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*Research Article*

# Baseline Creation for Carbon Dioxide Capture and Sequestration Plant using Monoethanolamine Absorbent

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**_Abstract_**

*This paper introduces a baseline for carbon dioxide capture and sequestration plants in which Monoethanolamine (MEA) is used as absorbent by providing practical outcomes from the pilot plant installed at Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal for the forward research in the field of carbon dioxide capture and sequestration (CCS).*

***Keywords:*** *Carbon capture, sequestration, energy penalty, CCS, post combustion, MEA, Amine based absorption.*

## 1. Introduction

In today's era of new and innovative ideas, everything requires electricity and the most common source of electricity production are coal based thermal power plants and these plants generate 60% of the total electricity around the world (Findings 2012). By this, another problem arises when we burn coal in these plants the exhaust gases are rich in carbon dioxide and thus they are the main cause of global warming (Cebrucean *et al*. 2014). But we can't eliminate/obsolete coal-based plants because these are the most convenient means of power production around the globe, that's why we go for clean technologies which reduce the emission of carbon dioxide in the open environment. The most common technology in the present day is carbon capture and sequestration (CCS) but this is new and growing technology and require more research to be finalized for implementation (Stanley 2015; Iea *et al*. 2007; Anon 2013). There are basically three approaches that can be implemented (Sethi *et al*. 2011):

(a) Pre - combustion
(b) Post - combustion
(c) Oxy - fuel combustion

## 2. Present scenario of Carbon dioxide emissions

By the valuation of the data we conclude coal based power plants are gradually increased, but on the same side gradual fall is noticed within last three decades. This data evaluates the need of carbon capture because the level of power generation is in increasing order. According to IEA- World Energy Outlook 2015 India today is home to one-sixth of the world's population and its third-largest economy, but accounts for only 6% of global energy use and one in five of the population – 240 million people – still lacks access to electricity, by this the warning bells are for India that the level of standard of innovation and technology is a prime need for making India compete with other developed and developing countries(Paper *et al*. 2016; Sood *et al*. 2016).

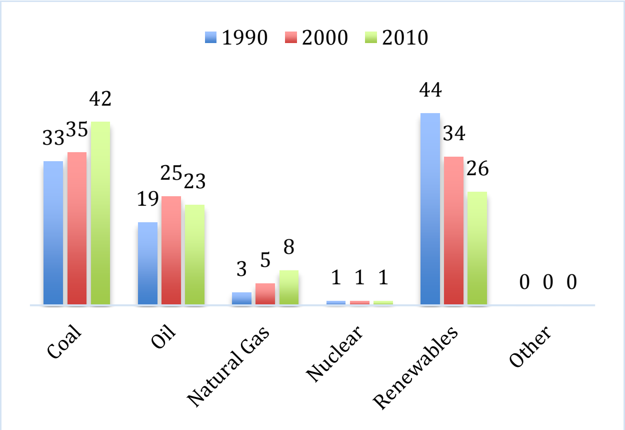
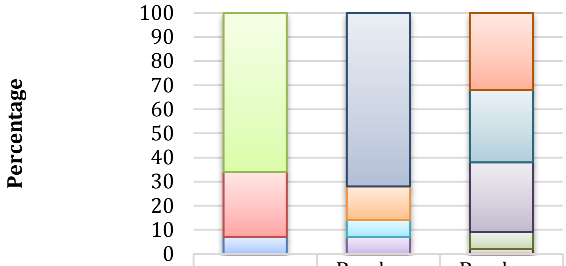



**Figure 1**: Indian Oil Mix : 1990, 2000, 2010 (Btoe: Billion tonnes oil equivalent)(Nations & Convention 2015)

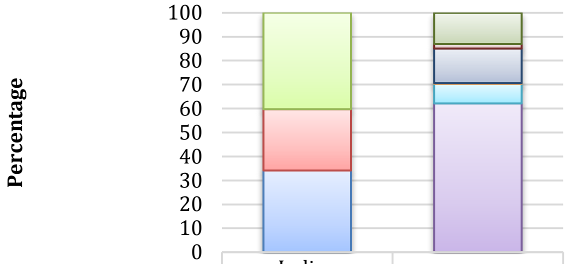
By considering this topic this paper is prime focused on creating a standard for researchers of India to come

*Corresponding author **Savita Vyas** is working as Assistant Professor; **J.S. Chouhan** as In charge Director and **V.K. Sethi** as Ex-Director (UIT), forward and make CCS successful. Approximately 68% of India's gross carbon dioxide emissions are from the energy sector. Around of which almost 48% of gross emissions are of electricity generation and rest major is from industrial sector.




