A study on CO_2 absorption using hybrid solvents in packed columns

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Abstract

Greenhouse gases emissions from large scale industries as well as gasoline based vehicles are mainly responsible for global warming since the 1980s. At present, it has triggered global efforts to reduce the level of GHG. The contribution of carbon dioxide (CO_2) in polluting the environment is at a peak due to the excessive use of coal in power plants. So, serious attention is required to reduce the level of CO_2 using advanced technologies. Carbon dioxide capture and storage may play an important role in this direction. In process industries, various carbon dioxide capture techniques can be used to reduce CO_2 emissions. However, post-combustion carbon dioxide capture is on top priority. Nowadays the researcher is focusing their work on CO_2 capture using hybrid solvent. This work highlights a review of carbon dioxide capture using various kind of hybrid solvent in a packed column. The various challenges for absorption efficiency enhancement and future direction are also discussed in the present work. It is concluded through the literature survey that hybrid solvent shows better efficiency in comparison to the aqueous solution used for CO_2 capture.

Keywords: carbon dioxide capture ; process industries ; hybrid solvent ; packed column

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1 INTRODUCTION

Air pollution is a serious concern nowadays because of the fuel consumption in various process industries and exhausts through vehicles in the entire world. Carbon dioxide gas emission is mainly responsible for air pollution and climate change in the atmosphere in the majority. The unabated outflow of carbon dioxide into the atmosphere from different sources is indicating the alarming situation for the future. Its removal is highly required in large scale process industries during processing operations. The Paris Agreement in 2016 forces the entire world to search out effective policies and technologies regarding greenhouse gas (GHG) abatement. At present existing coal-fired power plants are working using biomass as fuel in the blended form with coal in a certain quantity. According to the available data, coal-fired power plants are emitting carbon dioxide (CO_2) at a rapid rate in the atmosphere and accounting for roughly 40% of total CO_2 emissions [1]. The alternative way is that coal-based power plant should use biomass with coal to reduce GHGs [2]. Proximate and ultimate analysis of coal and sawdust has been compared as shown in Figures 1 and 2, respectively [3]. So, there is a number of biomass options that exist and its use in process industries may reduce the level of GHGs in the environment. The use of biomass energy is also proposed in low emission scenarios along with carbon capture and storage [4]. The GHGs increase gradually to 78% from the years 2000–2010 and concentrated on property impacts and liquid phase viscosity [5]. Sector-wise global CO_2 emissions by various sector are shown in Figure 3 for the years 2000–2005 [6]. At present, most of the people are using gasoline-based vehicles in the majority for their journey. According to data available, it

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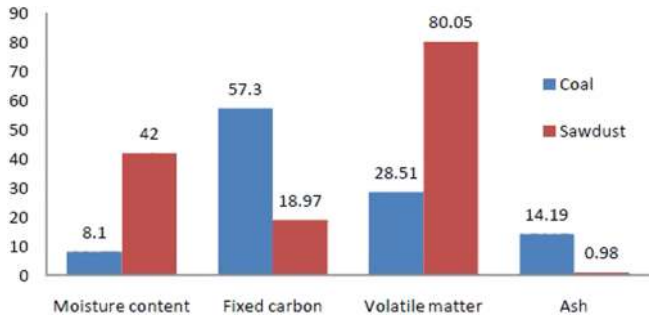

Figure 1. *Proximate analysis of coal and sawdust* [3].

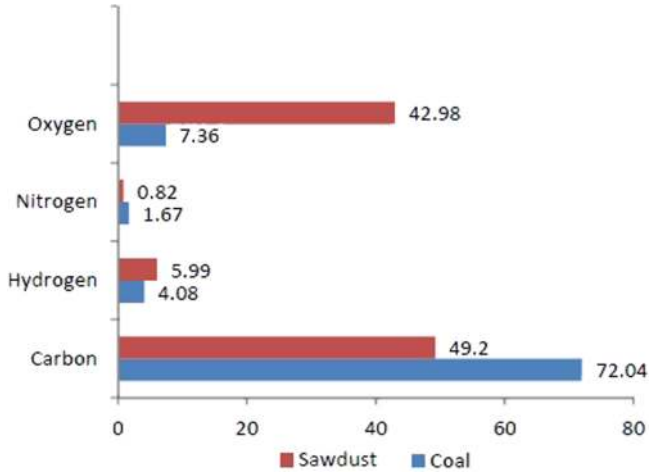

Figure 2. *Ultimate analysis of coal and sawdust* [3].

can be predicted that fossil fuel derivatives are utilized to create about 67% of the world's power, where, coal, flammable gas and oil contribute about 41%, 21% and 5%, respectively. Developing nations are in the race to acquire advanced technology to compete with developed countries resulting in atmosphere destabilization caused by expanding air convergence of CO_2 discharged amid the ignition of fossil fuel derivatives. So, CO_2 capture and its storage are highly required for other useful purposes. Broad research is going on around the entire world to handle these issues. Nowadays, a number of researchers are focusing their research on the adoption of various techniques to capture CO_2 in various process industries. Several techniques are available to solve this issue, but the major limitation is concerned with the requirement of higher energy and cost required to employ these techniques in process industries. The implementation of these techniques is not only consumed more energy but also reduces the efficiency of the concerned plant. However, environmental pollution can be reduced using these technologies in the process industries in the present scenario. Human being health and environmental pollution have a strong relation, so a reduction in GHGs is highly required for a human being healthy life. A comparison of per-capita CO_2 emissions in different countries is shown in Figure 4.

