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RESEARCH ARTICLE

COAL GASIFICATION AND RECENT ADVANCES IN CARBON REDUCTION EMISSION: A REVIEW

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Abstract

Global warming and the change in the climate with limited availability and increase in the cost of energy are posing challenges for the sustainability of the global digital- economy. As due to the increase in energy consumption the carbon dioxide emission has increased several times especially in the developing countries which are undergoing the development of industrialization. Coal gasification has emerged out to be as a clean coal technology, it utilizes coal more effectively for power generation thus, meeting the stringent environmental regulations. Coalgas technologies are bound to be adopted for electricity generations which in turn reduces the level of CO₂ emission and finally in the reduction of global warming. In addition to the this, various technologies are used in the reduction of the carbon emission to the atmosphere like carbon capture, geoengineering schemes, biological carbon dioxide mitigation, reduction techniques adopted by various industrial, building and agricultural. Wide range of literature is available on the carbon emission reduction and in this paper an attempt has been made to compile about the various technologies used in the reduction of carbon dioxide emission.

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Introduction:-

Global warming is one of the greatest threats to human survival and political stability. The main factor contributing to global warming is the increase of global carbon emission¹. A global surface warming limit of 2 degree Celsius or below has been adopted by more than 100 countries as a guiding principle for mitigation efforts to reduce climate change risks, impacts and damages. In order to attain 2⁰C the carbon dioxide concentration in the earth's atmosphere should be stabilized at least on a 400- 500 ppm level with the probability of 50- 75%. Unfortunately, the average carbon dioxide concentration was 385 in 2007, more than 400ppm in 2014 and is still growing and thus, is a matter of concern². Globally, the expansion in carbon emission is basically from energy supply, transport and industry, while residential and commercial buildings, forestry, deforestation and agricultural sectors also contribute substantial quantities of CO₂, methane and other greenhouse gases to the atmosphere¹.

However insufficient knowledge of carbon dioxide leads to large uncertainties in future climate predictions because the observation of CO₂ is spatially and temporally limited on the globe³. satellite measurement is one of the most effective approaches to monitor the global distributions of greenhouse gases at high spatiotemporal resolution and is expected to improve the accuracy of source and sink estimates of these gases⁴.

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Energy demand is increasing worldwide due to increasing world population and standard of living⁵. Due to the continuous depletion of oil and natural gas the future demand of energy is coal dependent as coal is probably the most abundant fossil energy of the world. Various drawbacks such as lower efficiency and carbon dioxide emission can occur due to the conventional utilization of coal for power generation^{5,6}. In order to overcome this, implementation of clean coal technologies, which include advanced gasification systems, as well as carbon capture storage and utilization techniques are used and many approaches are also designed in a way to reduce the carbon emission and mitigate the impact climate changes and are thus discussed in detail.

The usage of coal in the energy production needs the execution of well organised technologies to meet the dual targets of increased energy efficiency and also minimise the carbon footprint. Various attempts are being made to advance the gasification systems with lower units of emission of CO₂ and other contaminants, and pliable in-terms of product generated⁷. Coal gasification is the thermochemical process which produces electricity with higher conversion efficiency than conventional power methods with significant reduction in the emission products like CO₂, NO_x, SO_x and particulate matter i.e. conversion of carbonaceous feedstock into carbon monoxide, hydrogen and other byproducts⁸. The gasification technologies have been executed for several decades with entrained flow, fluidized bed and moving bed reactors and comprised the coal as the major feedstock⁹. This gasification reaction takes place inside the gasifier in which limited amount of oxygen is passed, the carbonaceous fuel reacts with this oxygen and steam and at elevated temperature higher than 750⁰ C and pressure of order of 30 bar to produce syngas and other by-products. This syngas is then used for the production of the energy⁸. Temperature is the controlling parameter in the endothermic gasification reaction, particularly with the carbon dioxide as the gasification agent⁸, as it makes the system more beneficial in-terms to diminish the greenhouse gas emissions and thus, increase the energy efficiency¹⁰. However, the presence of various inorganic species in the gasifier puts both positive and negative effect in steam gasification of coal in the fluidized bed at medium to low (650- 800 degree Celsius) temperature and at atmospheric pressure¹¹. Co-gasification of coal with waste biomass is also considered to give the favourable results of lowered carbon footprints, and potential synergy effects in-terms of process efficiency and product quality^{12,13}. The performance of gasification depends on the selection of suitable gasification technology which should match with coal properties and operating conditions. It is also affected by several parameters such as operating conditions like pressure, temperature and medium during pyrolysis and gasification, rank of coal and char structure¹⁴. Akanksha Mishra et.al in 2017 conducted the study on the effect of partial pressure on the gasification behaviour Jama coal (natural coke). The study concluded that by varying the partial pressure of CO₂ in the mixture of CO₂ and nitrogen showed the effect of partial pressure of CO₂ on the gasification of Jama coal and thus, the gasification is increased by increasing the partial pressure of CO₂⁵. Thus, the final objective is to select the best and most appropriate inorganic species for the said process which in turn thus reduces the carbon emission.

