

Integrating Renewable Solar Heat into Carbon Capture Operations

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Abstract—Abstract: By the post-combustion carbon capture process, more than 90% of the CO₂ can be removed from the point source (power plant) by chemical absorption using solvents like Amines. The method of chemical absorption, stripping, desorption, and compression of CO₂ from flue gases are energy-intensive; they shall reduce the electrical output of the power plant by approximately 30%. We can reduce the energy penalty if we can integrate solar thermal energy in the generation of steam for desorption of CO₂ as solar energy has the potential to meet the thermal demand of stripper reboiler in the power plant's solvent-based post-combustion CO₂ Capture. By carrying out this study on a high-temperature solar thermal system, we would be able to review the solar thermal technologies to provide energy to a CO₂ capture system. The Parabolic trough collectors and central receivers are high-temperature solar thermal systems to produce superheated steam for the CO₂ Capture system. In this paper, we shall discuss the high temperature solar thermal systems and the low temperature solar thermal systems. The low temperature solar thermal systems can integrate better with solvent stripping types of equipment. Since it's low-temperature produced, it can reduce the thermal degradation of MEA solvent as stripping temperatures are limited to about 120 degrees Celsius (°C), as the typical designs use saturated steam at temperatures slightly above 120 °C, for solvent stripping. The use of a high-temperature solar thermal system for direct electricity generation is more efficient than utilizing solar energy, as compensation for power lost in capturing CO₂ in a PCC power plant. The results show that the energy requirement of innovative CCS technologies from the flue gas range from 100–200 kJ/mole of CO₂. The operation of a power plant incorporated with solar assisted post-combustion CO₂ Capture (SACC) is primarily affected by the local environmental conditions, such as sunlight, visible light duration, the existing temperature, the type of solar thermal device and recovery ratio of CO₂.

Index Terms—PCC, Post-Combustion Carbon capture, carbon dioxide, solar thermal, Solar assisted post-combustion CO₂ Capture- SACC, Climate change, Chemical Absorption, Solvents, MEA solvent, TES- Thermal Energy Storage, Solar Thermal Energy Storage System, Integration of solar thermal, Amine-based CO₂ Capture, Optimization, CSP- Concentrated Solar Power

I. INTRODUCTION

The onset of the industrial revolution in AD 1700, man's need for energy has been continuously increasing for his sustenance and well being. For the first time, the man began to use a new energy source, viz coal, in large quantities. The Extensive use of other fossil fuels, oil, and natural gas started after the invention of the Internal combustion engine in AD1870. Thus began the fossil fuel era of using nonrenewable sources of energy in concentrated form. Man's large scale use of energy has led to a better quality of life, and simultaneously it has created many problems for humanity. The gravest of these are the harmful effect it has on Climate change. The fossil fuel combustion has caused severe air pollution problems in many areas because of the excessive release of large amounts of harmful gases into the atmosphere, mainly Green House Gases (GHC), responsible for Global warming. Industrialization increased CO₂ in the atmosphere from the pre-industrial era value of 280ppm to 415 ppm as of May 2019, as per Intergovernmental Panel on Climate Change (IPCC). Coal-fired power plants by itself contribute to over one-third of anthropogenic CO₂, making them a primary target area for emissions reduction human activity..

1.1 CCS for reducing the effects of climate change

Carbon capture and storage (CCS) refers to reducing, rectifying, and storing industrial CO₂ emissions. Carbon dioxide (CO₂), as one of the primary greenhouse gas (GHGs), has been well known for more than a century. CO₂ formed due to the combustion of Fossil fuel is adversely affecting the climate on Earth. Global Climate change due to emission CO₂ is a significant concern worldwide. An estimate indicates that power plant contributes to 70% of total CO₂ emissions worldwide due to fossil fuel combustion. Capturing and securely storing/sequestering CO₂ formed in the global combustion systems is an essential and achievable target. To remove CO₂ from the Combustion facilities, researchers around the globe have developed chemical solvents to absorb CO₂. For capturing CO₂ at minimum cost, a low-cost solvent with minimum energy requirements, demanding smaller equipment, which is less prone to corrosion, is found. MEA is an Amine based solvent used for removing CO₂ from the exhaust streams. A series of such amines are being investigated and put into practice. Aqueous ammonia (NH₃) as a chemical solvent is experimentally proven to be more effective for capturing CO₂ than amine-based processes.

