iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: XI Month of publication: November 2022

DOI: https://doi.org/10.22214/ijraset.2022.47265

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue XI Nov 2022- Available at www.ijraset.com

Carbon Dioxide: Capture, Sequestration, Compressor and Power Cycle

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***Abstract:** With an aim to reduce the effect of climate change, it is necessary to reduce the greenhouse gas (GHG) emissions significantly. Energy industry is one of the largest contributors for the same. Even though the usage of energy from renewable sources is increasing rapidly, the dependency for energy on conventional fossil fuels, such as coal or crude oil, will to remain relatively high for following few decades. One of the ways to curb the carbon footprint is implementation of carbon capture and storage (CCS) technology, where carbon dioxide (CO2) is captured from the atmosphere and stored for long-term in an empty gas or oil fields. CCS is an important component of the low-carbon based technologies which may help us meet the reduced CO2 emission targets.*
***Keywords:** CO2, Capture, Sequestration, Compressor, Power Cycle*

I. INTRODUCTION

Global warming and Climate change is caused by increase in the concentrations of greenhouse gases (GHG) produced due to various human activities. One of the important greenhouse gas is carbon dioxide (CO2), of which the concentrations are being increased at a rapid pace due to usage of carbon-based fuels. A large contribution of the increasing CO2 in the atmosphere is caused by the power industries based on the fossil fuel. For the year 2010, electricity and heat generation contributed for 41% of the CO2 emissions around the world. One of the options to reduce CO2 release is through the carbon capture and storage (CCS). CCS consists of capturing and separation of CO2 from different industries and energy-related sources, transporting it to a storage location for prolonged isolation from the atmospheric air. The International Energy Agency (IEA) has estimated that 17% of the reduction as per the requirements can be targeted with implementation of CCS. Hence CCS is an important aspect of the newly developing low-carbon technologies to meet the overall CO2 emission reduction. Adding on to it, the IEA has estimated that without CCS, the total cost for the reduction of the emissions by 50% would increase by 70% by the year 2050.

On an average, the global CO2 emissions have gone up by 1.0% per year since 1990 to 1995 and 1.4% between 1995 and 2001, a rate just below that of the consumption of energy in both the periods. In the individual sectors, there was no increase in CO2 emissions from the industries between 1990 and 1995 (0.9% since 1995 to 2001). There was an overall increase of 1.7% each year (2.0%) for transport sector, 2.3% each year (2.0%) for construction sector, and decrease by 2.8% per year (1.0%) in the agricultural sector as per IEA, 2003. Total emissions from burning of carbon based fuel consumption and flaring of natural gas was approximately 24 GtCO2 per year i.e. 6.6 GtC each year in 2001 of which the developed countries were contributing for 47% of energy-related emissions . The developing nations accounted for 13% of 2001 CO2 emissions. Developing nations in the Asia-Pacific region have released 25% of the global CO2 while the rest of the developing countries contributed for 13% of the total value.

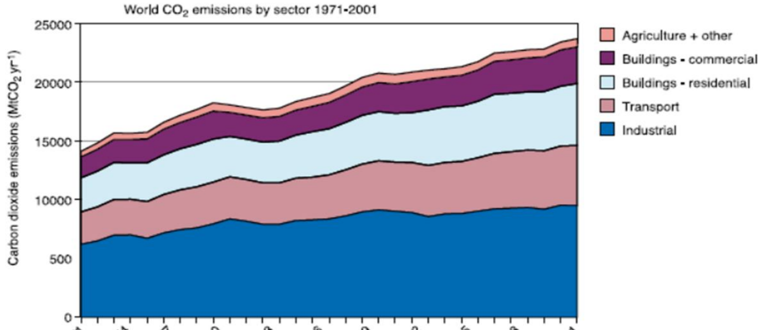

Fig. 1 IEA 2003 – CO2 emissions by various sectors

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II. CARBON CAPTURE TECHNOLOGIES

Huge amount of CO2 is emitted during the combustion of natural gas. This amount of Carbon dioxide is either released into the atmosphere or used in plants to manufacture secondary items for example in food processing industry. However, even though small quantity of the carbon dioxide emissions are reused by manufacturing industry, majority of the CO2 eventually ends up being released in the atmosphere. The general goal for the carbon capture and storage technologies is to produce carbon dioxide such that it can be stored or transported. For this, the carbon dioxide should be compressed to the liquid state for it to be transported easily through pipelines and eventually pumped into a geological formation. The carbon compression stage can thus be defined as part of the CCS technology. The technologies utilized for CCS are categorized as pre – combustion, oxy - combustion and post – combustion. These technologies are called so due to the timing when the carbon dioxide is eliminated during fossil fuel combustion .The oxyfuel or oxy – combustion process, is still under the developing stages and will need some more time before it becomes accepted commercially . This technology is used by power plants which is similar in a way to that used by various industrial activities which devoid of burning.

