Health, Environmental Effects, the Control of Emission from Power Plants and the Need for a New Emission Capture Technology.

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Abstract. It is well known that global warming is a major environmental concern and it is primarily caused by the release of pollutants (greenhouse gases) into the atmosphere. Electric power plants have been found to be major contributors of environmental pollution which results in health and environmental hazards. There have been several ongoing research on ways to curtail and capture emissions which have led to development of state-of-the-art technologies. However, these technologies have not been proven cost effective and as a result, they cannot be implemented on a global scale. Also, chemical based flue gas emission capture technology may lead to secondary pollutions. Prevailing cryogenic capture technologies show inadequacies due to cost ineffectiveness and its high energy demand. This paper focuses briefly on the effects of emissions from power plants on health and environment and talks about the need of a new single technology that captures each component of flue gas emissions without the use of chemical reagents and offers an affordable cost for global implementation for clean energy and environment.

1. Introduction

With increase in greenhouse gas emission, there is need to harmonize technological advancements with safe environmental practices. Pollutants have great influence on environmental quality and health on local, regional and global scales. However, current control measures for cutting down the continual emission rate are limited by exorbitant cost of implementation, operation and maintenance.

1.1. Health and environmental effects of emissions from coal and natural gas power plants.

The combustion of coal and natural gas in power plants [1] generates a number gases which are released into the atmosphere. They include: carbon dioxide ($CO_2$), steam, particulate matter, nitrogen oxides ($NO_x$) ($x = 0.5, 1, 2, 3$), sulfur oxide ($SO_2$), sulfur trioxide ($SO_3$), sorbent injection, ash, soot, mercury ($Hg, Hg^{++}, Hg$) and carbon monoxide. Sulfur oxide emission from power plants and cements factories poses various health and environmental threats which include: skin irritation, breathing difficulties, chronic bronchitis, eye irritation with corneal haze, pulmonary edema, psychic alterations, severe irritation from noise, throat, lungs and airway inflammation, mucus secretion, ozone –layer depletion, deforestation, corrosion of building materials and paints, acidification of waterways to the detriment of aquatic life. Both sulfur oxide ($SO_2$), sulfur trioxide ($SO_3$) form sulfuric acid droplets by reaction with atmospheric oxygen and moisture. These can form suspension of fine particles known as...
sulfate aerosols, which can alter the microphysical and optical properties of clouds and this plays a major role in the uncertainty of cloud models. Nitrogen dioxide (NO$_2$) emission results in formation of secondary pollutants such as ground level ozone/petrochemical smog, particulate matter and constituents of acid rain. It forms secondary particles called nitrates which causes haze and reduces visibility through the absorption of full spectrum of light. Exposure to nitrogen dioxide affects the human respiratory tract and increases vulnerability to, respiratory infections, coughing, wheezing, asthma, and lung cancer. Reacting with atmospheric oxygen and moisture, NO$_2$ yields nitric acid particles which can remain suspended in air and form aerosols. Both types of aerosols reflect sunlight and reduce visibility and cause a cooling affect. N$_2$O has a global warming potential of 298 – 310 [2] and atmospheric life time of 114 years. It leads to the formation of acid rain and is also a greenhouse gas that causes the depletion of the ozone layer. Mercury in flue gas from power plants can undergo reactions to transform it to extremely toxic compounds such as methylmercury (CH$_3$Hg) or dimethyl mercury CH$_3$HgCH$_3$ which are deposited on lakes, trees, and can be consumed by birds and fish [3]. Oxides of mercury are soluble in water, thus they can be absorbed by fish. Approximately 75 tons of mercury is emitted from coal power plants in the USA yearly, even after the removal of 30 tons of mercury by washing the coal before it is burnt. Exposure to mercury emissions results in mercury poisoning which has profound cellular, cardiovascular, hematological, pulmonary, renal, immunological, neurological, endocrine, reproductive and embryonic toxicological effects. Particulates pose various adverse effects on health and environment such as volcanic eruption due to changes in earth’s climate, drought, rainfall decline, global dimming, ocean acidification, asthma, lung cancer, cardiovascular disease, premature delivery, birth defects, vascular inflammation, atherosclerosis, etc. The earth’s climate system is undergoing aberrations as a result of carbon dioxide, methane, soot, nitrous oxide and other greenhouse gases being released into the atmosphere. They act as a blanket, trapping the heat from the sun and causing it to warm the planet. Some of the environmental and health effects of global warming are: melting of snow and glacier, drought, rise in sea level and coastal flood, heat waves, deforestation, increasing smog, asthma outbreak, malaria due to mosquito increase, presence of new pest, extinction of habitats such as coral reefs and alpine meadows, shrinking water supplies, changes in food supply, increasing effects of severe weather etc. Exposure of the human body to too much CO$_2$ creates acid imbalance in the lungs as there is more carbon dioxide absorbed in proportion to oxygen. This affects the internal respiration and the victim may experience symptoms such as asphyxiation, frostbite, kidney damage, coma, headaches, dizziness, nausea, increased heart rate, cardiac arrhythmia, memory disturbance, lack of concentration, restlessness, sweating, vomiting, eye and extremity twitching, visual and hearing disturbances (including hearing loss and ringing in the ears, photophobia, blurred vision, transient blindness), convulsion and death. According to a research paper by Mark Jacobson of Stanford University, anthropogenic carbon dioxide emission contributes not only to climate changes but also leads to about a thousand deaths and many more. Cases of respiratory illness and asthma in the United States per year with per degree Celsius rise in temperature is associated with air pollution. Globally the figure is 20,000 deaths per year, per degree Celsius rise. However, according to him the total global annual deaths due to environmental pollution is around 2 Million. World Health Organization (WHO: 2007) specified the premature death caused by CO$_2$ globally as 2 million (China -65000; India – 530,000; USA – 41,000)). The high cost of current technologies has limited the implementation of current technologies for controlling toxic gases from power plants and capturing industrial CO$_2$ emissions especially in developing countries.