A PCC system has an inherent advantage that it can easily be retrofitted to an existing plant with Amine as a solvent for CO₂ absorption and stripping. Figure 1 is a simplified diagram of amine absorption and stripping integrated to power plants using coal as fuel. Coal is burned as fuel in the boiler to produce steam. The resulting flue gases pass through other pollution control measures before allowing the residual gases to enter the absorber column. For getting CO₂ absorbed in the absorber column, flue gases flow in a counter-current direction of aqueous amine solvent, which reacts with CO₂ and absorbs it. The solvent, loaded with CO₂, is called a "rich" solvent made to flow through a heat exchanger, then to the stripper column for the regeneration of pure Amine solvents. This de-absorption is reheating of rich solvent to reverse the CO₂-amine reaction and liberate nearly pure CO₂. The "lean" solvent, or we can say a clean solvent, from all flue gases, is made to cycle back to the absorber to restart the absorption process. The pure CO₂ is compressed for piping and transportation for permanent storage

inside the geological sites after leaving the CO₂ capture system. For efficient removal of around 90% of the CO₂ from incoming flue gases, the CO₂ capture system designed.

The energy demand in a coal-fired power plant with a capital-intensive CO₂ capture system installed in it is 11-40% more than Power Plant without such a capture system. CO₂ capture system, fitted in a power plant, is an energy-intensive process because part of the thermal energy required for power generation used to run the CO₂ compression train and raise the rich solvent's temperature to that value, releasing CO₂. Thermal energy extracted in the form of steam is utilized for heating the solvent and drive the CO₂ compression train. A reboiler not shown in the diagram is made use of in exchange of heat between steam and CO₂ rich solvent in a traditional design. An alternate configuration shall draw hot steam exclusively from the power plant to strip CO₂ from the "CO₂ rich" solvent and use electricity for driving the CO₂ compression train of the CO₂ capture system.

The industrial technology for CO₂ Capture (CC) is by the reactive absorption by amines, such as monoethanolamine (MEA) and methyldiethanolamine (MDEA). Such processes take advantage of chemical absorption, which enhances absorption rates and hence used with relatively low CO₂ partial pressure in exhaust gases. The main disadvantage of the chemical absorption process is the large amount of thermal energy required for regenerating the solvent during the CO₂ extraction process. The problem is related to corrosion and solvent degradation. The steam extracted from the steam turbine cycle is utilized in the reboiler to fulfill its thermal energy demand. Since part of steam

is being used in the reboiler to meet its energy requirement hence balance steam available for usage for power generation decreases, this electrical efficiency penalty is approximately lesser by 9–12% of the fuel lower heating value (LHV). Chemical absorption technology with a membrane is also an innovative method for reducing the energy penalty has also been tried. The reduced power output and the additional cost of the CO₂ capture system increase the cost of electricity (COE) significantly. IPCC (2005), COE(cost of electricity), is raised by 42–66% and the

cost of CO₂ avoidance (COA) in the range of 30–50 USD per tCO₂.

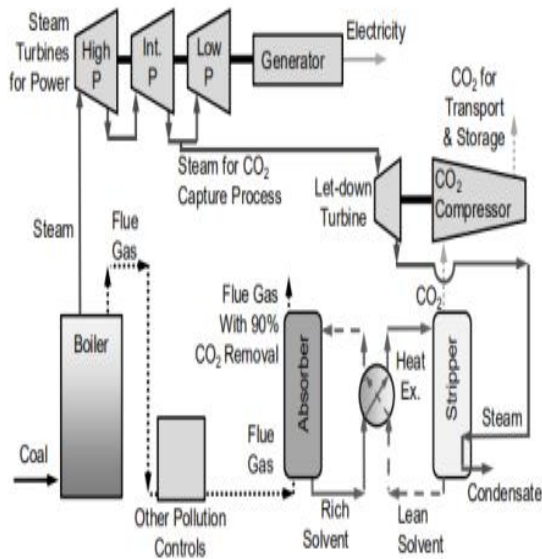


Figure 1 is a diagrammatic representation of a post-combustion CO₂ capture process in a coal-fired power plant. It elaborates that maximum energy consumed is during the compression of CO₂ and the de-absorption of chemical solvents.