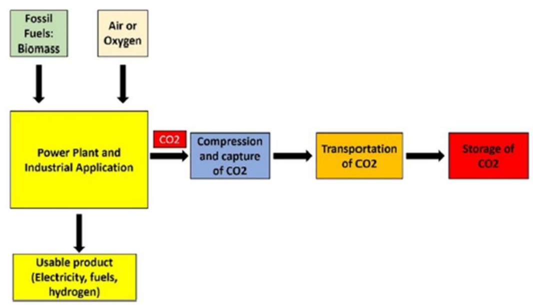

Fig. 1 Overview of Carbon Capture Technologies

A. Post Combustion

The post combustion process (PCC) absorbs the CO2 generated by the flue miasma following the combustion of fossil commodities or carbon based materials. The highest quantity of the electrical energy used by the world is obtained from power plants through the combustion process. As of today, the main process in coal fired power plants is the combustion of coal fused with air in the boiler or the furnace. It results in an exothermic reaction and the steam released from the process is used to drive a turbine generator. The high temperature flue gas that flow out of the furnace consists of nitrogen from the air and water vapor in small concentrations. The carbon dioxide is also produced from the hydrogen and carbon of the fuel used. Sulfide dioxide, nitrogen oxide and fly ash are also released due to the burning of impurities from the coal. Such toxic gases and few others like mercury should be eliminated as they are considered as pollutants owing to the emission standards. According to the scientists, chemical reaction is described as the best option for capture of CO2 from the flue gas of a pulverized coal plant. A solvent known as mono ethanolamine (MEA) is required to facilitate this chemical reaction process. MEA is a part of the different amine compounds. The flue gas is primarily scrubbed in an absorber. The absorber is used in the capture of approximately 85% to 90% of the CO2 produced. The dissolved CO2 in MEA is injected into a vessel known as the regenerator or the stripper. In this vessel, steam is used for the release of CO2. The Carbon dioxide produced following this process is highly concentrated. The gas is then compressed and conveyed to a location where it can be stored. The solvent used for this process is then forced back and recycled in the absorber. The Post Combustion process is suitable for capturing the CO2 from pulverized coal power plant or a natural gas fired boiler. The coal fired power plants have flue gas with carbon dioxide levels being denser when compared to the natural gas combined cycle, but with the use amine based solvents and capture systems, it is still possible to obtain higher efficiency .The natural gas is very pure hence the flue gas stream obtained from it is very clean. As a result, there will be no requirement for the cleanup for capturing the CO2 from flue gas.

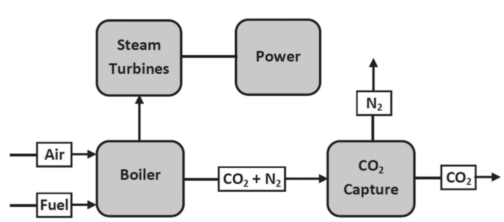

Fig. 3 Post – Combustion Process

B. Pre Combustion

The Pre-Combustion technology is based on the separation of carbon dioxide from fossil fuel commodities before the combustion process being started. It can be explained also as a reaction of fuel and O2 gas to produce carbon monoxide, hydrogen, and fuel gas. After the removing of carbon dioxide from this, we can obtain pure hydrogen. Carbon dioxide can be obtained through integrated gasification. The Pre-Combustion Process can also use for power plants that use natural gas. The primary step of the elimination of carbon from fuel is to it to a form which is easier to capture. The reaction between coal, steam and oxygen gas is the phenomenon for power plants powered by coal which occurs at high pressure and temperature. Output of this chemical reaction is a fuel made up of Carbon Mono-oxide and a mixture of hydrogen also known as syngas. Further, this gas goes through a combustion in the power plant to produce power. The power generated by this gas is generally referred as Integrated Gasification Combined Cycle (IGCC) power. In secondary step of this system, the carbon monoxide generated in first step is converted into carbon dioxide through a reaction with steam. This results in the formation of CO2 and hydrogen. Selexol, a glycol-based solvent, is used to capture the carbon dioxide through the chemical process. This leads to production of purified hydrogen stream which can be used in other power plants for producing the power. Comparatively simpler and cheaper separation of CO2 as to the operating pressure is higher and very high concentrations of CO2 with the use of IGCC plants, leads to being most preferred option though it is an expensive process when compared to the normal coal-based combustion plants. The operation for pre- combustion technology is based on physical absorption and then releasing the carbon dioxide as there is drop in sorbent pressure, compared to the use of a chemical to catch the carbon dioxide such as amines as used in post combustion capture process. The use of IGCC includes a few drawbacks such as there is a loss in energy during the CO2 capture due to the shift reactor and other steps during the process.