Existing clean energy technologies for removal and control of toxic emissions from coal combustion. Research on pollution and emissions from power plants has led to the development of technologies used in capturing and reducing emissions. Some of the current technologies for control of pollution (except carbon dioxide and carbon monoxide) used particularly in coal power plants include: (i) electrostatic precipitators (ESP), (ii) fabric filters, (iii) mechanical collectors, (iv) venturi gas scrubbers, (v) selective fuel switching, (vi) selective non catalytic reduction (SNCR) and selective catalytic reduction (SCR), (vii) wet flue gas desulfurization, (viii) dry FGD utilizing spray dryer absorber (SDA) [4], (ix) circulating dry scrubber (CDS), (x) dry sorbent injection (DSI), (xi) activated carbon injection technique, (xii) enhanced wet technology, (xiii) K-fuel technology. In this paper
discussions are made on the costs of implementing and operating some of these technologies. We may briefly describe them, and discuss also, the need for a cost effective technology that can capture all the components of flue gas.

1.2. Cost involved in using Flue Gas Desulfurization (FGD) systems for SO\(_2\) removal.

Typically, the estimated cost of building a new coal power plant is £800 million, the installation of FGD systems incurs an additional cost. Between the years 2008-2010, installation cost of FGD equipment was estimated to be $150/kW (that is $150 million for a 1000 MW coal power plant) which is about 11% of the cost of setting up the plant itself. Also, the FGD system is found to cause a reduction in the net power generation efficiency of about 2 to 4% due to increased parasitic load. It was predicted in 2009 that at the end of the next 12 years, about $200 billion will be spent in introducing FGD systems to new and existing combustion units [5]. SO\(_2\) removal cost which depends on the sulphur content of the fuel, power plant capacity, etc. ranges from $200-$2000 per ton. Using scrubbers, it costs about $50,000/MW for 70% removal and $250,000 for 95% removal [3]. The costs of wet and spray FGD systems for various power plant capacities [6] are displayed in table 1 below.

| Scrubber type | Unit Size (MW) | Capital Cost ($/kW) | O & M Cost ($/kW) | Annual Cost ($/kW) | Cost per ton of Pollutant removed ($) |
|---------------|---------------|---------------------|-------------------|-------------------|-------------------------------------|
| Wet >400      | 100-250       | 2-8                 | 20-50             | 200-500           |
| Wet <400      | 250-1,500     | 8-20                | 50-200            | 500-5000          |
| Spray >200    | 40-150        | 4-10                | 20-50             | 150-300           |
| Spray <200    | 150-1,500     | 10-300              | 50-500            | 500-4000          |

*(EIA, 2002; EPA, 2002; Srivastava 2001 [7].)