1.2 We are utilizing Solar Thermal Energy for de-absorption of rich solvent & compression of pure CO₂. Because of the extraction of steam from the power cycle for meeting the CO₂ capture process's energy requirements, the net steam available for power generation reduces, resulting in reduced power plant output and net energy availability. One of the proposed methods to reduce or eliminate steam extraction from the power plant would be making use of solar thermal energy to produce steam when solar energy is available. The electricity demand is maximum during the day when solar thermal energy is available, which can suitably be utilized in the CO₂ capture process, thus increasing the electrical output. A solar thermal energy storage (TES) system can sustain the high power plant output by using during the period of no sunlight. Thus high CO₂ removal rate with power plant output nearing base plant capacity can be maintained using the solar thermal storage system.

II. SUPERHEATED STEAM DEMAND FOR THE CO₂ CAPTURE PROCESS

(2.1 System diagrammatic layout) Steam is required to make the CO₂ capture system functional. The optimum amount of steam is a function of the size of the primary power plant and the nature of the CO₂ capture system's design. Figure 1 shows a basic CO₂ capture system with one absorber, and a stripper with no material and energy flows (flue gases, solvent, steam, or CO₂) enters or leaves at more than one location of each component. Monoethanolamine (MEA) is an essential chemical solvent for this process. The tripping temperatures are restricted to about 120 degrees Celsius °C to slow down the thermal degradation of the MEA solvent. For CO₂ rich solvent stripping saturated steam at a temperature slightly above 120 °C is used. Higher temperature and pressure superheated steam are required for the let-down turbine if steam must first drive CO₂ compressors. A typical CO₂ capture system extracts about 50% of steam flow from between low and intermediate-pressure turbine sections.

A typical power plant analysis was carried out on a power plant, having a PCC of CO₂ with MEA solvent. It considered a 500-megawatt gross electrical output (MW) coal-fired power plant 453 MW net output without CO₂ Capture. The superheated steam is extracted at 945 kilopascals (kPa) and 355 °C to drive the CO₂ compression train with a turbine in the CO₂ capture process. The steam enters the turbine at 945KPa pressure and 355 °C temperature and expands to 446Kpa and 281 °C, gets desuperheated at 148 °C, 446Kpa temperature, and pressure respectively. The solvent is rich in CO₂ heated by this desuperheated and saturated steam to release CO₂.

The thermal energy demand for solvent stripping in a CO₂ capture process is 500 MW, which requires a steam mass flow rate of 212(Kgs/s). The energy needed for extracting one ton of CO₂ is 4.34GJ or 4.34GJ/t of CO₂. The steam required for solvent stripping shall vary with the type of solvent irrespective of process configuration. Ultimately the kind of chemical solution or its blends determines the amount of steam required for CO₂ absorption and stripping. Solvents like concentrated piperazines(PZ) have higher thermal stability(150°C); hence, it shall require higher-temperature saturated

steam. Changing the stripper configuration changes the steam requirements.

We can have several stripper configurations such as double matrix stripper with multiple flash tanks. A three-stage flash tank configuration is more efficient and less energy-consuming than a simple stripper. The size or load of the base power plant determines the steam requirement. In case the CO₂ compression train is stimulated electrically, steam needed for the regeneration of CO₂ is at low temperature and pressure. Figure-2 depicts a CO₂ desorption system using a double matrix stripper with multiple flash tanks. Such a complex configuration shall require heat input at varying temperatures and pressures, unlike a single stripper column shown in figure-3.

A solar thermal energy system is a variable energy source that provides heat input to a CO₂ stripper at multiple temperatures and pressure. A study has found that a three-stage flash tank configuration requiring variable energy is more efficient than a simple stripper configuration working at a fixed temperature and pressure.

Steam requirements for CO₂ Capture is a function of basic power plant configuration. The quantity of steam required depends upon the steam turbine configuration. In case the CO₂ compression train is electric motor is driven rather than steam turbine driven, the temperature and pressure for steam required for solvent stripping are much lower. Even though Solar thermal energy is sufficient for solvent stripping, there would be a significant reduction in net power plant output due to CO₂ compression.

III. VARIOUS CONCENTRATING SOLAR POWER(CSP) TECHNOLOGIES

In this section, we shall briefly describe numerous solar thermal technologies available and find out their potential if it can meet some or all of the energy requirements for CO₂ Capture or not.

3.1 Low Temperature and low-efficiency CSP Systems.

Solar thermal technologies either concentrate solar energy or they do not focus at all includes flat plate collectors (FPC), evacuated tube collectors ETC), and compound parabolic collectors (CPC). The working temperature range for an FPCs is 40 °C to 200 °C

which runs most efficiently at 100 °C. ETCs can reach the operating temperatures up to 200 °C, and CPCs can reach 300 °C, but costs are higher than FPCs. ETCs and CPCs are high-temperature solar thermal systems that can quickly achieve steam conditions required for solvent stripping. FPCs are used for solvent stripping only at below-average regeneration temperatures.