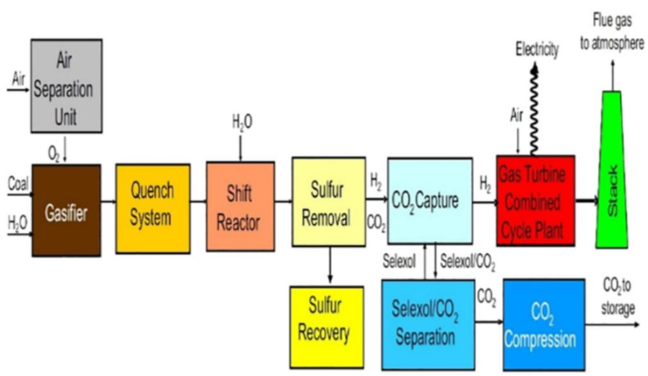

Fig. 4 Pre – Combustion Process

C. Oxy Combustion

A carbon capture process is the oxy–combustion method which has been a recently developed technology. This process makes use of pure oxygen for the combustion and thus eliminating the quantities of nitrogen. Fly ash is also removed from flue gases, thus resulting to output gas consisting of only CO2, few water droplets and some impurities such as sulfur dioxide. For the removal of water vapor from this, the flue gases are compressed, and the temperature is reduced. As a result, through this process, we are left with pure carbon dioxide which can be stored directly. The key advantage of oxy – combustion over other methods is the avoidance of use of an expensive Carbon dioxide capture system. Replacing the Carbon dioxide capture systems in post combustion process, the oxy combustion incorporates an air separation unit (ASU) which produces extremely clean oxygen with purity of approximately 95% to 99% for oxyfuel process when compared to IGCC plant of the same volume. Significant cost is affected by the Air separation unit. Generally, extra gas transformation is needed to limit the air pollutant concentration so as to meet the appropriate environmental guideline. This results in a reduction of unwanted materials in the flue gas recycle. As the temperature required for burning of pure oxygen is higher than air, oxy combustion process makes use of large portion of the stream as the flue gas is used back in the boiler to maintaining optimal operating temperature. System's Sealing is one of the important aspects in the design to maintain the required oxygen and nitrogen as found in the gas. Sealing of the system prevents the leakage of air into the flue gas. Hence, during maintenance, it is considered as one of the critical issues as the leakages at the joints and flanges are difficult to eliminate specifically along the flue gas duct. It is necessary to eliminate pollutants from the Oxy-Combustion systems as this may reduces the efficiency of the process to 90%.

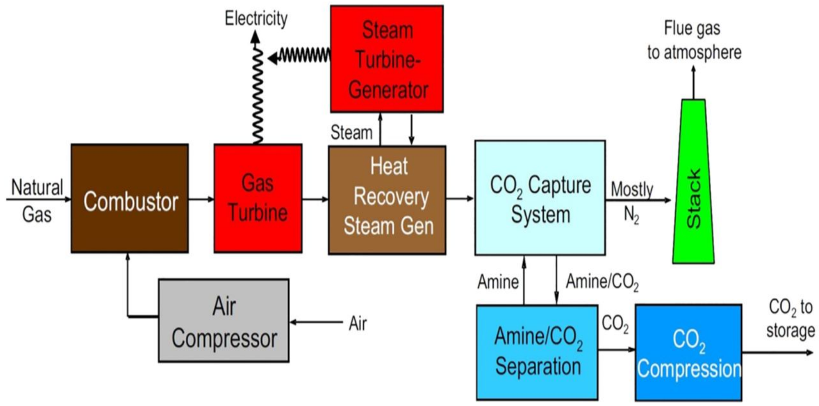

Fig. 5 Oxy – Combustion Process

III.SEQUESTRATION

Among the several methods of CO2 transport, transportation with the help of pipeline is the most economical considering the huge amounts of CO2 and long distances. Various studies for understanding the pressure drop behavior of supercritical CO2 and the dense carbon dioxide phase through the pipelines have been conducted. From results, we can interpret that the pressure through the pipeline keeps on dropping till the CO2 evaporates and leading to blockage of the pipeline. As a result, we can conclude that there is a maximum safe transport distance. If it is required to transport CO2 beyond the safe limit of transportation, there will be requirement of boosting pump stations along the pipeline. Carbon dioxide can be transported for long distances in two states i.e., either as a supercritical fluid or as a sub-cooled liquid. Due to the lower density and high pressure drops, gas-phase transport is a disadvantage.

