

Comparison of Selexol™ and Rectisol® Technologies in an Integrated Gasification Combined Cycle (IGCC) Plant for Clean Energy Production

Isah Yakub Mohammed^{1*}, Mohamed Samah², Adam Mohamed², Gbadegesin Sabina³

¹Department of Chemical Engineering, Abubakar Tafawa Balewa University Bauchi, Nigeria

²Department of Chemical Engineering, the University of Khartoum, Sudan

³All Grace Energy Limited, Nigeria

*Corresponding author: chemicalmyhib@yahoo.com

Abstract: In this study, a comparison of Selexol™ and Rectisol® technologies in an Integrated Gasification Combined Cycle (IGCC) plant for Clean Energy production was carried out. The overall plant efficiency, individual solvent performance, the operating conditions and the energy requirements, the capital and operating cost were analyzed as well as the safety and environmental impacts. The result revealed that both the Selexol™ and Rectisol® reduce the overall plant efficiency by approximately 9% and 10% respectively. Rectisol® process showed ability to recover more carbon dioxide and sulfur than the Selexol™ process. It was also found that Selexol™ solvent gives good absorption at room temperature while Rectisol® solvent works better at reduced temperature which increases the power cost. The capital cost for constructing a carbon capture plant was found to be higher when using Rectisol® due to the process complexity. Finally, based on economical trade-offs it is recommendation to use Selexol™ technology in the IGCC plant for clean energy production.

Keywords: Selexol™; Rectisol®; IGCC, Pre-combustion; Carbon capture

I. Introduction

The increasing demand for energy has resulted in an increase in the anthropogenic emission of CO₂ and other greenhouse gases that contribute to global warming. The need for reduction of the amount of CO₂ emission to the atmosphere has led to different inventions of CO₂ abatement technologies such as high efficiency conversion processes, the use of low carbon fuel and Carbon capture & storage (CCS). The CCS has been considered as an option for limiting CO₂ emissions from the combustion of fossil fuels [i]. This approach includes oxy-fuel combustion, post-combustion capture and pre-combustion capture [ii, iii, iv, v, vi]. In oxy-fuel combustion, the fuel source is combusted with O₂/air and the flue gas is cleaned for a carbon free stream. The post combustion capture removes CO₂ after the combustion of the fuel source. Amine based and ammonia solvents are being considered in this direction. For pre-combustion capture, the CO₂ is removed prior to the combustion process through a series of chemical reactions or processes. This may include the methods of fuel switching and higher energy conversion processes [vii, viii]. The objective of fuel switching is to utilize means that possess lower carbon content in its composition or

produces less emission during energy generation [iii, v]. Renewable sources of energy such as solar, wind, wave, etc are examples of fuel switching options as they do not emit CO₂ during the generation. However, despite this simple and straightforward as well as advantageous solution to carbon dioxide emissions, the energy output of these fuels is lower and larger amounts of the fuel sources are required compared to fossil sources. This may result in higher capital and operating costs [iii, v, vi]. Biomass co-firing is one of the options currently used in the industry. It is a process where a proportion of a biomass fuel is burnt together with a proportion of coal. The energy density of coal is significantly greater than biomass and therefore energy output will be lower. Natural gas is also another alternative fuel as its combustion emits lower levels of harmful substances into the atmosphere [iii, v]. The higher efficiency conversion process operates based upon the increased energy output of power generation plants for every unit of fuel used through more efficient processes which in turn reduces the mass of carbon dioxide released into the atmosphere per unit of energy produced. An example of a higher efficiency conversion process is integrated gasification combined cycles (IGCC) [ii, iii, iv]. Sources of fuel in the IGCC plant could be coal, natural gas, heavy hydrocarbon oil or biomass [x]. As shown in Figure 1, the fuel with oxygen from the air separation unit is converted to synthesis gas (syngas) in a gasification unit where many reactions take place including combustion. Syngas, which consists mainly of hydrogen and carbon monoxide with other traces like sulphur compounds, with other traces like sulphur compounds, is passed through a series of purification units and sent to a water gas shift catalytic reactor for conversion of carbon monoxide to carbon dioxide. The gas stream from reactor is sent to the acid gas removal (AGR) unit where CO₂ is separated and processed for further sequestration.