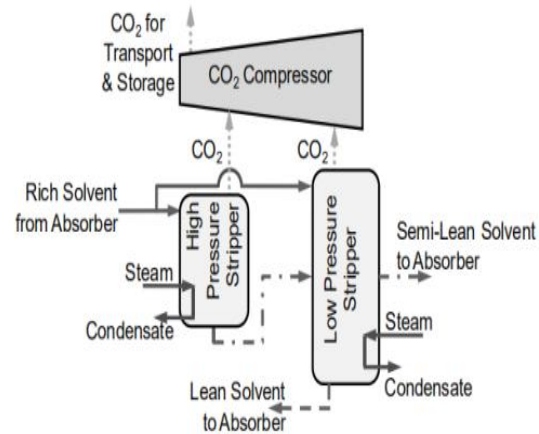


Fig2 In a double matrix stripper, the CO₂ rich solvent is fed into two different strippers, operating at two different pressures.

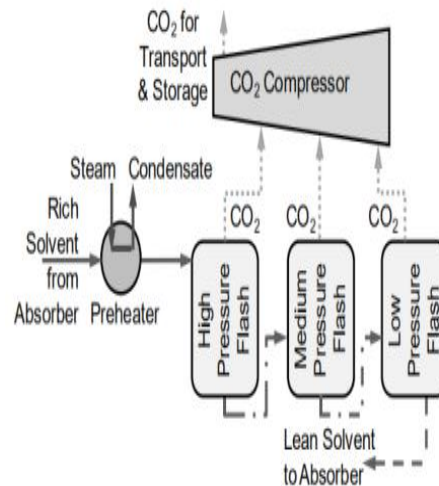


Fig3 The Flash tanks, as shown above, is a three-stage flash tank with decreasing pressure configuration using a single preheater with a facility to install more.

At an Industrial scale, energy requirements to make CO₂ capture system functional is substantial, and this cannot be reduced any further without any technical innovation. Hence, the low capital investment in the

land area is the only viable option left. A vast solar field might create labor and maintenance logistics issues and increase pumping heat transfer fluid and steam costs.

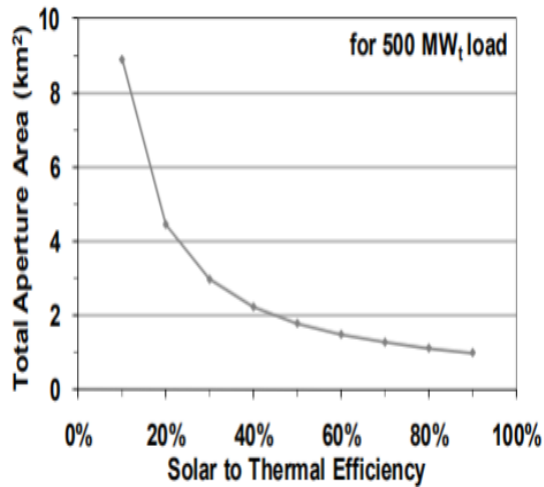


Fig 4 Energy requirements are very high for a CO₂ capture system(500 MW in this example). The solar thermal efficiency must be high, to reduce the size of the aperture area of the solar thermal collectors.

Fig.4 is a plot of the required aperture area(km²) of a solar field versus solar thermal efficiency percentage to make CO₂ capture system functional in a 500 MW power plant. The average direct normal solar insolation for the panhandle is 561 watts per square meter (W/m²). Solar thermal efficiencies vary from 10% to 90% of the area requirements also decrease substantially as efficiency increases.

To meet same energy requirements in a low solar insolation area would require a more massive sized collector. However, even if sizing for peak insolation is around 900 W/m² and assuming 90% efficiency, the aperture area must be greater than 0.6 km². The massive parabolic trough Solar Electric Generating System (SEGS) installed at Harper Lake, California, is of 0.484 square kilometers (km²) and produces 80 MW electricity. The potential usage of thermal storage using solar

thermal energy, if considered, shall reduce the aperture area when the solar thermal efficiency is minimum. If actual solar thermal energy collected (in Watts/m²) is more than the designed/defined solar insolation, excess solar energy is collected, shall be stored in the solar thermal storage system, which justifies its

requirement. The solar energy left after CO₂ Capture is to be used for other power

cycle requirements. For this additional, components are required. The actual efficiency and energy output of a particular technology at a given time depends on instantaneous solar insolation and the difference in temperature of the heat transfer fluid and ambient air. Though CPCs and ETCs can produce temperatures required for solvent stripping and have higher efficiencies than FPCs, large area requirements might still become a practical limitation. Nevertheless, CPC, ETC systems are explicitly designed for CO₂ capture process, conditions could be promising if the benefits of improved plant integration outweigh the costs of aperture area