Commonly, transportation of carbon dioxide in the sub-cooled liquid state has a few advantages compared to the supercritical state transport, of which the most important is that due of the lower compressibility and comparatively higher density of the liquid within the similar pressure range, there are lower pressure losses and enables the use of pipe of smaller size.

Considering the case of the transportation of fluid through pipeline, it generally occurs under isothermal and adiabatic conditions. For a given length of a CO2 pipeline segment that is buried and has no insulation, it can be treated as isothermal. In this case, the temperature of CO2 is of the soil that is surrounding the pipeline. Therefore, the transport of CO2, which was started in a supercritical state, goes to a gaseous state process during some point through the pipeline due of the pressure drop. Considering a constant pipe diameter, velocity of carbon dioxide increases along the pipeline. In a few, this may eventually lead in a very high pressure drop or even "choking" conditions.

Among the viable options or method for CO2 storage, the preferred option have been geologic formation especially the depleted oil and gas reservoirs considering environmental risks and uncertainties related to the geologic storage are comparatively lower when compared to ocean storage. The CO2 in the liquefied form is transported and stored by various companies using EOR (Enhanced Oil Recovery) technique for tertiary recovery from the fields by reducing the density of the oil and hence mobilizing it easily. Following this trails have already been conducted and the storage locations have shown their ability to store fluid CO2 for millions of years. However, there are certain environmental risks such that there may be chances of leakage of CO2 through fractures leading to contamination of ground water.

Along with the depleted oil and gas reservoirs, the deep aquifers are one of the promising option in the long run. The transportation costs for the in aquifers is also comparatively less. Considering the uncertainty of the environmental effects of Carbon dioxide in aquifers, they can be mitigated by selecting the suitable storage sites. For an ideal situation, the aquifers will have an impermeable cap, thus avoiding the release of injected Carbon dioxide, but will have high porosity as well as permeability below leading to the injected CO2 being distributed in uniform proportion throughout. These kind of aquifers are saline and are separated from shallow freshwater aquifers. For ensuring longer storage duration, chemical reactions between Carbon dioxide and the surrounding rock may eventually lead to formation of stable carbonate compounds.

Another huge potential for the storage of CO2 are deep coal beds. The CO2 that is injected in the coal seam leads to displacing the fossil fuel methane that is adsorbed onto the surface of the coal, enabling the recovery of methane and utilizing it commercially. However, this process is still in very early stage of the development.

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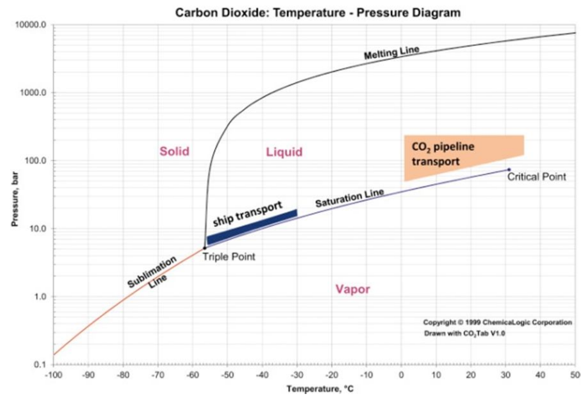


Fig. 6 Phase Diagram of CO2 with modes of transport

IV. COMPRESSOR

Compression of Carbon Dioxide is an essential part of the process in the development of various carbon capture and storage technologies which involves a huge reduction in the volume of CO2. For this same reason, the diameter of the first impeller is quite larger when compared to that of the impeller for last stage. As of today, CO2 compressors are expensive due to the overall pressure ratio being high (100:1) and, also, stainless steel is required to accommodate Carbon dioxide in the presence of water vapor. The high costs is a result of the aerodynamic design practice which limits the design pressure ratio for each stage for heavier gases like as CO2. As a result, the CO2 compressors are contributors for a huge capital and operating cost associated with the carbon capture and sequestration system (CCS).