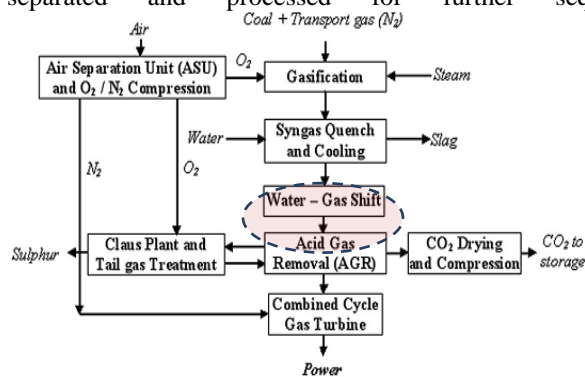


Figure 1: Simplified diagram for the IGCC process [ix]

The objective of this study was to compare Selexol™ and Rectisol® technologies for CO₂ capture in IGCC plant. Selexol™ and Rectisol® are trade names for physical solvent. Selexol™ is a mixture of dimethyl ethers of polyethylene glycol (DEPG) while Rectisol® is chilled methanol. These technologies have been used traditionally for purifying syngas for chemical synthesis. But recently, reformed designs are being developed for carbon capture in power plants and hence the need for serious investigation of their feasibility.

II. Methodology

Information from open literature was used to carry out the study. Attention was focused on the process flow, material and energy requirements, solvents properties and performances, costing and level of carbon captured as well as environmental impact.

III. Discussions and Justification

Selexol™ process removes carbon dioxide (CO₂) and hydrogen sulphide (H₂S) together with other components such as carbonyl sulphide (COS), hydrates mercaptans and hydrogen cyanide that may be present in the syngas. Selective removal of H₂S with deep CO₂ is accomplished with double absorption and stripping towers. The gas stream and the solvent are contacted in the first column where H₂S is scrubbed, while CO₂ removal is achieved in the second column as shown in Figure 2. CO₂ is flashed off in horizontal tanks and the solvent is regenerated in the stripping column where sulfur is removed. The Selexol™ process is sensitive to operating temperature and pressure but more effective in the temperature range between -8 and 175°C [xi], along with high pressure and high acid gas system [xii]. One of the advantages of the Selexol™ process is the high solvent stability; low volatility and low vapour pressure. Hence, during regeneration its losses are minimized.

Rectisol® is one of the processes concerned with flue gas contaminants related to coal and oil gasification. The process is similar to Selexol™ flow scheme but requires additional process unit due to the necessity of methanol refrigeration. Refrigeration is needed to maintain the solvent within a temperature range of -40°C to -62°C [xiii]. This is necessary in order to minimize solvent losses due to its high volatility and to increase CO₂ solubility. The H₂S is removed in the hot regeneration column while the CO₂ is recovered via stripping by lowering the pressure of the refrigerated methanol in the stripping column as shown in Figure 3. The advantage of the Rectisol® process is that the methanol solvent used is very cheap and it has a low selectivity of H₂ [x, xiii].

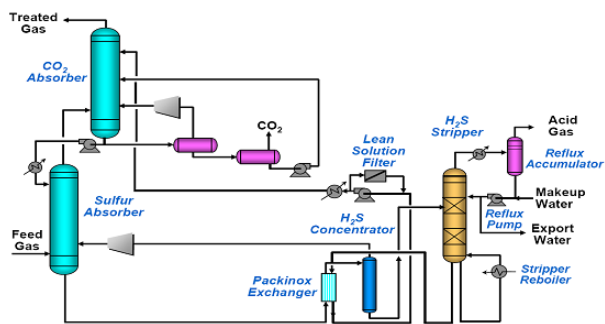


Figure 2: Flow diagram for the Selexol™ Process [xii]

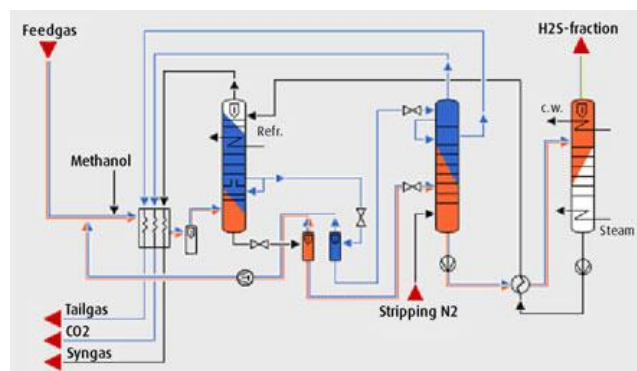


Figure 3: Flow diagram for the Rectisol® Process [xiv]