Carbon emission reduction in-case of agricultural sectors. The agricultural sector contributes the sufficient amount of methane and carbon dioxide emissions, which in-turn can be from mushroom production sectors, Lucerne production sector, the livestock sectors, fisheries, cotton production sector etc¹. Ebrahimi and Salehi in 2015 conducted a study which concluded that the carbon emission of mushroom production were 23 and 32 kg CO₂-eq ha⁻¹ respectively for efficient and inefficient units and finally carbon emission from mushroom production was reduced to 27% in the efficient units as compared to inefficient units¹⁵. Visser et al in 2015 conducted a study in the cotton production sector and concluded that if the waste is broadcast and incorporated in the soil there will be the 27% reduction in the farm carbon emission and 15% reduction in the whole farm to ship carbon footprint¹⁶. Wang et al. in 2015 conducted a study in which a remote sensing approach was used to assess the effect of China's land use change on carbon emission and thus, concluded in half if the province of China are benign overall in terms of ecosystem circulation and there is also fairness, economic efficiency of carbon emissions during 2000- 2010¹⁷.

Carbon dioxide reduction by assessment of carbon capture, utilization and storage (CCUS): Energy conservation alone cannot halt the build-up of carbon dioxide, so researches and ways are made to capture and store the gas¹⁸. Presently increase in energy production is closely associated with rise in fossil- carbon emissions. Therefore, carbon capture, utilization and storage (CCUS) to reduce CO₂ levels in the atmosphere is being addressed around the world. Currently, CCUS is still in the early stages of technological development and still requires the development in-terms of reduction of cost, increased efficiency, environmental safety and social acceptance¹⁹⁻²². There are three major approaches for carbon capture and storage: pre-combustion capture, oxyfuel process and post combustion capture²³, further CO₂ emission capture can also be done by biological CO₂ mitigation which is usually done by a group of fast growing micro-organisms i.e. micro-algae as its carbon dioxide capturing capacity is 10-50 times larger than a normal plant and thus, growing on the high concentration of CO₂¹⁸. Various world-wide projects have tried different

industrial approaches adopted to carbon capture. Aqueous-ammonia and monoethanolamine are the popular solvents used to capture and separate CO₂ from the flue gas stream. Additionally, Gopalakrishna in 2015 suggested the use of hydrotalcite like compounds and metal-based oxides for CO₂ capture²⁴. Pre-combustion capture involves the production of synthesis gas (syngas, fuel gas) which produces H₂ at different intervals than that of CO₂ and is thus known as hydrogen economy. Oxy-fuel combustion results in a flue gas composed mainly of H₂O and high CO₂ concentration in output stream. The major advantage of this type of carbon capture storage is easy separation of exhaust gases. The post-combustion has the higher CO₂ concentration after combustion from the flue gases, the major advantage of this type of combustion is that it offers more flexibility without changing the combustion cycle²³. Zhu et al. in 2015 conducted a comprehensive evaluation of CCUS's potential for future development and contribution to carbon emission reduction in China with a regional energy-economy-environment integrated assessment model and concluded that CCUS will take about 30 years before effective systems for carbon emissions reductions are found although there will be development of CCUS after 2040 its contribution to emission abatement will always be lower than that of energy substitution²⁵.

