00	95	65	67	70
11	15:30	98	68	67	72
12	16:00	94	68	67	71
13	16:30	91	67	66	71
14	17:00	88	65	65	69

TABLE III. EXPERIMENTAL DATA FOR DAY-2.

Date : 29th April, 2014 Maximum Solar Insolation :671 watts/m²					
Sr. No.	Time	Temperature(°C)			
		T1	T2	T3	T4
1	9:00	42	29	30	37
2	9:30	49	33	32	39
3	10:00	53	36	36	42
4	10:30	60	40	40	45
5	11:00	63	44	45	51
6	11:30	67	47	51	55
7	12:00	70	51	55	58
8	12:30	72	53	57	60
9	1:00	74	57	59	62
10	1:30	77	59	60	63
11	2:00	80	61	60	65
12	2:30	84	64	63	68
13	3:00	88	65	64	71
14	3:30	93	66	66	74
15	4:00	93	67	66	73
16	4:30	90	65	65	71
17	5:00	87	65	64	70

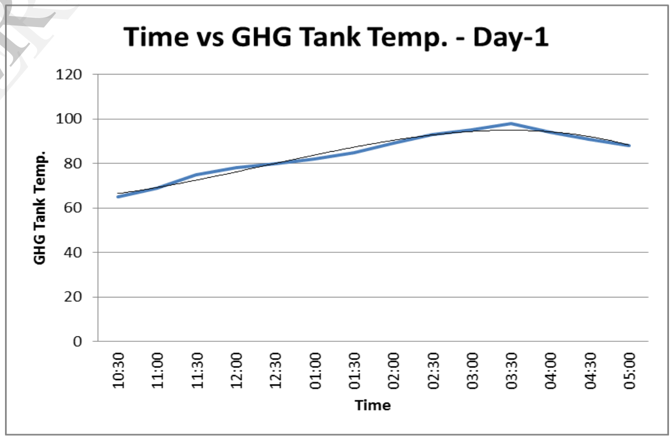

Fig. 10. Time Vs. GHG / CO_2 Tank Temperature for 28/04/2014.

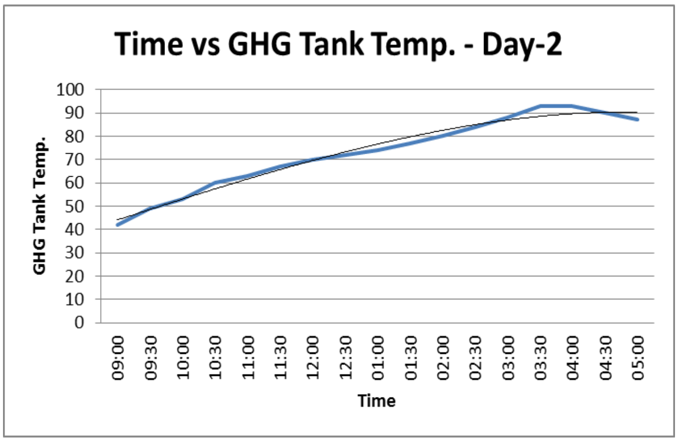

Fig. 11. Time Vs. GHG / CO_2 Tank Temperature for 29/04/2014.

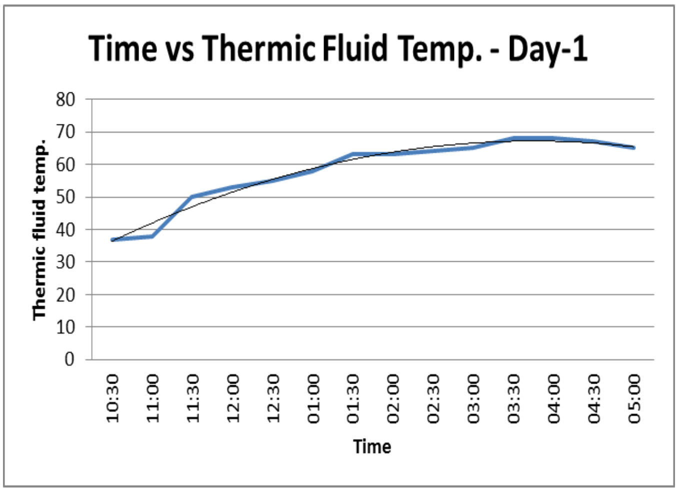

Fig. 12. Time Vs. Thermic Fluid Temp. for 28/04/2014.