Table 1 below gives a summary of properties for both solvents. The characteristics of an efficient physical solvent include high solubility for CO₂ and H₂S at the operating conditions, low viscosity at the lowest operating temperature as well as high boiling point to reduce losses [xiii, xiv]. Properties of Selexol™ showed that it is chemically and thermally stable and capable of absorbing more CO₂ with higher selectivity (CO₂ vs. H₂S) compared to Rectisol® at high temperature [xvi]. However, DEPG's high viscosity especially at low temperatures results in a low mass transfer rate in the absorption column [xvii]. DEPG's low vapour pressure is an advantage as it facilitates solvent regeneration [xi]. On the other hand, for Rectisol, high methanol volatility results in potential solvent loss and make-up requirements, while CO₂ solubility increases and tends to maximize due to required low operating temperature [xvi]. However, methanol cost is relatively low so economical trade-offs are applied for optimization.

In terms of process energy demand, Rectisol® requires more energy than Selexol™ due to the requirement for additional process unit to aid regeneration and recirculation of the chilled methanol which in turn results in higher electricity requirements, high cost and complexity [xiii]. Table 2 shows the energy requirements from a simulation study of an IGCC plant with Selexol™ and Rectisol® technologies for 90-91% carbon capture. The result indicates that the energy consumption of Rectisol® is higher than that of Selexol™ process for the specified CO₂ recovery. This was attributed to the refrigeration requirement.

Table 1: Properties of solvents [xi, xv]

Properties	Selexol™	Rectisol®
Viscosity at 25°C (cp)	5.8	0.6
Density (kg/m ³)	1030	785
Molecular weight	280	32
Vapour pressure at 25°C	0.00073	126
Freezing point (°C)	-28	-92
Boiling point at	275	65
CO ₂ solubility ft ³ /Us gal	0.485	0.425

Table 2: Energy consumption of the CCS process [vix]

Duty	Units	Selexol TM	Rectisol [®]
Power duty	kWh/kg CO ₂	0.1080	0.1186
Heating duty	MJ/kg CO ₂	0.2238	0.3740
Cooling duty	MJ/kg CO ₂	0.5590	0.6156

Economically, although Rectisol[®] equipment sizes are smaller due to low circulation rate, it requires more equipment for dehydration, solvent recovery and CO₂ compression [xi]. Moreover, approximately 5% of Rectisol[®] equipment requires stainless steel material owing to low operating temperature and solvent corrosiveness [xvii]. The material of construction in SelexolTM process is basically alloy steel [xviii]. However, low viscosity reduces the tray efficiency though packing and tray requirements are increased [x]. The estimated capital cost for the addition of a Rectisol[®] process to an existing IGCC plant producing 544MW is \$81 million (\$149/KW) while the operating cost was estimated to be \$8.3 million. For the addition of a SelexolTM process, the total capital cost is \$40 million at \$75/KW and its annual operating cost was estimated to be \$6 million [xix].

Hazard associated with SelexolTM process is less compared to Rectisol[®]. Upon ingestion of SelexolTM, little abdominal discomfort may be observed; while Rectisol[®] can potentially cause blindness or death [xx].

IV. Conclusion

SelexolTM and Rectisol[®] processes have been studied for capture technology in an Integrated Gasification Combined Cycle (IGCC) plant. An overview of IGCC process was provided, along with a detailed description of SelexolTM and Rectisol[®] processes. Different parameters including operating conditions, solvent stability, energy requirement, safety, operating and equipment cost have been investigated. SelexolTM process showed both chemical and thermal stability. It was able to operate efficiently at normal conditions; thus, less energy requirement and operating cost. The Rectisol[®] process needed more equipment for refrigeration and regeneration. Although, the sizes and recirculation rate were significantly smaller compared to the SelexolTM process. Furthermore, the health, safety and environmental aspect were considered. SelexolTM was discovered to be a low toxic and flammable solvent in contrast to Rectisol[®] which may result to death upon inhalation. After all, both selexolTM and Rectisol[®] processes showed ability for CO₂ reduction; the Rectisol[®] process was found to be more suitable for down stream applications where high quality of syngas is required. In conclusion, carbon capture by the SelexolTM process integrated with IGCC plant offered better performance.