A. Internally Geared Compressor

Current CO2 compressor are comparatively expensive as they have to ensure a higher overall pressure ratio of approximately 100:1 and, also, stainless steel is required to accommodate Carbon dioxide in the presence of water vapor. The general turbomachinery design practice is to aim to limit the inlet Mach number at the inlet stage so as to avoid generation of shock waves in the blade passages resulting to the aerodynamic losses therefrom. This is typically achieved by regulating rotational speed. The Mach number being a function of the molecular weight, the effect is observed with gases heavier-than-air such as CO2. As a result, due to speed limitation, in case of carbon dioxide compression pressure ratio of approximately 1.7–2.0:1 can be achieved per stage. Hence, in such cases, eight stage compression is required to reach the total pressure ratio of 100:1. This problem is also followed with a requirement to intercool CO2 between the subsequent compressor stages. Owing to the lower volume and higher pressure in each following stage, impellers can be individually optimized for integrally geared compressors. This attribute enables it to spin high-pressure impellers at higher speed than previous stages. It is possible to design different speeds for individual stages. The overall survey leads to the conclusion that, the integral-gear compressor offers multiple advantages over in-line centrifugal configurations, for most Carbon capture applications, such as:

1) Higher efficiency,
2) Optimization of impeller flow coefficient for each pair of impellers,
3) Axial inlet of flow to each stage,
4) Intercooling possible after each stage,

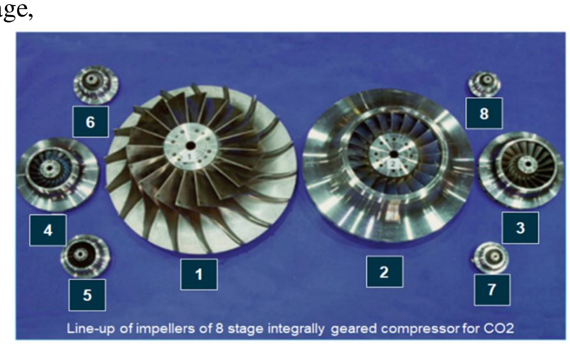


Fig. 7 Internally Geared Compressor

B. Barrel Compressor

Barrel compressor is a single shaft per casing centrifugal compressor with number of impellers varying upto 15 as per flow and discharge pressure requirement. Typically the flow enters the compressor a suction end and after passing through impellers, it is discharged. In case of higher discharge temperatures; gas is routed to an external heat exchanger for cooling, and then it enters into the next compressor casing for additional compression. As the centrifugal compressor that has vertically split casing also looks similar to a cylinder and is also known as barrel compressor. Against horizontally split casing type of compressors, a multi-stage centrifugal compressor with a vertically split casing is preferred for applications with higher pressures. In case of Co2 CCS application; this type of compressor configuration shall be of two casing with five to six impellers per casing to achieve a final discharge pressure of approx. 150 bara.

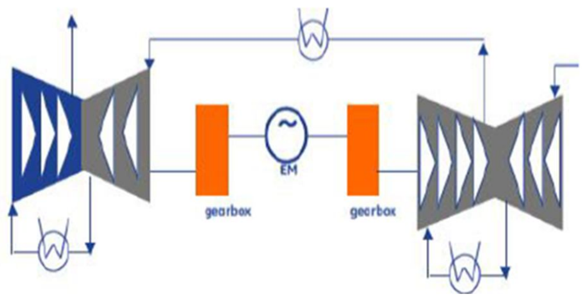


Fig. 8 Barrel Compressor

V. POWER CYCLE

The major advantage of the supercritical CO2 cycle when compared with the helium Brayton cycle is similar efficiency at significantly lower temperature that is 550 ^{o}C against 850 ^{o}C, but at the higher pressure. The supercritical CO2 cycle can be used in any type of nuclear reactor which has core outlet temperature approximately over 500 ^{o}C . Making use of the advantage regarding abrupt change of properties near the critical point of Carbon dioxide, the work done for compression can be reduced, resulting in a notable efficiency improvement. Considering basic design parameters, turbine inlet temperature can be assumed to be 550oC and the compressor outlet pressure at 20 MPa. For the above stated operating conditions, the direct cycle achieves thermal efficiency of 45.3 % along with reduction of the cost of the power plant by almost 18% when compared with a conventional Rankine steam cycle. The capital for the basic design is similar compared with a helium Brayton cycle, but the sCO2 cycle operates at comparably lower temperature. The current reactor operates with carbon dioxide up to 650oC, that is used as inlet temperature of an advanced design for the turbine. The thermal efficiency is close to 50% for the advanced design as well as the reactor system using direct supercritical CO2 cycle is almost 24% less costly than the steam indirect cycle and 7% lesser for helium direct Brayton cycle.