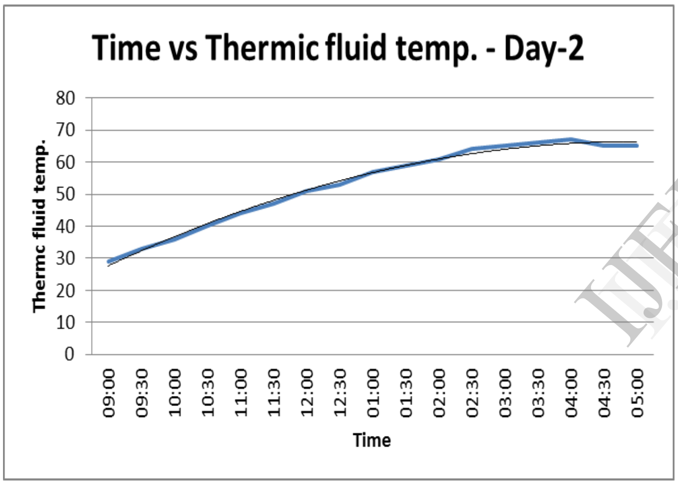

Fig. 13. Time Vs. Thermic Fluid Temperature for 29/04/2014.

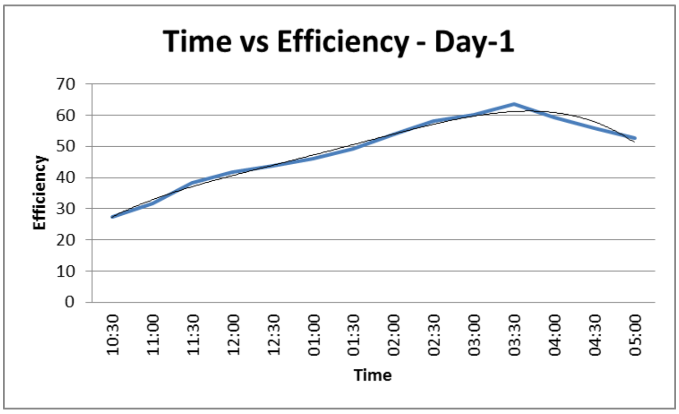

Fig. 14. Time Vs. Efficiency for 28/04/2014.

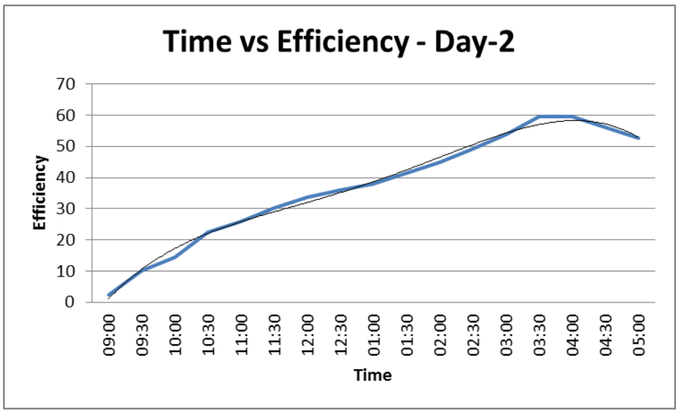

Fig. 15. Time Vs. Efficiency for 29/04/2014.

Result And Discussion

Maximum temperatures of CO_2 in the GHG Tank are observed between 03:00 pm to 04:00 pm, as is evident from figures 10 and 11. The maximum temperature is of the order of 94-98^{o}C. The heating of CO_2 begins early. On the first day, a temperature of about 65^{o}C was observed at 10:30 am. Hence, the readings were recorded from 09:00 am onwards on the second day. The trend line for the plots is third order polynomial, with an R-squared value of around 0.98.

The thermic fluid temperature in the insulated thermic fluid tank reaches a maximum value of around 67^{o}C between 03:00 pm to 04:00 pm, as shown in figures 12 and 13. It is slightly lower than the maximum thermic fluid temperature at the GHG Tank outlet. The trend line for the plots is second order polynomial, with an R-squared value between 0.97-0.99.

The insulations of both GHG Tank and the insulated thermic fluid tank have not been optimized. Further improvement in temperatures as well as performance of the system will take place on improving upon this aspect of the system. It will also enable maintaining temperature and hence retaining heat for a longer time in the storage media, namely GHG / CO_2 as well as thermic fluid. This is being done in the ongoing study on the system.

Maximum efficiency of the system is observed to be about 63%, around 03:30 pm on the first day. High values of efficiency lie in the range of 58%-63%. Optimization of insulation and flow rates can further improve the efficiency of the system.

Conclusion

Encouraging results are obtained for the prototype model of GHG Tank developed. The CO_2 temperatures go to a high value of about 98^{o}C and those of the thermic fluid reach around 70^{o}C, the maximum thermic fluid temperature at GHG Tank outlet reaching about 74^{o}C. Efficiency of the system is around 60%, which can be further improved upon by proper insulation and better heat exchanger sizing and design.

A scaled up optimized model of the system will be able to give temperatures as high as 150°C, and the heat retained and stored can be utilized for low and medium temperature process heating applications in several industries that give out CO_2 as effluent in large quantities, which would otherwise add to pollution and hence, global warming.

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