2 CARBON DIOXIDE REMOVAL TECHNIQUES

Carbon dioxide capture and sequestration is a process that comprises the set of various technologies to stripped out CO_2 from various process industries like coal and gas-based power plants. There are many technologies that can be applicable nowadays like a liquid solvent, chemical looping. Three basic techniques used to capture carbon dioxide viz. Pre-combustion, Post-combustion and oxy-fuel combustion are shown in Figure 5. The pre-combustion technique is used to reduce the level of carbon dioxide from the fuel before its combustion stage (see Figure 6). In post-combustion, carbon dioxide is captured after the fuel combustion in a closed circuit where no new medium replenished (see Figure 7). In order to separate CO_2, the stripper is used and the absorber is used to absorb it. The process takes place in different columns. The main purpose of oxy-fuel combustion is to remove inert gases from the combustion of flue gases. In this method, complete combustion is done by firing fuel with only oxygen. This oxy-fuel combustion process is shown in Figure 8. Amongst these techniques, post-combustion CO_2 capture using chemical process is most efficient and cost effective in comparison to other techniques used [2]. Its efficiency is around 90%. This process has more capacity to absorb CO_2 at less time. The changes in design parameters and with different column structure, the capture ratio using different solvents can be increased. So, this study is mainly based on the CO_2 capture using hybrid solvent.

3 CARBON DIOXIDE CAPTURE SCENARIO

At present, environmental pollution is a big challenge for the entire world. CO_2emissions in the atmosphere through process industries are increasing at a rapid rate. Nowadays population growth and its requirement to fulfill its daily needs is increasing and to satisfy these needs they used vehicles and household products and consumed electricity. According to the Paris summit, India committed that by 2020 they would reduce emission about 30–35% [13]. The CCS system (carbon capture and storage) is a rising technology to reduce greenhouse emissions. The various new approach and application are made to reduce GHGs according to Paris settlement on 4 November 2016 [14]. Due to this agreement, renewable energy resources are going to be promoted by various nation governments with the implementation of subsidy offered to customers. It will also help in to reduce emissions in the environment. The current report of the International Energy Agency stated that CO_2emissions are gradually increasing in the present scenario and is approximately 32.3 Gt occurring from fossil fuel. The various decision making and optimization models were reviewed to capture CO_2 [15]. The new approach to capture CO_2 has also been developed. In the recent developments, different types of hybrid process to capture CO_2, such as absorption type, adsorption type, membrane type, cryogenic type and hydrate chemical looping combustion,

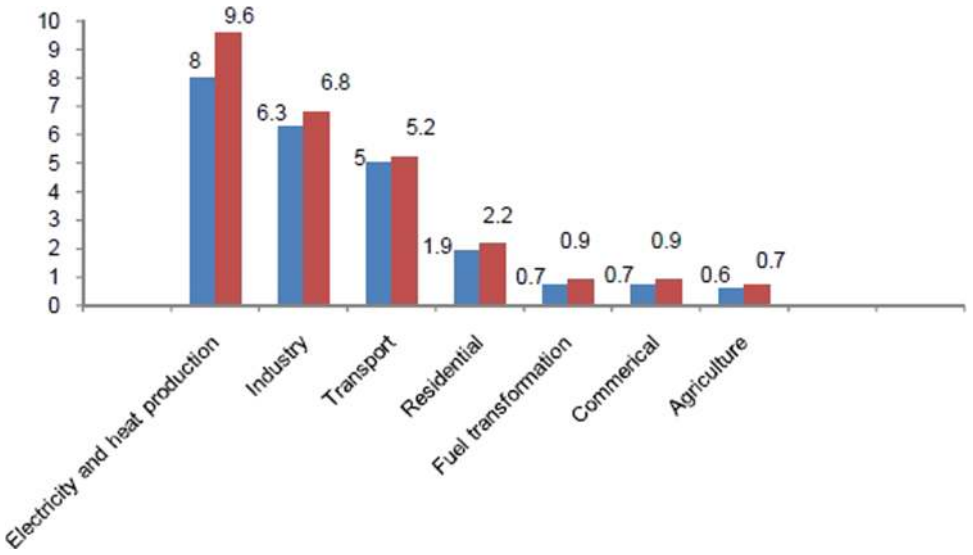

Figure 3. *Sector-wise global CO_2 emissions for the year 2000–2005* [6].