The **Allam-Fetvedt Cycle** which operates as a recuperated, high-pressure, Brayton cycle using a transcritical CO_2 as the working fluid with the oxy-fuel combustion regime. This cycle starts by combustion of a gaseous fuel with oxygen and a high-pressure, hot and recycled supercritical CO_2 working fluid in a chamber. The recycled Carbon dioxide stream serves the purpose of reducing the combustion flame temperature as well as diluting the combustion products with an aim of working fluid is the cycle being predominantly CO_2. The pressure in the combustion chamber may be as high as 30 MPa and the combustion feedstock consists of about 95% recycled CO_2 . The combustor then releases a high-pressure exhaust which can be supplied to a turbine expander that operates at a pressure ratio from 6 to 12. The discharge from expander leaves in the form of subcritical CO_2 mixture majorly mixed with water derived from combustion. This fluid is passed through an economizer heat exchanger, that cools the expander discharge upto 65 °C against the stream of CO_2 which is being recycled to the combustor. Upon exiting the economizer, the exhaust from the expander is cooled down to near ambient temperature through central cooling system, thus enabling water to be extracted from the working fluid and further recycled for any other use.

The remaining working fluid that contains almost pure CO_2 then enters a compression stage followed by the pumping stage. The compression system is an inter-cooled centrifugal compressor that has inlet pressure below the CO_2 critical pressure. The Carbon dioxide working fluid is then compressed and cooled down to ambient temperature. At this point of the cycle, the combined process of compressing and cooling the working fluid achieves a density in higher of 500 kg/m3. Under such condition, the stream is pumped to the high combustion pressure as per requirement with the help of a multi-stage centrifugal pump. At the end, this high-pressure working fluid is passed through the economizer heat exchanger again, so as to be reheated and returned to the combustion chamber.

The net Carbon dioxide from the addition of fuel and oxygen in the combustion chamber is extracted from the high-pressure stream. In this case, the resultant CO_2 is at high-pressure and quite high purity which can be directly transported for sequestration or utilization without need of any further compression. For this process to achieve such high thermal efficiency, a close temperature approach is required at the high-temperature region of the primary heat exchanger. As the cooling process is employed at the between compression and pumping stages, a huge energy imbalance would generally exist in the cycle between the cooling expander exhaust flow and the reheating CO_2 recycle flow. The Allam-Fetvedt Cycle amends the imbalance by incorporating small heating of range between 100 °C to 400 °C at the lower-temperature end of the recuperative heat exchanger. One of the most probable convenient source of this heating is an Air Separation Unit (ASU) which is needed for the oxy-fuel combustion regime.