3.2 High temperature and high-efficiency CSP Systems.

The Balance of this study pays attention to high temperature solar thermal technologies that attain higher temperatures and have higher efficiency over a wide range of ambient temperatures. The high-temperature systems are preferred over the low-temperature systems because they are smaller in size, with high operating temperature/efficiency having the potential process integration benefits of low-temperature/efficiency systems used solely for solvent stripping. However, careful examination is required to validate this assumption. For solar-to-electric energy conversions, three high temperatures/efficiency solar energy collection devices, namely parabolic Dish, power tower, and parabolic trough, are considered. All of these solar thermal technologies are compared in the context of electric power generation and evaluated for their applicability for steam production for the regeneration of chemical solvents in the CO₂ capture system. Table 1 sums up typical cost and performance parameters for each solar collector when utilized for electric power generation. These parameters, particularly efficiency and costs, are primarily dependent on market conditions and analytical assumptions such as power plant capacity factor and thermal energy storage. Real values are the function of the site/location and are design specific.

3.2.1 Parabolic Dish, CSP

It is a concentrating solar energy collector, which uses reflecting mirrors to optically reflect Sun's solar

incident energy on a small receiving area called a "solar dish. The solar energy is intensified many times at the focal point. The two tracking mechanisms and(Direct Normal Irradiance)DNI of sun rays lead to a proper focus throughout the day; thus, we can achieve temperatures in the range of 1500°C. The heat transfer fluid contained in the receiver, heated to the desired temperature and ressure to generate electricity with the help of the engine contained in it. Prime movers used for electric generation are Stirling and Brayton engines. At the focal point of the Dish, there is a combination of a Stirling engine and a generator to transform thermal energy into electricity. By installing a series of several dishes, we can increase the capacities of the solar-powered Stirling engine. Dish systems are modular; sizes range from 5 to 50 kW, they can achieve the highest efficiency of all types of CSP systems.

Parabolic dish systems are considered state of the art, renewable source of electricity generation because of their high energy conversion efficiency, minimal water requirements, siting flexibility, and quick installation. Parabolic dish systems are dry cooling types; hence they do not require a cooling system or cooling towers, enabling them to provide electricity in water-constrained regions. In the dish system, water consumption is for mirror washing only, which is significantly less than other thermal technologies.

There is a comparatively large quantity of cooling water requirement for condensing steam, which as come after passing through a turbine.

Even though the absorber surface is capable of producing high temperatures, these systems are not designed to store or transport thermal energy for steam generation. Parabolic dish collectors are made exclusively for the production of electricity. They do not appear suitable for meeting the heat requirements of solvent stripping and regeneration of solvents in a CO₂ capture system.

3.2.2 Central Receiver(Power Tower) CSP

The central receiver system(CRS) or power tower system uses a set of Heliostat mirrors, with a two-axis sun tracking system, to continuously track Sun's apparent motion in the sky and keep on reflecting sunlight at a predetermined focal point. Out of all the CSP technologies developed for Solar Thermal Power Generation (STPG), the CRS can work at the highest temperatures and achieve the highest efficiency in

electricity generation. At the focal point is kept, a receiver having a molten salt heat transfer fluid (HTF) this HTF is used both in the receiver and a heat storage system. The use of a common HTF in the receiver and heat storage device gives flexibility in the operation of a power plant, enabling solar collection systems to be decoupled from electric generation yielding high capacity factors with solar only plant systems. Central receiver system(CRS) power plants with olten salts as a storage medium are an excellent choice for a solar thermal power plant in providing dispatchable power to the power plant.