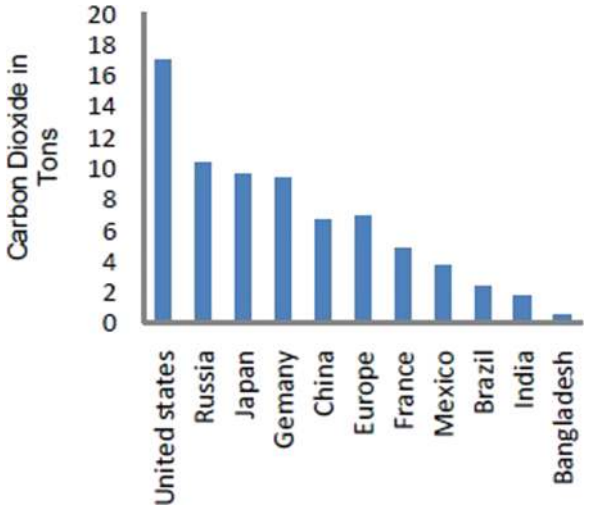

Figure 4. *Comparison of per-capita CO_2 emissions in different countries* [8].

has occurred [16]. A new system is evolved for the absorption of carbon dioxide using double absorption heat transformation, which increases the energy level to a certain limit to reach the required temperature. The Aspen Plus 11.0 simulation software is used to stimulate the temperature and flow of CO_2 [17]. The new technologies and the method of implementations are carried out using chemical absorption and scrubbing methods. Alternatively, power-intensive methods like membrane module for carbon dioxide separation in the latest years appears to be an aggressive replacement for standard chemical absorption [18]. In order to reduce the emissions, the project was made by the clean development mechanism to control these emissions. According to the Central Electricity Authority 2017 report, power generation capacity using various resources have been shown in Figure 9 to a capacity of 25 MW [19].

The optimal solution and important parameters like flow rate and gas rate etc are calculated by the Taguchi method to capture CO_2 from packed bed scrubber [20]. An experimental set-up was proposed for post-combustion CO_2 capture using a hybrid solvent [Monoethanolamine (MEA)-Methanol (MeOH)]. A comparison with MEA and MEA-MeOH solvent was compared and concluded that MEA-MeOH hybrid type solvent is better than MEA to capture CO_2 in process industries [21]. The regeneration performance of desorption of CO_2 from the hybrid solvent was proposed and a comparison was done with the packed columns [22]. The bio-inspired material (BMS) is used for carbon capture and storage (CCS) and is used in energy applications. A comparison with MEA and MeOH solvent was proposed and concluded that concentration and liquid flow rate have a large effect on system performance. The emission increases rapidly in the environment. The carbon dioxide capture process is used for solvent selected intensified in post-combustion [22]. A continuous bubble column scrubber is used to capture CO_2 gas by MEA and concluded that the gas flow rate and temperature are minimal [23]. A kinetic model was also used to capture CO_2 using post-combustion process. A comparison was done with MEA degradation in large scale [24]. The performance of potassium carbonate in the solvent absorption process was studied using Aspen simulation [25]. In this post-combustion process, regeneration heat was proposed by utilizing the chemical solvent and comparison was done with diethylenetriamine (DETA) and MEA [26]. The research has been done on the comparison of chipped retention and desorption with amine desorption using multiple fast screening methods [27]. The fluid stream rate was assumed to be greater with the wetted territory in CO_2 capture [28]. The carbon dioxide capture efficiency found to be greater than 85% with a low ammonia content up to 6 wt% [29]. The interfacial flows by the organized pressing of the segment using computational fluid dynamics have been analyzed to improve the numerical reproduction method [30]. A study also has been done to measure the impact of reaction parameters

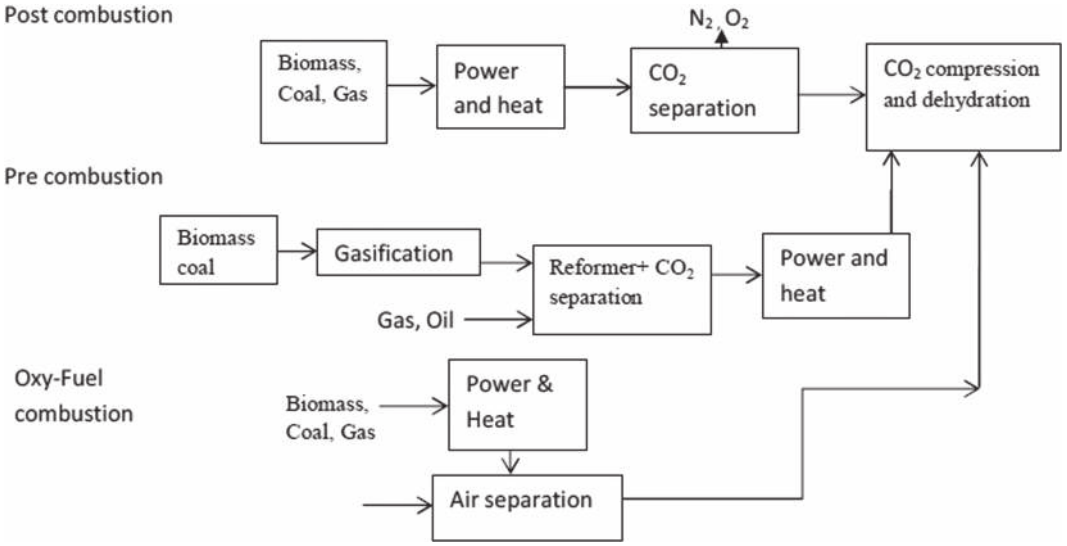

Figure 5. *Different CCS techniques* [9].