| | Sectoral break-up | Break-up from energy sector | Break-up from industrial sector |
|---|---|---|---|
| Cement | | | 32 |
| Others | | | 30 |
| Iron and Steel | | | 29 |
| Food Processing | | | 7 |
| Ammonia | | | 2 |
| Electricity | | 72 | |
| Transport | | 14 | |
| Others | | 7 | |
| Residential | | 7 | |
| Energy | 66 | | |
| Industry | 27 | | |
| LULUCF | 7 | | |

**Figure 2:** India's $CO_2$ emission sector wise(Energy & Special n.d.; Iea *et al.* 2007)




| | Indian power production scenario sector wise | Total power production fuel wise |
|---|---|---|
| RES (MNRE) | | 13 |
| Nuclear | | 1.9 |
| Hydro (Renewable) | | 14.4 |
| Oil | | 0.3 |
| Gas | | 8.2 |
| Coal | | 62.1 |
| Private | 40.3 | |
| Central | 25.6 | |
| State | 34.1 | |

**Figure 3:** Indian power scenario(Total *et al.* 2016)

As the data in figure 2 shows the dominance of the energy sector and figure 3 data justify that maximum emissions are from coal-based power plants.

## 3. Process methodology

Carbon dioxide capture and sequestration plant were setup at Rajiv Gandhi Proudyogiki Vishwavidyalaya, Bhopal in 2008. The solvent used for capturing of carbon dioxide is Monoethanolamine (MEA) descriptive information about MEA is described in property table 1.

**Table 1:** MEA standard properties (Ethanolamines n.d.)

| Properties | Monoethanolamine |
|---|---|
| Formula | $HOC_2H_4NH_2$ |
| Molecular Weight | 61.08 |
| Apparent Sp. Gr. at 25/4°C | 1.0113 |
| ΔSp. Gr./ Δt at 10-80ºC | 0.0008 |
| Boiling point at 760 mm of Hg (ºF) | 171 (340) |
| Absolute Viscosity at 20ºC in cP | 21.1 |
| Absolute Viscosity at 30ºC in cP | 16.2 |
| Surface Tension at 25ºC (dynes/cm) | 48.3 |
| Solubility at 20ºC (% by wt.) | |
| In Water | Complete |
| Water in | Complete |

The percentage of carbon dioxide in flue gases from coal-based power plants lies between 7 to 8.5%, thus, the most suitable process is chemical stripping at atmospheric pressure.

Test run of plant was performed for over 1300 hours and data has been recorded over the time by data acquisition system (DAQ)

## 4. Chemical dosage

For MEA tank 2M MEA solution with 52 liters diluted to 300 liter

For scrubbing 30 kg of $NaHCO_3$ diluted (with water) to 300 liter

## 5. Background Study

Carbon capture is basically a gas purification process in which removal of gas phase impurities by vapor phase stream(Dubois & Thomas 2009; Øi 2007). According to that, in this pilot plant absorption into a liquid process is used for stripping of carbon dioxide from flue gas. As absorption refers to the transfer of a component of a gas phase to a liquid phase in which it is solute, by this a new problem arises which is related to the selection of solvent. This problem was firstly sorted by R.R. Bottom in 1930 develops alkanolamine as an absorbent for acidic gases(Richard n.d.). Thus, the other members of alkanolamine family show up in the market and they were also evaluated as an absorbent of $CO_2$ and $H_2S$. Thus, it is easy for us to select a chemical solvent for stripping of flue gases.

Flue gas properties based on solid fuel (coal), Constituents of coal under ultimate analysis (Anon n.d.).

Coal = carbon + hydrogen + sulphur + nitrogen + oxygen + moisture + ash

Since the detailed composition of the mineral matter is not generally known, it is assumed that

Mineral matter – ash = 0.1 ash
= water of hydration of minerals

### 6. Flue gas analysis

Flue gas was analyzed at doorstep of CCS pilot plant and the average data recorded is shown in table 1 as the flue gases are taken from a diesel generator which runs boiler and used for producing steam. The data was recorded by combustion gas analyzer.

**Table 1:** Flue gas analysis

| Particulars | Amount |
|---|---|
| $O_2$ (Oxygen) | 18.1% |
| Excess air | 7.30 λ |
| Gas temperature | 97.7°C |
| Air temperature | 42.7°C |
| Difference temperature | 55.0°C |
| Efficiency net | 86.0% |
| Loss net | 14.0% |
| CO (Carbon monoxide) | 11610 ppm |
| NO (Nitrogen oxide) | 51 ppm |
| $NO_X$ | 52 ppm |
| $C_XH_Y$ | 1.85% |
| $SO_2$ | 3569ppm |
| $CO_2$ | 14.1% |