TES's use gives the high-temperature system flexibility of operation, and an uninterrupted power supply to enable our CO₂ capture system to work on the solar-only mode of operation. An example of an extensive thermal storage system (15h, 647MWh, 625°C salts) with an isolated tank immersion heaters. This high-capacity liquid nitrate salt storage system is an efficient, low-risk, high-temperature molten salts at 565 °C in stationary storage, here temperature drops by merely 1-2 °C per day. At the receiver, the heat transfer fluid, a molten salt, absorbs the Heliostat's reflected solar energy and is used to produce the steam to drive a turbine. For example, a Solar two System with a Central receiver system(CRS) and a molten salt storage system has an advantage of high capacity thermal storage, ease/good availability of ortable/dispatchable power, and low-cost electricity production least kilowatt-hour cost of production. Most modern Heliostats are computer-controlled plane mirrors whose reflective surface is kept perpendicular to the bisector of the angle between Sun's direction and target, as seen from the mirror.

The solar is light reflected in a fixed route, and the destination seen as stationary relative to the Heliostat. The computer is assigned the latitude and longitude of Heliostat's position to Earth at a particular date and time. Using astronomical theory computer calculates the angle of elevation and compass bearing of the Sun as seen from the surface of Heliostat. As per the given direction of the target, the computer calculates the course of the required angle and sends control signals to the stepper motor to turn the mirror to the correct alignment. The system of operation frequently repeated to keep the mirror correctly oriented.

A single computer controls all the mirrors in large installations having many mirrors called fields of

eliostats. At the focal point of the areas of Heliostat is keeping a receiver with molten salt as HTF or heat collecting medium. The HTF travels through a heat exchanger to heat water to produce steam and generate electricity through a steam turbine.

The HTF temperatures in the CRS can meet or exceed heat required for a steam generation used exclusively for solvent regeneration or driving of CO₂ compression train in a CO₂ capture process.

The coupling of Solar Thermal Storage device with CO₂ capture process, for extraction of heat, for steam generation allows plant operators to have increased control over the use of solar-based energy.

Another downside of all Rankine cycle-based solar power generation systems is the massive cooling water requirement, especially since sites with high solar insolation often have low water availability. However, when using solar thermal energy for CO₂ capture processes, steam exits the CO₂ capture system from the re-boiler as condensate that can go back to the steam generator in the solar thermal energy system. Thus, there is no water requirement associated with steam cooling and condensation as with a solar-to-electric facility; water consumption is for mirror washing and process makeup water.

3.2.3 Parabolic Trough CSP.

The Trough technology uses rows of long parabolic mirrors with single-axis tracking to focus solar energy and heat the working fluid, i.e., HTF, such as VP-1 to temperatures close to 390 °C. The main components of a parabolic trough collector (PTC) are solar collectors (mirrors), heat receivers(HTF), and supporting structures. They are a concentrating solar thermal collector straight in one dimension and curved as a parabola in the other two, having a focal point along a focal line of a trough. The temperature along the focal line is in the range of 350°C-400°C. Like a Central receiver or power tower, the heat in the solar collector working fluid must be exchanged with water to generate steam.

The high temperature achieved and thermal efficiency of parabolic trough solar collectors may not be as high as central receiver/ power tower solar collectors. However, they are a relatively efficient system to be easily coupled to a solar thermal storage device. When utilized to produce steam for Rankine cycle based electricity generation, due to lower operating temperatures, slightly increase water consumption

relative to central receivers towers due to less efficient heat transfer to the condensers. The demand for water is far less when using parabolic troughs for CO₂ capture systems.

In solar to electricity generation facilities, there is no water requirement associated with steam cooling and condensation. Water expenditure is limited to mirror washing and process make up.

The HTF runs along the length of the trough at its focal line by concentrated sunlight along the tube. Furthermore, the HTF gets heated to a high temperature by the energy of the sunlight. The HTF is piped to a heat engine to run a generator for producing electricity. This electricity is used in a CO₂ capture system to run the CO₂ compression train.

Parabolic troughs generate heat at sufficiently high temperatures to produce superheated steam to drive CO₂ compression train. However, heat transfer driving forces are relatively small, requiring a great deal of heat exchange surface. Troughs can quickly achieve temperatures suitable for producing saturated steam used in solvent stripping. Parabolic trough technology is the most mature and low-cost high efficiency solar thermal system. It requires water at a much lesser scale than a tower-based process.

3.2.4 Thermal Storage.

Installing a thermal storage system shall allow flexibility of solar energy usage when insufficient sunlight is available during periods of dense cloud cover during the day or

when used at night. Installing thermal storage and oversizing the solar collection system could increase power plant capacity factor and markedly improve plant economics. Central receivers and parabolic troughs operate at high temperatures to make them suitable for thermal storage. The most sophisticated thermal storage system uses two tanks, one at high temperature and the other at low temperature and exchanging heat between them.