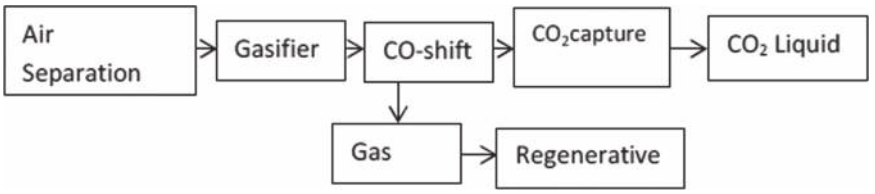

Figure 6. *Process of pre-combustion* [10].

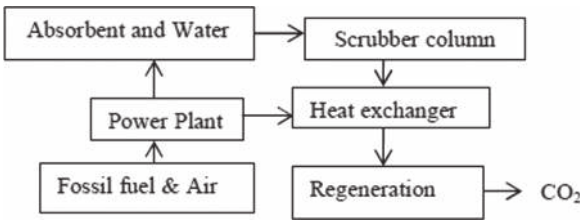

Figure 7. *The process of post-combustion* [11].

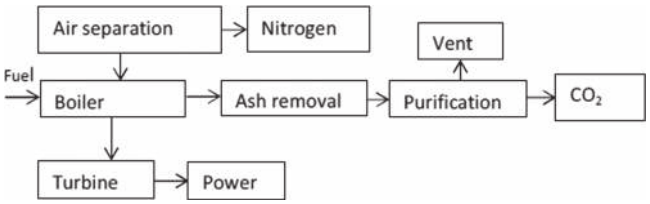

Figure 8. *Process of oxy-fuel combustion* [12].

on absorption efficiency, absorption process intensification along with simultaneous capture with another pollutant [31]. This study focused on the measurement of three characteristics of packing material contact area of liquid–gas, mass transfer and five different structured and random packing [32]. The CO_2 absorption in aqueous diethylene amine was also performed and compared with structured packing using artificial neural network [33]. The novel solvent was used to evaluate the performance of CO_2 absorption and compared it with the packed columns. It was observed that the gas stream rate has a greater impact on the absorption performance of CO_2 [34]. A study based on an efficiency penalty with carbon capture and storage system in coal-fired power plants was suggested. According to this study, it was concluded that the role of CO_2 scrubbing solver may play an important role and may increase the efficiency of power plants by 2% [35]. A study based on reactive absorption in a pilot plant using four solvent namely N-methyldiethanolamine, N-methyl propane di-amine, Amino-2-methyl-1-propanol and N-methyl-1,3-propane-amine was done and concluded that solvent 4 is promising one [36]. The activated carbons that are used as a separation medium to capture CO_2 seize are examined in term of absorption equilibrium and it avoids the regeneration process [37]. The development of technology from a few years are promising taking place in the application of the post-combustion process. Among all of them Ca-looping is one of the developed technology [38]. The BMS was used in various applications to protect the environment. It possesses excellent chemical and thermal stability [39]. The chemical looping is also going to be used by the researchers for carbon capture and it takes place with the gasification process [40]. Nowadays, CO_2 capture is also proposed with the new hybrid system integrated molten carbonate fuel cells using Aspen Plus software. The performance of the system is examined and compared with the coal power plant to capture CO_2 using MEA

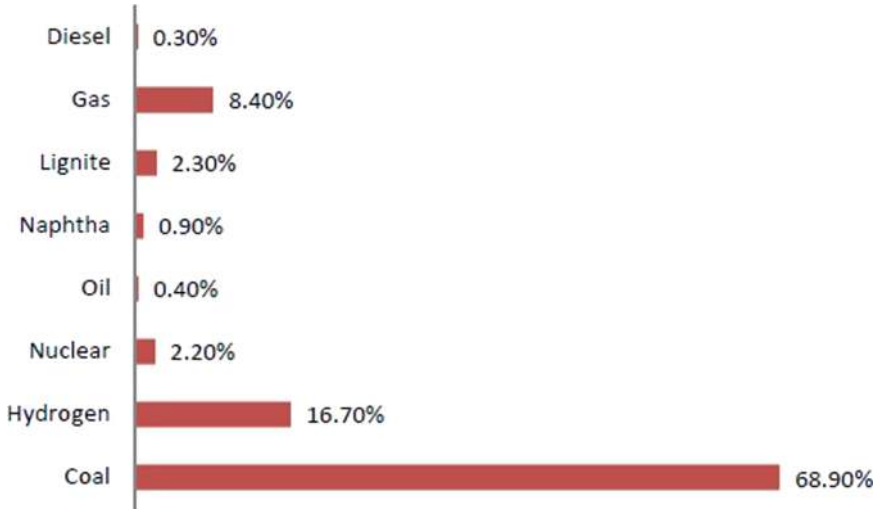

Figure 9. *Power generation capacity using various resources* [19].