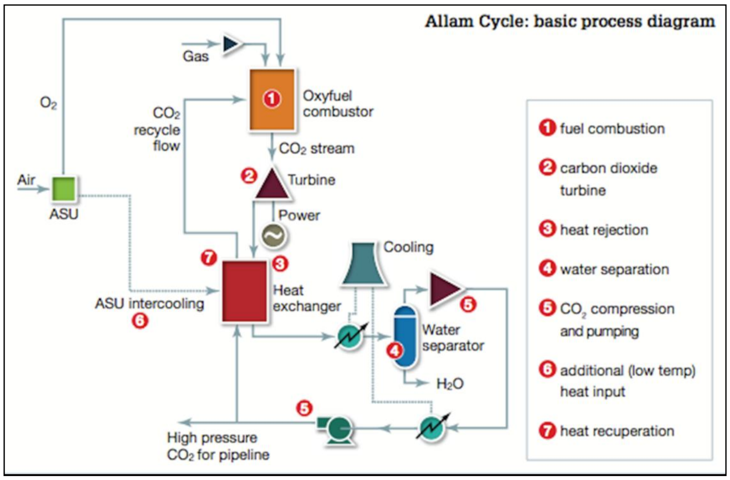


Fig. 9 Allam Cycle

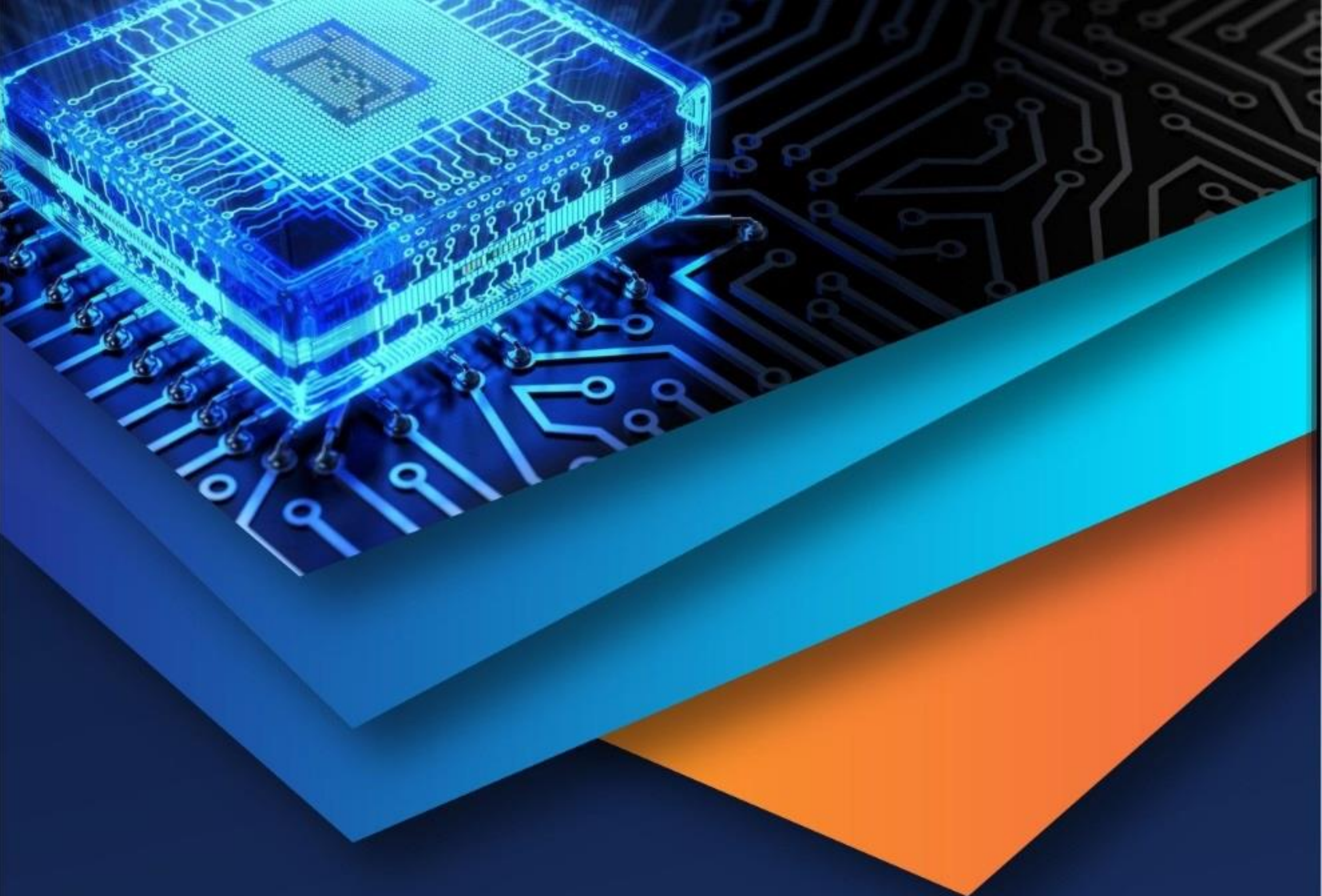
VI. CONCLUSIONS

In this paper we have an overview of the Carbon Dioxide capture and storage as an option for the mitigation of global warming. Capturing CO2 from the atmosphere is the primary and most important part of the process for generation of the condensed stream which can be stored easily. The major natural reservoirs that can store the CO2 are the geological formations and the deep ocean beds. Capture and storage of the carbon dioxide is most applicable to large, centralized generators for example power plants and large industries. With the help of this technology, we can have a of carbon neutral process, allowing minimal carbon emissions while producing electricity . The drawback of the present CCS processes are that the energy required to operate this system and the overall waste produced are comparatively higher than the conventional plants. In the future, it is necessary to design higher efficiency plants to achieve the net impact zero. The top aim in the upcoming Carbon capture and storage technology would be to reduce the costs and environmental impacts, as well as increase the carbon capture efficiency. Many new technologies are being developed to increase the CO2 storage into the ocean. The captured CO2 can be transported through the ship and can be injected directly in the ocean bed. CO2 that has been loaded on to the ships could be dispersed either via a pipeline or directly transported to platforms that feed the CO2 lake on the sea floor. Such CO2 lakes should be deeper than 3 km such that CO2 has higher density than sea water.