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References

- i. Steeneveldt, R., Berger, B., Torp, T.A. (2006). CO₂ Capture and Storage Closing the Knowing-Doing Gap. *Chemical Engineering Research and Design* 84 (A9): pp. 739-763.
- ii. Woudstra, N., Woudstra, T., Pirone, A., Stelt, T., (2010) Thermodynamic evaluation of combined cycle plants, *Energy Conversion and Management, Volume 51, Issue 5; 1099-1110.*
- iii. Drage, T.C., (2012) Carbon Abatement Technologies, from H84PGC Power Generation and Carbon Capture. At University of Nottingham WebCT, Blackboard. [Accessed 27/03/14]
- iv. Trapp, C., and Colonna, P., (2013). Efficiency improvement in pre-combustion CO₂ removal units with a waste-heat recovery ORC power plant. *J. Eng. Gas Turb. Power*, 135(4):042311–1–12
- v. Henson, J., (2014) Carbon abatement technologies at: <https://connect.innovateuk.org/web/carbon-abatement-technologies> accessed 10th August 2014
- vi. Yakub, M. I., Mohamed, S., & Danladi, S. U., (2014) Technical and Economic Considerations of Post-combustion Carbon Capture in a Coal Fired Power Plant. *International Journal of Advances in Engineering & Technology (IJAET), Volume 7 Issue 5, pp. 1549-1581*
- vii. Valero, A., and Usón, S., (2006) Oxy-co-gasification of coal and biomass in an integrated gasification combined cycle (IGCC) power plant. *Energy, Volume 31, Issues 10-11; 1643-1655.*
- viii. Olajire, A.A., (2010) CO₂ capture and separation technologies for end-of-pipe applications – A review. *Energy* 35; 2610-2628
- ix. Cormos, C.-C. (2011). Evaluation of Power Generation Schemes based on Hydrogen-fuelled Combined Cycle with Carbon Capture and Storage. *International Journal of HydrogenEnergy*, 36 (5), 3726-3738.
- x. Abass, O. A. (2010). CO₂ capture and separation technologies for end-of-pipe applications - A review. *Energy*, 35(6), 2610-2628.
- xi. Burr, B., & Lili, L. (2008). A comparison of physical solvents for acid gas removal. Texas, USA: Bryan research and engineering, Inc. Bryan.
- xii. UOP, A Honeywell Company. (2009). Meeting Staged CO₂ Capture Requirements with SelexolTM Process. USA.
- xiii. Ibsen, K. (2006). Sulphur Primer. San Francisco, California: National Renewable Engineering Laboratory, Nexant Inc.
- xiv. Linde Engineering at: http://www.linde-engineering.com/en/process_plants/hydrogen_and_synthesis_gas_plants/gas_processing/rectisol_wash/index.html; Accessed 23rd March, 2014
- xv. Munder, B., Grob, S., Fritz, P.M., (2010) Selection of Wash Systems for Sour Gas Removal. 4th International Freiberg Conference on IGCC & Xtl Technologies.
- xvi. Matthias, K., et al. (2009). Syngas conditioning. Germany: IEA Task meeting.
- xvii. Descamps, C., Bouallou, C., & Kanniche, M. (2008). Efficiency of an Integrated Gasification Combined Cycle (IGCC) Power Plant including CO₂ removal. *Energy*, 874-881.
- xviii. Koren, N., et al. (2002). Process Screening Analysis of Alternative Gas Treating and Sulphur Removal for Gasification. USA: Prepared for US Department of Energy by SFA Pacific, Inc.
- xix. United States Environmental Protection Agency (EPA). (2006). Final Report; Environmental Footprints and Costs of Coal-Based Integrated Gasification Combined Cycle and Pulverised Coal Technologies. Washington, DC.
- xx. Hydrogen Energy International LLC. (2009). HECA feasibility study, report #4 - AGR technology selection. California.