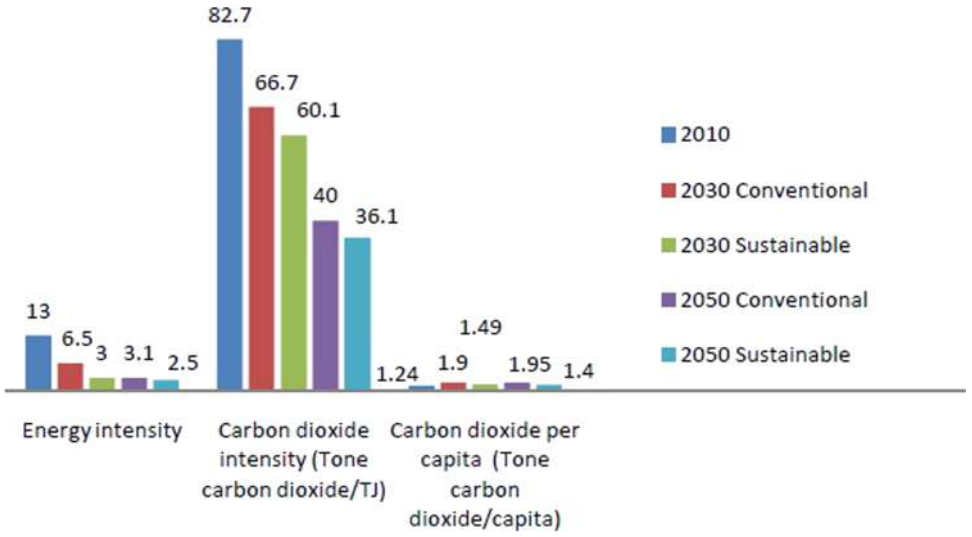

Figure 10. *CO_2 sustainable and conventional scenario up to 2050* [51].

solution [41]. Global warming is increased gradually so that new techniques are developed regularly to utilize CO_2 in the present scenario. For this purpose, CO_2 is captured and stored regularly in a certain tank [42]. The CO_2 capturing is achieved with three new technologies, mainly absorption, along with the time-based solvents, likely econamine and econamine FG+ and Ca-looping, and were evaluated with the power plants [43]. The solvent desorption was used to decrease the energy utilization in carbon dioxide capture using MEA solution to stimulate the process by HYSYS 3.2 software [44]. In this process, absorption takes place and divides the GHGs from emissions and numerical modeling provocating the post-combustion process [45]. There are several techniques to reduce the emission in the present scenario. Three new techniques evolved i.e. amine scrubber, chemical looping and oxy-fuel combustion [46]. The oxy fuel-fired plant performance was analyzed and the energy was stored. The solution is provided with a sensible heating temperature incorporated with ASU and a central processing unit for storage of energy [47]. The mainly occurring emissions are from coal. The power generation is around 60–80% from the coal [48]. In the pre-combustion process, the integrated gasification cycle is utilized to capture CO_2. The rate of flow can be examined by oxygen transport membrane [49]. The performance of CO_2 absorbed in the absorption column and certain dixon rings were used with DETA solution at a temperature ranging from 301–303 k. The solution was examined with standard solution MEA. The volumetric typical mass transfer took place in the absorption column into aqueous DETA and the column is packed with random packing like Sulzer DX-type packing with certain temperature ranging from 30–50°C [50]. CO_2 sustainable and conventional scenario to 2050 is shown in Figure 10 [51].