**Table 2:** Comparative operating data for MEA, DEA and SNPA-DEA systems

| Gas Plant | A | B | B | C | D |
|---|---|---|---|---|---|
| Feed Gas<br>Mole % H2S<br>Mole % CO2 | 2.1<br>0.7 | 7.1<br>5.9 | 7.1<br>5.9 | 2.4<br>4.9 | 16.5<br>8.0 |
| Solvent<br>(% active reagent in water solution) | 18%<br>MEA | 15%<br>MEA | 24%<br>SNPA-DEA | 22.5%<br>DEA | 27.5%<br>SNPA-DEA |
| Solvent circulation (moles amine per mole acid gas) | 1.8 | 2.5 | 1.3 | 1.5 | 1.0 |
| Gallons solvent per mole acid gas | 74 | 123 | 68 | 84 | 44 |
| Reboiler steam<br>lb steam/gal solvent<br>lb steam/mole acid gas | 1.0<br>74 | 1.2<br>148 | 1.5<br>72 | 1.2<br>101 | 1.0<br>44 |

By taking reference of table 2, it is clear that MEA is economical and viable for capturing of carbon dioxide as compared from DEA and SNPA-DEA, another factor for selecting MEA as solvent is due to its easily availability in Indian market.

### 7. Working phase

The captured carbon dioxide was stored in MEA. Thus, by Henry's Law: The equilibrium concentration of molecular $CO_2$ in solution is proportional to their partial pressure in the gas phase(Sander 1999).

Ionization of water
$H_20 \rightarrow H^+ + OH^-$ (i)

Ionization of dissolved H2S
$H2S \rightarrow H^+ + HS^-$ (ii)

Hydrolysis and ionization of dissolved $CO_2$
$CO_2 + H_20 \rightarrow HCO_3^- + H^+$ (iii)

Protonation of alkanolamine
$RNH_2 + H^+ \rightarrow RNH_3^+$ (iv)

Carbamate formation
$RNH_2 + CO_2 \rightarrow RNHCOO^- + H^+$ (v)

The reaction (ii), (iii) and (v) are driven to the right by increased acid gas partial pressure. The reaction equilibria are also sensitive to temperature, causing the vapor pressure of absorbed acid gases to increase rapidly as the temperature is increased(Jansen & Ramirez 2014; Richard n.d.). As a result, it is possible to strip absorbed gases from amine solution by application of heat.

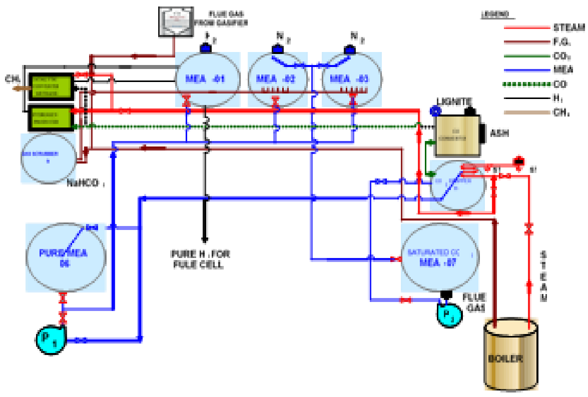



**Figure 4:** Process flow diagram of $CO_2$ capture and sequestration plant installed at RGPV campus(Sethi *et al.* 2011)

The installed pilot plant is based on post-combustion capture by the batch method. This plant also introduces the conversion of exhaust carbon dioxide into useful fuel by catalytic conversion because in India there are no such potential sites where carbon dioxide can be stored and this technology increases the plant approach to any site. This makes this research area versatile and economically viable for futuristic trends of carbon capture and sequestration.

Thus, such plants require energy input to convert zero baseline carbon dioxide to higher calorific fuel, by that means energy penalty is there and overall efficiency of the plant get reduced(Stanley 2015; Coal & Gas 2013). A progressive data was published by Dumitru Cebrucean showing the comparison diagram in figure 5.

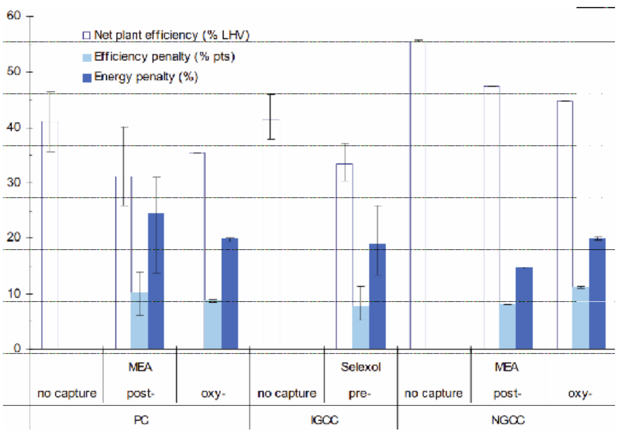



**Figure 5:** Efficiency of power plants with and without $CO_2$ capture(Cebrucean *et al*. 2014; Coal & Gas 2013)

The above chart clears that energy penalty is the main reason on which researchers have to focus to make CCS plant viable at the global level to mitigate GHG prone effects.