From the above table, the cost of using FGD is high for smaller power plants.

1.3. Costs involved with chemical method for control of NO\(_x\) using chemicals/ reagents.

The installation cost of SCR is approximately $200 per kW and NO\(_x\) removal cost per ton ranges from $1,400 to $3,000. This is dependent on the power plants size [8,9]. Reports from air pollution control technology factsheet estimate the cost of NO\(_x\) removal per ton to be:

i. Industrial coal boiler: $2,000 - $5,000
ii. Industrial oil, gas and wood fired boiler alongside an electrostatic precipitator for particulate matter: $1,000 - $3,000
iii. Large gas turbine: $3,000 - $6,000
iv. Small gas turbine: $2,000 - $10,000.

As a result of application of modern emission controlling technologies for SO\(_2\) and NO\(_x\) the emissions are gradually decreasing in USA but not in India as can be seen in the data provided in the Appendix.

1.4. Cost of mercury removal.

Using ACI, the US Department of Energy estimated the cost of mercury removal to range from $37,500-445,000/lb. mercury [3] and the cost of using carbon injection to range from $25,000-$70,000/lb. mercury extracted. The EPA estimated the cost of 90% removal using carbon injection to range from $5000- $28000/lb. mercury [10]. All of which are quite expensive. Also, it is said that these removal costs can increase subsequently the price of electricity (per kWh) by 0.1 to 0.8 cents [11-12]. It is also noteworthy that in the ACI, the fly ash will contain carbon and mercury (making the fly ash unsalable) which is very hazardous and its disposal incurs additional costs to electricity production.
generation. However the figures listed above did not include disposal costs nor loss of income from the sale of fly ash.

Current techniques of capturing Carbon dioxide

1.5. Post-combustion.
This process involves the cooling of emitted CO$_2$ gas from power plants and industries, the cooled gas is afterwards bubbled through a vertical column absorber packed with solvents such as ammonia or amine which can preferentially absorb the CO$_2$ (nevertheless, researchers are still in search of more efficient solvents). The amine solution (MEA) is dropped from the top of the vertical column (in some systems) and the reaction takes place on the beads, the reaction between the MEA(R-NH$_2$) and the CO$_2$ in the flue gas forms a weakly bonded but stable compound called carbamate. Challenges arising from this technique includes amine losses due to thermal or oxidation degradation. Oxidation degradation can be controlled using oxygen inhibitors however thermal degradation is still a cause for concern. It occurs predominantly during the regeneration reaction where high temperature is experienced in the packing column [13-14] (this gives an explanation for 20-30% of all amine losses) [15]. Also, degradation products such as nitrosamines and nitramines which are highly soluble in water [16] are shown to be geno-toxic and possible carcinogens [17]. Available data on the 23 nitrosamines that may form during amine based capture has been studied and 2 out of the 23 have been declared probably carcinogenic to humans by the International Agency for Research on Cancer, while the 7 are classified as possibly carcinogenic to humans. Not much data is available on nitramines but they are likewise suspected to be carcinogens. The presence of oxygen or oxidizing gases in flue gas can corrode amine systems. Corrosion rates can be reduced by employing corrosion inhibitors, lowering the concentration of MEA, using appropriate materials for the construction of the amine system, and using temperature controls [18]. All of which contribute additional costs to the amine capture system.