A new model (inexact carbon capture and storage model) to capture and store CO_2 has also been developed [51]. The most evolved technology for CO_2 capture is Amine scrubbing where purification of the solvents is highly required [52]. Investigated research on the ability of the carbon capture and storage (CCS) system implemented in power plant affect the cooling system and water utilization. The water utilization and demand for usage gradually increases from 2030 to 2050 and may create a problem in the future [53]. So, the new system is evolved in the capturing of CO_2 is the cryogenic process. This is installed in the underline of the power plant and examined with hybrid systems [54]. The study has also done on the cost of the post-combustion process in the supercritical power plant and natural gas power cycle power plant [55]. It was also concluded that the most reduced emission takes place in oxy-fuel combustion in comparison to post- and pre-combustion [56]. A solvent-based post-combustion solar assisted carbon capture was proposed for a coal-based power plant [57]**.** The gasification process has been made for the reduction of emission in nature. So, the waste reduction algorithm was used for gasification among the integrated gasification to capture CO_2. The new techniques evolved, like a gas–liquid solvent, chemical looping and iron-oxygen carriers. Among this chemical, looping was a promising one [58]. The experiment was examined for gases present in the atmosphere; these were absorbed in the absorption column with the packed structure to improve the capacity of absorption in the hybrid solution like MEA-MeOH [2]. A new technology (external cooling loop cryogenic carbon capture) was used to capture CO_2 for a coal fired with capacity 550 MW and captures nearly 85–90%. The stimulation was based on Aspen Plus software [59]. In the year 2050, the entire world should adopt one policy to decrease the emission coming out of various industries. It is the decarbonization of power storage and the different process is required to capture the carbon dioxide [60]. The hot potassium carbonate solvent was used in pre-combustion to achieve 90% of CO_2 capture [61]. Further, there is scope for amine based product to capture CO_2 [62].

4 CHALLENGES AND FUTURE SCOPE

It is already concluded through the literature that MEA makes a strong bond with CO_2 and requires a huge amount of energy to split it up. So, the process optimization is the primary goal to minimize the energy consumption and thereby a cost-effective process is highly required to enhance plant efficiency. The impact of the solvent used in the process on environment is also a big concern. In the near future, it is expected that the absorption process may be improved and challenges can be overcome for the experimental set-up in process industries to capture CO_2. Also, the improvement in hybrid solvent based CO_2 capture systems will increase the efficiency of process industries. The absorption efficiency of the process may be optimized using controlled operating factors. At present, the development of closed processes for removal and capture of CO_2 is highly required in process industries.

5 CONCLUSIONS

This paper discusses the use of various hybrid solvents in a packed column for CO_2 capture. The various techniques using hybrid solvent are compared in this study. It is concluded that MEA-MeOH shows better efficiency in comparison to aqueous MEA solution. Regeneration temperature is also found to be lower than an aqueous MEA solution. The study also concludes that MEA-MeOH performance cannot be enhanced by adding glycerol with it. However, a number of hybrid solvents have been studied; still, more research is highly required to minimize methanol vaporization.

REFERENCES

[1] Spigarelli BP, Kawatra SK. Opportunities and challenges in carbon dioxide capture. *Biochem Pharmacol* 2013;**1**:69–87.

[2] Viebahn P, Vallentin D, Höller S. Integrated assessment of carbon capture and storage (CCS) in South Africa's power sector. *Energies* 2015;**8**:14380–406.

[3] Fogarasi S, Cormos C. Assessment of coal and sawdust co-firing power generation under oxy-combustion conditions with carbon capture and storage. J Clean Prod 2016;**142**:3527–35.

[4] Vaughan NE, Gough C, Mander S *et al.* Evaluating the use of biomass energy with carbon capture and storage in low emission scenarios OPEN ACCESS evaluating the use of biomass energy with carbon capture and storage in low emission scenarios. *Environ Res Lett* 2018;**13**:1–11.

[5] Tan Y, Nookuea W, Li H *et al.* Property impacts on carbon capture and storage (CCS) processes: a review. *Energy Convers Manag* 2016;**118**:204–22.

[6] Tan LS, Shariff AM, Lau KK, Bustam MA. Factors affecting CO_2 absorption efficiency in packed column: a review. *J Ind Eng Chem* 2012;**18**:1874–83.

[7] Fogarasi S, Cormos C. Technico-economic assessment of coal and sawdust co-firing power generation with CO_2 capture. *J Clean Prod* 2014;**103**:1–9.

[8] Singh U. 2014. *Estimating the Environmental Implications of Implementing Carbon Capture and Storage in Indian Coal Power Plants*. IEEE 226–32.

[9] Chouliaras C, Kuipers B, Geerlings H. Carbon capture and storage (CCS) an assessment of the barriers and uncertainties for the full-scale deployment, pp. 1–78. *Master Thesis*. Erasmus University Rotterdam 2013.

[10] Nagy T, Mizsey P. Comprehensive study of carbon-dioxide capture from industrial gases with monoethanolamine-water mixture. *Ph.D. Thesis.*. Budapest University of Technology and Economics 2016.

[11] Garg A, Shukla PR, Parihar S *et al.* Cost-effective architecture of carbon capture and storage (CCS) grid in India. *Int J Greenh Gas Control* 2017;**66**:129–46.

[12] Wall TF. Combustion processes for carbon capture. *Proc Combust Inst* 2007;**31**(1):31–47.

[13] Krishna V, Vyas S. An innovative approach for carbon capture & sequestration on a thermal power plant through conversion to multi-purpose fuels—a feasibility study in Indian context. *Energy Procedia* 2017;**114**:1288–96.

[14] Vögele S, Rübbelke D, Mayer P *et al.* Germany's 'no' to carbon capture and storage: just a question of lacking acceptance. *Appl Energy* 2018;**214**:205–18.