Carbon dioxide emission reduction can also be done by a process known as geo-engineering (climate engineering) which artificially cools the earth and has become the effective means of mitigating global warming. Most of its schemes are based on the increase of planetary albedo which in turn are of low cost and reduce the temperature anomalies due to carbon emission²⁶.

The Inter-governmental Panel on climate change reported that 40% of Global energy consumption done by building sector and contributes a quarter of global total carbon emission. Kim et al. in 2015 introduced the CO₂ cost and schedule management system for building construction projects by using the earned value management theory, which evaluates the accurate forecasting of the project performance so it can minimise the CO₂ emission²⁷. Similarly, Wang et al. in 2015 proposed the method which estimated the total carbon emission from the various steps of the construction processes and concluded that 80% of CO₂ emissions generated from the production of raw materials¹⁷. In-order to reduce the emissions the main focus should be put on material production processes in which the low carbon fossil systems are preferred.

Carbon emission reduction in industrial sectors: carbon emissions are generated in almost all activities of industrial sectors, emissions continue to rise, necessary improvements in industrial practices are lagging behind (Stal, 2015)²⁸. The CO₂ reduction targets in iron and steel industry is that more attention must be paid to industrial symbiosis, a system's approach which is designed to build upon win-win synergies between environmental and economic performances through physical sharing of 'waste' energy, exchanging of waste materials, by-products and infrastructure sharing among co-located entities.

Cement industry is also considered as one of the most notable carbon emitters. This sector accounts for about 1.8Gt of CO₂ emissions in 2006, approximately 7% of the total anthropogenic CO₂ emissions worldwide (Gao et al., 2015)²⁹. Ishak and Hashim in 2015 found that 90% of CO₂ emissions from cement plants were generated from clinker production while the remaining 10% was from raw materials preparation and the finishing stage of production cement, they also reviewed various CO₂ emissions reduction strategies, including energy efficiency improvements, waste heat recovery, the substitution of fossil fuel with renewable energy sources, the production of low carbon cement and CCS (carbon capture storage)³⁰.

Carbon emissions in the rubber industry are nearly associated to energy consumption, Dayaratne and Gunawardena in 2015 suggested that rubber manufacturing should modify and adapt virtuous manufacturing model and execute energy-efficient measures to attain sustainable production and the corresponding financial barriers can be solved through the clean development mechanism³¹.

Carbon emission reduction in paper industry: Leon et al. in 2015 suggested manufacturing strategies using advanced sheet structure design and fibre modifications in super-calendered (SC) paper production and lightweight coated (LWC) paper production resulting in the manufacture of paper products with equal or better properties while using less wood-fibre raw material and energy. The future manufacturing strategies (FMC) when applied to SC resulted in the reduction of carbon emission by 23%, with a total of 10.7g CO₂-eq emissions saved per square meter of SC paper while in LWC paper, carbon emissions were reduced by 20%, which were equal to a total of 19.7g CO₂-eq saved per square meter of LWC paper³².

Carbon emission reduction in Methanol industry: using the multi- objective optimization approach of CO₂-efficiency to maximize methanol production and minimize CO₂ emission in the green integrated methanol case (GMIC) would lead to the reduction of 16% in the CO₂ emission with respect to the reference methanol case (RMC) at the expense of 5% decrease in the methanol production (Taghdisian et al. 2015)³³.

Conclusion:-

The demand for energy is increasing day by day and the energy production is closely associated with the increase of fossil carbon emissions. Without the concern about the carbon emissions the fossils are considered to be the main source of energy. In-order to minimize the production of CO₂ into atmosphere various technologies are used like the wide spread implementation of low fossil carbon emission renewable systems, the coal gasification, various carbon capture techniques, biological CO₂ mitigation, the geoengineering schemes, the industrial and the agricultural processes involved in the reduction of emission etc are clearly the most direct and effective approaches to reduce the CO₂ emission to the atmosphere.

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