1.5.1. Installation cost for amine technology.
The cost of scrubbing CO$_2$ is 25-40% as much as the total output cost of electricity which is very expensive; especially for older plants operating at 35% efficiency or lower [19]. Husbye et al [19-21], presents a cost analysis of amine based CO$_2$ capture, according to him, it costs about 750 euros per ton for a flue gas with 2.5% CO$_2$ concentration, while for 20.5% CO$_2$ concentration; it decreases to 375 euros per ton. Even for a 90-100% capture from industrial plants, the cost is still quite high. The power plant design by Choi et al shows that the installation cost for a plant with total removal capacity of 2820 tons of CO$_2$ per day is $114 million [20]. Also, the carbon capture and storage (CCS) plant at Mongstad in Norway has an investment cost of NOK 20-25 billion [22] which is equivalent to $2.4 to $3 billion.

1.6. Metal Organic Frame (MOF) Work Technology.
It involves filling a large column with MOF balls and passing flue gas through one end of the column and receiving the flue gas with significantly less CO$_2$ out of the other end. The process is repeated a few times on the exit gas stream in order to ensure maximum adsorption of CO$_2$. Thereafter, the CO$_2$ is heated to a climacteric temperature to release the CO$_2$ which is obtained in a fairly pure form. The released CO$_2$ is afterwards compressed and transported to its required destination. Almost 220MW power has to be diverted for the capturing of CO$_2$ using MOF column in a 500MW plant, leaving only 280-300MW at most for use. It costs about $2.9 billion to fill the columns with MOF balls and these costs more than 1000 times the cost of current amine based technology. Asides the capital cost (which is very high), the operational costs is about 3 times the cost of the most cost effective amine based technique [23]. This technique is still in its research stage and has not been commercialized. At this current stage of development, it is also not practicable in developing countries. Other technology applied in cutting down emissions includes carbon sequestration, the use of oxyfuels, breaking down of lignite coal to syngas which is then used as a fuel in power generation, the Climeworks capture device which is designed to capture CO2 directly from the air (costs about $1000 per ton of CO2), etc.
All of these have their individual economic and operational concerns. Analysis by Jeffrey Rissman and Robbie Orvis [24] shows that coal plants equipped with current CCS are almost three times more expensive than onshore wind power and more than twice as expensive as solar photovoltaics (PV). Though these costs will decline with continuous research and development, the potential for cost improvement is limited. Coal with CCS will always need significant subsidies to compete economically with wind and solar.

Global costs of carbon capture and storage.

The capital cost of the CCS facilities, even with latest technological advancements is still in the order of billions of dollars- consequently it is not affordable and practicable on a large scale in many countries yet (especially, developing countries like India). Kemper County employed new coal-gasification technology which is reported to have been commissioned after a total expenditure of about $US7.5 billion. The initial cost of the 500 MW power plant project was $1.8 Billion. After which the coal giant Southern Company (SC) announced in June 29, 2017 its plans to discontinue work on the carbon capture segment of its power plant in Kemper, Mississippi. SC has decided not to use the amine based technology to capture the plant’s greenhouse gas emissions. Due to the addition of CCS facility to the Boundary Dam, the planned cost shot up terrifically, however, the high costs were attributed to many other factors aside CCS. The world’s second largest “Petra Nova CCS Project” located in Thompsons, southwest of Houston, Texas commenced in 2010. This was preceded by the announcements made by the U.S. DOE. The project commenced at a cost of $1 billion. Although these projects have made somewhat progress in capturing CO₂ emissions, the impact is very minute when viewed on a global scale and these technologies cannot be implemented worldwide due to their heavy costs. Therefore, there is a need for better and cost efficient technology that can capture components of emissions, particularly CO₂ and store the capture product in a cost effective manner.

Need for a new emission capture technology.