[15] Frederick J, Tapia D, Lee J *et al.* A review of optimization and decision-making models for the planning of CO_2 capture, utilization and storage (CCUS) systems. *Sustain Prod Consum* 2017;**13**:1–15.

[16] Song C, Liu Q, Ji N *et al.* Alternative pathways for efficient CO_2 capture by hybrid processes—a review. *Renewable and Sustainable Energy Reviews* 2018;**82**:215–31.

[17] Wang D, Li S, Liu F *et al.* Post combustion CO_2 capture in power plant using low temperature steam upgraded by double absorption heat transformer. *Appl Energy* 2017;**227**:603–12.

[18] Wang Y, Zhao L, Otto A *et al.* A review of post-combustion CO_2 capture technologies from coal-fired power plants. *Energy Procedia* 2017;**114**:650–65.

[19] Sharma B, Singh N, Kumar R, Sharma K. 2017. *CO_2 Baseline Database for the Indian Power Sector*. Central Electricity Authority, Ministry of Power, Government of India.

[20] Chen P, Yang M, Wei C *et al.* Selection of blended amine for CO_2 capture in a packed bed scrubber using the Taguchi method. *Int J Greenh Gas Control* 2015;11–8.

[21] Gao J, Yin J, Zhu F *et al.* Integrated study of a hybrid solvent MEA-Methanol for post combustion carbon dioxide capture in packed bed absorption and regeneration. *Sep Purif Technol* 2016;**167**:17–23.

[22] Notz R, Prasad H, Hasse H. Post combustion CO_2 capture by reactive absorption: pilot plant description and results of systematic studies with MEA. *Int J Greenh Gas Control* 2012;**6**:84–112.

[23] Chen PC, Luo YX, Cai PW. CO_2 capture using monoethanolamine in a bubble-column scrubber. Chem Eng Technol 2015;**38**(2):274–82.

[24] Léonard G, Toye D, Heyen G. Experimental study and kinetic model of monoethanolamine oxidative and thermal degradation for post-combustion CO_2 capture. *Int J Greenh Gas Control* 2014;**30**:171–8.

[25] Smith K, Lee A, Mumford K *et al.* Pilot plant results for a precipitating potassium carbonate solvent absorption process promoted with glycine for enhanced CO_2 capture. *Fuel Process Technol* 2015;**135**:60–5.

[26] Zhang X, Fu K, Liang Z *et al.* Experimental studies of regeneration heat duty for CO_2 desorption from diethylenetriamine (DETA) solution in a stripper column packed with Dixon ring random packing. *Fuel* 2014;**136**:261–7.

[27] Luo X, Liu S, Gao H *et al.* An improved fast screening method for blended amine-based solvents for post-combustion CO_2 capture. *Energy Procedia* 2017;**114**:1848–54.

[28] Haroun Y, Raynal L, Alix P. Prediction of effective area and liquid hold-up in structured packings by CFD. *Chem Eng Res Des* 2014;**92**(11):2247–54.

[29] Li K, Yu H, Yan S *et al.* Technoeconomic assessment of an advanced aqueous ammonia-based postcombustion capture process integrated with a 650-MW coal-fired power station. *Environ Sci Technol* 2016, 2016;**50**(19):10746–55.

[30] Iso Y, Huang J, Kato M *et al.* Numerical and experimental study on liquid film flows on packing elements in absorbers for post-combustion CO_2 capture. *Energy Procedia* 2013;**37**:860–8.

[31] Zhang M, Guo Y. Rate based modeling of absorption and regeneration for CO_2 capture by aqueous ammonia solution. *Appl Energy* 2013;**111**:142–52.

[32] Mangalapally HP, Hasse H. Pilot plant experiments for post combustion carbon dioxide capture by reactive absorption with novel solvents. *Energy Procedia* 2011;**4**:1–8.

[33] Fu K, Rongwong W, Liang Z *et al.* Experimental analyses of mass transfer and heat transfer of post-combustion CO_2 absorption using hybrid solvent MEA-MeOH in an absorber. *Chem Eng J* 2015;**260**:11–9.

[34] Jie G, Jun Y, Feifei Z *et al.* Study on absorption and regeneration performance of novel hybrid solutions for CO_2 capture. *China Pet Process Petrochemical Technol* 2016;**1**:66–72.

[35] Goto K, Yogo K, Higashii T. A review of efficiency penalty in a coal-fired power plant with post-combustion CO_2 capture. *Appl Energy* 2013;**111**:710–20.

[36] Prasad H, Notz R, Asprion N *et al.* Pilot plant study of four new solvents for post combustion carbon dioxide capture by reactive absorption and comparison to MEA. *Int J Greenh Gas Control* 2012;**8**:205–16.

[37] Rashidi NA, Yusup S. An overview of activated carbons utilization for the post-combustion carbon dioxide capture. *Biochem Pharmacol* 2016;**13**:1–16.

[38] Martínez I, Grasa G, Parkkinen J *et al.* Review and research needs of Ca-looping systems modelling for post-combustion CO_2 capture applications. *Int J Greenh Gas Control* 2016;**50**:271–304.