The highest value of $CO_2$ percentage shows that saturation of $CO_2$ level in MEA. When the level of saturation achieved the batch process is completed and the preferred MEA solvent (Rich in $CO_2$) is shifted towards regeneration tank where $CO_2$ is separated from MEA by applying external heat input by raising its temperature to 140-160ºC. Thus, $CO_2$ is achieved in gaseous form and the post treatment of $CO_2$ can be performed for conversion to fuel gaseous form and the post treatment of $CO_2$ can be performed for conversion to fuel.

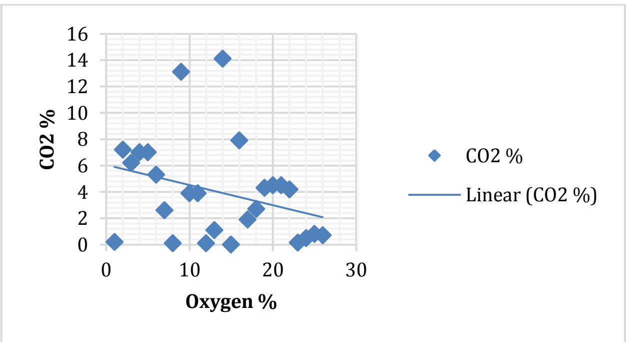



**Figure 6:** $CO_2$ concentration plots v/s oxygen percentage

## Conclusion

The paper concludes the target area of research for optimizing and reducing the energy penalty, also the field where these plants are to be implemented for abatement of carbon dioxide in the atmosphere. The other aspect of this paper also focus on the selection of absorbent on the basis of its carbon dioxide capture capacity and also opens the gateway for further development in the field of CCS. The overall run of plant also gives suitable data by which we conclude the overall efficiency of pilot plant 93%.

## References

Anon, Fuels_And_Combustion_3Rd_Edition.
Anon, 2013. Technology Roadmap.
Cebrucean, D., Cebrucean, V. & Ionel, I., 2014. CO2 Capture and Storage from Fossil Fuel Power Plants. Energy Procedia, 63(ii), pp.18–26. Available at: http://www.sciencedirect.com/science/article/pii/S1876610214018189.
Coal, B. & Gas, N., 2013. Cost and Performance Baseline for Fossil Energy Plants Volume 1 : Bituminous Coal and Natural Gas to Electricity. , 1(September).
Dubois, L. & Thomas, D., 2009. CO2 absorption into aqueous solutions of monoethanolamine, methyldiethanolamine, piperazine and their blends. Chemical Engineering and Technology, 32(5), pp.710–718.
Energy, W. & Special, O., India Energy Outlook.
Ethanolamines, D., Personal Care , (111), pp.1–2.
Findings, K.E.Y., 2012. Global Coal Risk Assessment : Data Analysis and Market Research. , (November), pp.1–76.
Iea, C.P., Oecd, J.E. & Iea, J.P., 2007. C Arbon C Apture and storage in the CDM. , (December).
Jansen, D. & Ramirez, A., 2014. Performance Requirements for CO2 Capture Technologies; How Realistic are Capture Cost Targets? Energy Procedia, 63(63), pp.45–52. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1876610214018207.
Nations, U. & Convention, F., 2015. India,
Øi, L.E., 2007. Aspen HYSYS Simulation of CO 2 Removal by Amine Absorption from a Gas Based Power Plant. , pp.73–81.
Paper, C. *et al*., 2016. Self-Energy Sufficient Village : A novel approach for modernizing and improving village life Self-Energy Sufficient Village : A novel approach for modernizing and improving village life. , (May).
Richard, K., Arthur Nielsen,
Sander, R., 1999. Compilation of Henry ' s Law Constants for Inorganic and Organic Species of Potential Importance in Environmental Chemistry.
Sethi, V.K. *et al*., 2011. A novel approach for CO2 sequestration and conversion in to useful multipurpose fuel. Journal of Environmental Research And Development, 5(March 2011), pp.732–736.
Sood, A., Vyas, S. & Singh, P., 2016. A novel approach for an energy efficient lighting system and reducing the power consumption A novel approach for an energy efficient lighting system and reducing the power consumption. , (November 2015).
Stanley, T., 2015. 7 IEA International CCS Regulatory Network Meeting.
Total, S. *et al*., 2016. All india installed capacity ( in mw ) of power stations. , pp.1–7.