Due to continuous increase in the demand for energy, and the inability of renewable energy technologies to effectively replace the use fossil fuels fully, the world will continue to face increasing release of emissions into the environment, unless controls are put in place to combat it. Emissions such as mercury has the ability to travel long distances thus its effect can be experienced on a global scale. In order to curtail the effects of these emissions (such as a global warming, which requires more than 50% carbon capture to have significant impact), the need for emission capture technologies cannot be overemphasized. However, as discussed earlier, current emission control technologies are very expensive are not practicable in developing countries. Some technologies like the amine based carbon capture result in harmful secondary pollution e.g. nitrosamines and nitrarnines which are found to be possible carcinogens. Therefore, there is need for a new single technology to capture each component of the emissions cost effectively, without use of any chemical reagent. The technology should be such that a portion of the captured components would pay for the capture cost and ensure that the storage of the captured components is much easier and cost effective, compared to the current methods of transporting captured CO₂ through pipe lines to empty underground coal or oil field. If such a technology is effectuated in power industries, it will eliminate pollution and its resulting adverse effects on health and environment. In the second article “PATHWAY(S) TO CLEAN AIR, MITIGATION OF CLIMATE CHANGE AND 100% RENEWABLE/CLEAN ENERGY TRANSFORMATION” [25] we shall briefly discuss such technology, which has been researched in depth theoretically and discovered to be the most cost effective, and energy efficient technology that can achieve 100% capture of emission in a way that each component can find industrial use. The procedure is based on a novel cryogenic capture technique using innovative ideas such as generating auxiliary power using the heat of the flue gas. In this new technology the nitrogen, which constitutes nearly 70% of the flue gas is cooled to a few degrees above its boiling point. This is used to fractionally cool the incoming flue gas, after being subject to specified pressures and the ashes, oxides of mercury etc. are separated by using existing technologies and special ceramic filters. The flue gas is expanded at several stages and cooled further. The process separates individual component of flue gas into liquid form while the CO₂ is separated in the form of dry ice. The new technology is being patented by the Dilip K. De (Provisional US patent (# 62593828 filed on Dec. 31, 2017. Non-provisional patent #15915007, dt. March 7, 2018)). Only electrical energy with fixed amount of water
is used in this capture technology. The net energy cost estimate for capturing 1 ton of CO$_2$ is about $8 per ton, if auxiliary power is generated using the heat of the flue gas and about $25 per ton, if auxiliary power is not generated. However, these cost estimates include capture of all the affiliated pollutants along with each ton of CO$_2$ capture. Thus the technology will be much more cost effective than any existing technology.

Appendix

![Graph A1](image1.png)

Figure A1 shows Correlation between daily maximum temperature minus the optimum temperature, and relative mortality for people aged over 65 years. [26]

![Graph A2](image2.png)

Fig. A2 [28] Shows the sulphur dioxide emissions in USA from coal fired electric power plants during the period 2006-2015. It shows that the emission declined gradually over years. It is primarily due to expensive emission control technologies put in some of the plants. However, these technologies cannot be implemented on a global scale due to heavy installation and operation costs.

![Graph A3](image3.png)

Fig. A3 [29] The satellite data from NASA shows significant decline of SO$_2$ in 2016 China, compared to that in 2005 in China. This can be attributed to the emission control technologies in China.

![Graph A4](image4.png)

Fig. A4 [29] NASA satellite data shows significant growth of SO$_2$ emissions from power plants in India in 2016 relative to that in 2005. Available emission control technologies cannot be afforded in developing such as India

| NO$_x$ Emissions | All Sources | Power Plants | Power Plant % | Coal Plants | Coal Plants as % of Power Plants |
|------------------|-------------|--------------|---------------|-------------|---------------------------------|
| Illionois        | 1,112       | 279          | 25.1          | 268.4       | 96.2                            |
| Indiana          | 860.3       | 350          | 40.7          | 349         | 99.7                            |
| Michigan         | 859.9       | 207          | 24            | 183.6       | 88.7                            |
| Minnesota        | 487.6       | 87.2         | 17.9          | 83.8        | 96.1                            |
| Ohio             | 1,149       | 431.4        | 37.5          | 429.5       | 99.5                            |
| Wisconsin        | 506.8       | 109.6        | 21.6          | 106.5       | 97.2                            |
| Total            | 4,975.6     | 1454.3       | 29.4          | 1420.9      | 97                              |

Table A1 [30] Nitrogen oxide emissions in six Midwest states in 1999 (tons per year)
The table A1 above shows that coal power plants are key contributors in the release of NO\textsubscript{x} emissions into the environment.

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