Another thermal storage option is known as a thermocline energy storage system in a solid media held in a single container. By regulating the flow of hot liquid from top and cold fluid from the bottom of the tank, the thermal energy demand can be varied. The elimination of one container in the thermal storage system can significantly reduce capital costs. The technology of large scale solar energy storage, using molten nitrate salt storage medium at the Solar Two

facility, has been successful. Thermocline systems are in comparatively early stages of development but show potential for future use. The purpose of using solar energy for CO₂ Capture is to reduce turbine steam extraction and increase power plant output. Adding thermal storage to the solar energy system would add additional control over power plant output. Storing the quantity of energy required for CO₂ Capture on a scale of hours would require a storage system on the order of thousands of MWh. The demonstrated systems such as that at SOLAR TWO are only on the size of hundreds of MWh, substantially larger storage systems are under study.

IV. INTEGRATING SOLAR THERMAL SYSTEMS WITH CO₂ CAPTURE

As we are aware, solar thermal energy varies because of the relative motion of the Sun. The amount of solar energy arriving Earth's surface changes over the year, from an average of 0.8kwh/m² per day during winter in the north of Europe to more than 4-kWh/m² per day during peak summer this region. This variation depends on the time of the day and season. As we know, more solar radiation is present during midday then during either morning or late afternoon. The amount of solar energy incident per unit area and day depends upon:-

- (a) latitude
- (b) local climate
- (c) season of the year
- (d) The inclination of the solar collectors in the direction of the Sun.

To provide thermal energy, for the CO₂ capture process, when solar thermal energy is unavailable or insufficient to fulfill CO₂ Capture energy requirements, a facility/an arrangement is designed to make use of turbine steam as well. This additional steam extraction method from the turbine is catered for the seamless and smooth functioning of the CO₂ capture system. Fig5 shows a process configuration of using the steam formation from solar thermal energy for running CO₂ compression train and solvent stripping to regenerate pure Amine based solvents. We need to design a multipurpose system where the operator can switch steam tapping to avoid CO₂ emission penalty in low solar energy.

To have a smooth, cost-effective, and efficient functioning CO₂ capture system, the plant operator

has an option/choice of using extracted steam solar steam or a combination of the two for best performance. In this research, our focus is primarily on the use of solar thermal energy for heating chemical solvents for the desorption of CO₂ and releasing chemical solvents for the next cyclic

process of CO₂ absorption. To use solar thermal energy exclusively for a fully functional carbon dioxide capture system, we need to have gigantic solar collectors with the solar thermal storage device. Such a system would be bulky and costly, not a cost-effective option. Thus we are limiting our study for meeting the only fraction of the total energy requirements for a CO₂ capture system. Our research is limited to discussing technology for the generation of steam by using solar thermal means and utilization of this steam to use it in the de-absorption of solvent in a CO₂ capture system, thus reducing the energy penalty of the power plant.

The CO₂ compression and solvent stripping are part of the CO₂ capture system. The carbon dioxide is compressed by taking a tapping of steam in the turbine and running the compressor train, or an electric motor electrically drives the compressor train. The solvent stripping process requires superheated steam.

If solar thermal energy is designed exclusively to meet the energy demand for solvent regeneration, an alternative arrangement should be made to exchange heat directly between the solar thermal working fluid and the rich amine solvent. Fig-6 depicts a method by which the CO₂ stripper gets heat from the heat exchanger and re-boiler. The heat exchanger exchanges heat through solar heat transfer fluid, and the re-boiler is supplied energy through a direct steam tapping from a let-down turbine. The re-boiler heats the rich solvent and transfers the latent heat of saturated steam using its sensible heat. The option to use extracted steam for solvent regeneration must be maintained when solar energy is unavailable or insufficient to avoid excessive CO₂ emissions. When solar energy is unavailable or solar power is inadequate to generate steam, the CO₂ system will not function, increasing excessive CO₂ emissions in the exhaust. For efficient operation of all the arrangements, we shall carefully manage controlling flows of extracted steam to re-boiler, solar heat transfer fluid to heat exchanger device, and split of solvent flows to the heat exchanger and re-boiler.

Either of the systems explained above could use thermal storage devices described in section 3.2.4 above. A thermal storage device would be required to utilize excess solar energy, at times the Sun's illumination is high, and a large-sized solar collection device can capture more energy than needed for solvent stripping in a CO₂ capture system, excess heat stored in thermal storage devices.