[39] Kumar P, Kim KH. Recent progress and innovation in carbon capture and storage using bioinspired materials. *Applied Energy* 2016;**172**:383–97.

[40] Fan J, Zhu L, Hong H *et al.* A thermodynamic and environmental performance of in-situ gasification of chemical looping combustion for power generation using ilmenite with different coals and comparison with other coal- driven power technologies for CO_2 capture. *Energy* 2016;**119**:1–10.

[41] Duan L, Xia K, Feng T *et al.* Study on coal- fi red power plant with CO_2 capture by integrating molten carbonate fuel cell system. *Energy* 2016;**117**:578–89.

[42] Consoli CP, Wildgust N. Current status of global storage resources. *Energy Procedia* 2017;**114**:4623–8.

[43] Clarens F, Jorge J, Rafael M *et al.* Life cycle assessment of CaO looping versus amine-based absorption for capturing CO_2 in a subcritical coal power plant. *Int J Greenh Gas Control* 2016;**46**:18–27.

[44] Cenu V, Nori M, Darie G, *et al. Improvements in the CO_2 Capture Process by Optimizing the Solvent Regeneration Temperature*. IEEE 2016.

[45] Ben-Mansour R, Habib MA, Bamidele OE *et al.* Carbon capture by physical adsorption: Materials, experimental investigations and numerical modeling and simulations—a review. *Appl Energy* 2016;**161**:225–55.

[46] Atsonios K, Panopoulos K, Grammelis P *et al.* Exergetic comparison of CO_2 capture techniques from solid fossil fuel power plants. *Int J Greenh Gas Control* 2016;**45**:106–17.

[47] Arias B. An analysis of the operation of a flexible oxy-fired CFB power plant integrated with a thermal energy storage system. *Int J Greenh Gas Control* 2016;**45**:172–80.

[48] Akash AR, Rao AB, Chandel MK. Prospects of implementing CO_2 capture and sequestration (CCS) in the proposed supercritical coal power plants in India. *Energy Procedia* 2015;**90**:604–12.

[49] Vellini M, Gambini M. CO_2 capture in advanced power plants fed by coal and equipped with OTM. *Int J Greenh Gas Control* 2015;**36**:144–52.

[50] Fu K, Chen G, Sema T *et al.* Experimental study on mass transfer and prediction using artificial neural network for CO_2 absorption into aqueous DETA. *Chem Eng Sci* 2013;**100**:195–202.

[51] Wu Q, Lin QG, Wang XZ *et al.*. An inexact optimization model for planning regional carbon capture, transportation and storage systems under uncertainty. *Int J Greenh Gas Control* 2015;**42**:615–28.

[52] Wang T, Hovland J, Jens KJ. Amine reclaiming technologies in post-combustion carbon dioxide capture. *J Environ Sci* 2014;1–14.

[53] Schakel W, Pfister S, Ramírez A. Exploring the potential impact of implementing carbon capture technologies in fossil fuel power plants on regional European water stress index levels. *Int J Greenh Gas Control* 2015;**39**:318–28.

[54] Safdarnejad SM, Kennington L, Baxter LL, *et al. Investigating the impact of Cryogenic Carbon Capture on Power Plant Performance*. IEEE 2015.

[55] Rubin ES, Davison JE, Herzog HJ. The cost of CO_2 capture and storage. *Int J Greenh Gas Control* 2015;**40**:378–400.

[56] Azapagic A, Cue RM. Carbon capture, storage and utilisation technologies: a critical analysis and comparison of their life cycle environmental impacts. 2015;**9**:82–102.

[57] Qadir A, Sharma M, Parvareh F *et al.* Flexible dynamic operation of solar-integrated power plant with solvent based post-combustion carbon capture (PCC) process. *Energy Convers Manag.* 2015;**97**:7–19.

[58] Petrescu L, Cormos C. Waste reduction (WAR) algorithm applied for environmental impact assessment of coal gasification with carbon capture and storage. *J Clean Prod* 2014;**104**:220–35.

[59] Jensen MJ, Russel CS, Bergeson D *et al.* Prediction and validation of external cooling loop cryogenic carbon capture (CCC-ECL) for full-scale coal-fired power plant retrofit. *Int J Greenh Gas Control* 2015;**42**: 200–12.

[60] Hanak DP, Biliyok C, Manovic V. Rate-based model development, validation and analysis of chilled ammonia process as an alternative CO_2 capture technology for coal-fired power plants. *Int J Greenh Gas Control* 2015;**34**:52–62.

[61] Urech J, Tock L, Harkin T *et al.* An assessment of different solvent-based capture technologies within an IGCC e CCS power plant. *Energy* 2014;**64**:268–76.

[62] Sharma SD, Azzi M. A critical review of existing strategies for emission control in the monoethanolamine-based carbon capture process and some recommendations for improved strategies. *Fuel* 2014;**121**: 178–88.