REFERENCES

[1] Anderson, Soren and Newel, Richard, " Prospects of Carbon Capture and storage Technologies", Resources for the future, RFF-DP 02-68, January 2003
[2] L. D. Danny Harvey, "Carbon-free Energy Supply ", pg 389-424, Earthscan, UK ,2010
[3] [1] Kidnay, Arthur J., and Parrish, William R., (2006), "Fundamentals of Natural Gas Processing", Taylor and Francis Group, LLC.
[4] [2] Scholes, Colin A., Kentish, Sandra E., and Stevens, Geoff W., (2008), "Carbon Dioxide Separation through Polymeric
[5] Membrane Systems for Flue Gas Applications", Recent Patents on Chemical Engineering, 1, 52-66
[6] [3] Sam Wong, David Keith, Edward Wichert, Bill Gunter, and Tom McCann. (2003), "Economics of Acid Gas Reinjection:
[7] An innovative CO2 Storage Opportunity," Greenhouse Gas Control Technologies, J. Gale and Y. Kaya, Elsevier Science
[8] Ltd.
[9] [4] IEA Energy Technology Essentials, "CO2 Capture & Storage"(Dec2006), ww.iea.org/textbase/techno/essentials.htm
[10] [5] Donnelly, H.G., Katz, D.L.; (1954) "Phase equilibria in the carbon dioxide-methane system", Ind. Eng. Chem, 46, 511-517
[11] [6] Moore, Jeffrey J., Walker, Stephen T., and Kuzdal Mark J., (2002), "Rotordynamic Stability Measurement During Full-
[12] Load, Full-Pressure Testing of a 6000 PSI Reinjection Centrifugal Compressor", Proceedings of the Thirty-First urbomachinery Symposium, , Houston, TX.

[13] Ofe´ lia de Queiroz Fernandes Arau´ jo and Jose´ Luiz de Medeiros, "Carbon capture and storage technologies: present scenario and drivers of innovation", Current Opinion in Chemical Engineering, 17:22–34, 2017.
[14] Berend Smit, Jeffrey A Reimer, Curtis M Oldenburg and Ian C Bourg,Ed, Introduction to Carbon Capture and Sequestration, ser The Berkley lectures on energy. USA: Imperial College Press, 2014, vol 1.
[15] Howard Herzog and Dan Golomb, Carbon Capture and Storage from Fossil Fuel Use, Volume 1, Encyclopedia of Energy, Massachusetts, United States, 2004.
[16] R. Stuart Haszeldine, "Carbon Capture and Storage: How Green Can Black Be.?," SCIENCE vol. 325, pp.1647-1652, Sept. 2009.
[17] J.C.M. Pires, F.G. Martins, M.C.M. Alvim-Ferraz and M. Simões, "Recent developments on carbon capture and storage: An overview" Chemical engineering research and design, vol. 89, pp 1446–1460, 2011. journal article?
[18] Jochen Ströhle, Alexander Galloy and Bernd Epple, "Feasibility Study on the Carbonate Looping Process for Post Combustion CO2 Capture from Coal-Fired Power Plants, Energy Systems and Technology," in Energy Procedia 1, Technische Universität Darmstadt, 64287 Darmstadt, Germany, 2009, p. 1313-1320.conf paper
[19] Howard Herzog, Carbon Dioxide Capture and Storage, 978–0–19–957328–8 13-Helm-c13 Helm Hepburn (Typeset by SPi, Chennai) 263 of 283 June 21, 2009 12:8? type of article
[20] C.F. Martín, S. García, J.J. Pis, F. Rubiera, and C. Pevida, "Doped phenol-formaldehyde resins as precursors for precombustion CO_2 capture adsorbents,"Energy Procedia vol. 4, pp 1222–1227, 2011.
[21] Michael L. Szulczewskia, Christopher W. MacMinnb, Howard J. Herzogc, and Ruben Juanesa, "Lifetime of carbon capture and storage as a climate-change mitigation technology," PNAS, vol. 109, pp. 5185–5189, April 2012. Available: https://www.co2captureproject.org/co2_trapping.html
[22] Jon Gibbins, and Hannah Chalmers, "Carbon capture and storage, Energy Technology for Sustainable Development Group," Mechanical Engineering Department, Imperial College London, UK, Energy Policy 36, pp 4317–4322, 2008.
[23] Jason J. Heinrich, Howard J. Herzog, and David M. Reiner, "Environmental Assessment of Geologic Storage of CO2," Massachusetts Institute of Technology Laboratory for Energy and the Environment, Publication No. LFEE 2003-002 Report, 2004.
[24] Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos and Leo Meyer, "IPCC Special Report on Carbon Dioxide Capture and Storage," Prepared by Working Group III of the Intergovernmental Panel on Climate Change Published for the Intergovernmental Panel on Climate Change, report no, year.
[25] [14] Pen-Chi Chiang and Shu-Yuan Pan, "Carbon Dioxide Mineralization and Utilization," Springer Nature Singapore Pte Ltd. 2017, DOI 10.1007/978-981-10-3268-4
[26] Keywan Riahi, Edward S. Rubinb, Margaret R. Taylorb, Leo Schrattenholzer and David Hounshellb, "Technological learning for carbon capture and sequestration technologies," Energy Economics vol. 26, pp 539 – 564, 2004.



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