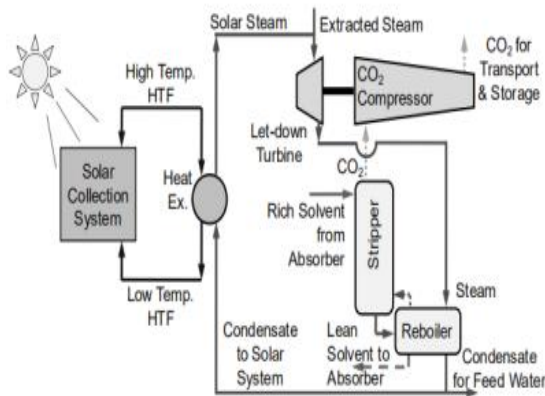


Figure-5 The steam produced by solar thermal energy can be an alternative method to fulfil the requirements of CO₂ compression and solvent stripping.

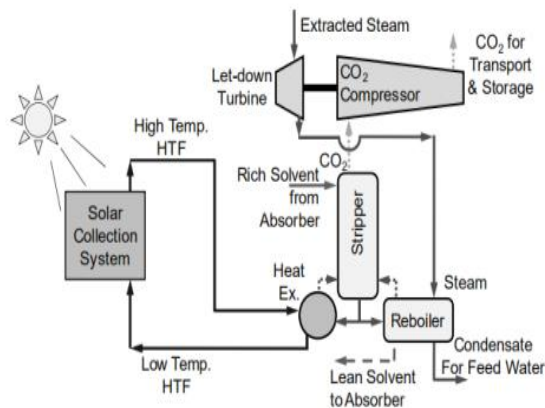


Figure-6 represents a different method of utilizing solar thermal energy for de-absorption of solvent heat directly exchanges heat between the solar thermal working fluid and rich amine solvent.

V. CONCLUSION

This paper carries out a preliminary review of the feasibility and outcome of utilizing solar thermal technologies to meet CO₂ capture energy requirements. The requirements of heat for the CO₂

capture system vary considerably with the base power plant and the design configuration of the CO₂ capture system. For driving the CO₂ compressor train, using solar steam and superheated steam above a pressure/temperature of 900kPa/350 °C will be required. However, lower temperature saturated steam in the range of 120-150 °C can do solvent stripping. A low-temperature, solar thermal technology with low efficiency, can be used to provide heat for stripping of solvent in a stripper; however, high-temperature, high-efficiency systems produce steam to drive CO₂ compressor train

with a smaller space(land area). Parabolic dish technology is used mainly for solar-to-electric energy conversion with limited energy storage capability; thus, it is unsuitable to meet CO₂ capture thermal energy needs. High temperature concentrated solar power system like Central receivers (power towers), and parabolic troughs are technologically most suitable for providing heat to the CO₂ capture system, chiefly when coupled with thermal storage to augment capacity factor and improve plant economics.

Low-temperature constraints might limit parabolic troughs capability to provide superheated steam for CO₂ compression. However, technological maturity and comparatively low cost make them the paramount near-term option among high temperature/efficiency systems. For a 500 MW gross capacity, coal-fired power plant using parabolic trough collectors for providing heat for CO₂ compression, and solvent stripping would need a collector with a total aperture area of 2 km² or more, with average insolation of 561 W/m². Devoid of thermal storage, a system would need capital

costs on the order of half the base power plant's price with CO₂ Capture, and system cost and area grow substantially if the collector field is oversized for thermal storage.

Utilizing solar thermal energy for CO₂ Capture as a replacement for a steam extraction from a primary power plant source allows increased power plant output at the increased cost of operating the solar thermal system. High CO₂ prices shift operating costs in support of using solar thermal energy over bypassing CO₂ Capture.

However, improved operating profits are unlikely to offset the capital cost of the solar thermal system. It is more efficient for high-temperature, high-efficiency solar thermal systems to generate electricity directly

than to supply heat for CO₂ Capture to increase power plant output. Nevertheless, a low temperature solar thermal technology is used solely for rich chemical solvent stripping, and low heat has the potential for seamless integration with the CO₂ capture process. It should be a primary focus of future research work.

Utilizing solar thermal energy for CO₂ Capture is technologically feasible, but considerable capital and operating cost reductions are necessary to offer a monetary improvement over steam extraction. A more pragmatic approach shall use solar energy for just fulfilling a fraction of the stripping heat necessity.

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