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Present status and overview of Chemical Looping Combustion technology

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A B S T R A C T

World climate change occurring mainly due to human activities has led to an environmental concern all over the planet. Global CO_2 emission has reached an alarming level which is regarded as the most lethal anthropogenic greenhouse gas emissions. To have a check on the carbon emissions, many clean coal technologies were proposed out of which Chemical Looping Combustion (CLC) technology came out as the most promising technology of all. The process of CLC avoids direct contact between the fuel and the air. It is based on the transfer of oxygen from air to fuel by means of a metal based oxygen carrier and this process is blessed with inherent sequestration of CO_2. This paper presents a review of the CLC technology and it's all round advancement during last 10-15 years. The all round development of the process include progress in terms of the use of gaseous, solid as well as liquid fuels, the evolution in the oxygen carriers and the reactor systems being used in the process. The development in the oxygen carriers has gained maturity, the use of solid fuels is gaining momentum, and the liquid fuels need further attention for its development. Recently, a fair number of hours of continuous operation in pilot plants have instilled the confidence required in further development of this process towards commercialization. The big stride that the CLC technology has taken in such a small duration of time, there leaves no doubt that this technology has the potential to grow manifolds with further research.

Contents

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1. Introduction

The greatest scientific achievement of the nineteenth century is the discovery of electricity and the subsequent centuries are making use of electricity so extensively that it has almost changed the face of the Earth. In the past century and a half, electricity has steadily evolved from a scientific curiosity, to a luxury of the affluent, to a modern need. The rising need of electricity has called for an increase in its generation manifold. World electricity generation rose at an average annual rate of 3.6% from 1971 to 2009 [1]. As of 2013, the total electricity production of the world was 23,127,000 GW h [2] out of which production by the use of fossil fuels constitutes around 67% (coal 41%, oil 5% and natural gas 21%) of the total energy production in the world. Nuclear energy constitutes around 13% of the production while renewable energy sources, viz., hydro; geothermal; solar photovoltaic; solar thermal; wind and tidal energy; together constitute about 18% of the energy generation while the remaining is produced with the help of biofuels [3]. Taking a look at the Indian scenario, the total installed capacity is 258,701 MW as on 31.01.2015 [4] out of which coal fired thermal power plants constitute 60.37% of the total generation. Table 1 gives a detailed comparison of the total installed capacity from different generating sources of India in the years 2005 and 2015. It is observed that there has been a significant increase in installed capacity of electricity since 2005 to 2015. It is interesting to note that the share of coal towards electricity production has been increased both in absolute value as well as in percentage in the last 10 years. The total coal requirement of India is projected to be about 1300 million tonnes in 2025. Therefore, it is evident from the above that fossil fuels are the main sources of electricity production in the world as well as in India and it will continue to be so for another century or two mainly due to the following reasons: i) the world fossil fuel reserves can sustain production of energy to meet the rising demands for the next couple of centuries, ii) it is less costly than other alternatives, iii) renewable energy sources face complex constraints for large-scale applications and hence are unlikely to meet the energy demands in the foreseeable future, and iv) nuclear energy due to constraint on its spent fuel management and vulnerability to catastrophic hazards makes it unlikely to play a vital role in meeting energy demand [5,6]. The decrease in the fossil fuel reserves in the near future will have its effect on its prices and the production cost will increase. On the other hand, with the advancement of technologies in the renewable sector, the prices are likely to come down with respect to the generation cost presently with renewable energy sources. Even then with the decrease in renewable energy costs and the increase in fossil fuel prices being taken into account, it is projected that only about 13.3% of the total energy consumption in 2030 will be from renewable sources [7]. Fossil fuels, mainly coal, are used in thermal power plants all over the world to generate electricity. Combustion of coal converts the chemical energy into thermal energy which is further converted into mechanical energy in the turbine and finally converted to electrical energy in the electrical generator. Combustion of coal at thermal power plants emit gases mainly carbon dioxide (CO_2), sulphur oxides (SO_x), nitrogen oxides (NO_x), chlorofluorocarbons (CFCs), other trace gases and air borne inorganic particulates, such as fly ash and suspended particulate matter (SPM) [8]. Most of the gases emitted during combustion, known as greenhouse gases, are considered to be detrimental to the Earth's atmosphere as these gases absorb radiation within the thermal infrared range and then re-radiate it back to the surface resulting in an elevation of Earth's surface temperature which is termed as Global Warming. Since the early 20th century, the Global air and sea surface temperature increased by about 0.8 °C, with about two-thirds of the increase occurring since 1980 [9]. Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 [10]. The United Nations' Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess scientific, technical and socio-economic information concerning climate change, its potential effects and options for adaptation and mitigation. The fourth Assessment Report of the IPCC in 2007 is the largest and most detailed summary of the climate change situation ever undertaken. The key findings of the report were: "warming of the climate system is unequivocal", and "most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas (GHG) concentrations [11]." There are several greenhouse gases resulting from human activities. However, the main gases attributing to the greenhouse effect (GHE) are H_2O, CO_2, CH_4, N_2O, CFCs and SF_6. Among these, the gas considered to be contributing the most to the GHE is CO_2 because of two factors: i) CO_2 represent the largest emissions of all global anthropogenic GHG emissions (around 75% of all GHGs), and ii) CO_2 has a very high residence time in the atmosphere: the lifetime of CO_2 from fossil fuel uses might be 300 years, plus 25% that lasts forever [12]. Hence it is the most important anthropogenic greenhouse gases of our concern. Presently each year around 5 Gt of Carbon is released into the atmosphere from fossil fuel combustion [8]. The Global atmospheric concentration of CO_2 has increased from a pre-industrial value of about 280 ppm to 399 ppm in July, 2014 [13]. Its concentration has increased every year and the rate of increase has accelerated from about 0.7 ppm

Table 1
Installed capacity of electricity in India (fuel wise).

Fuel	As on 31.01.2015		As on 31.01.2005	
	MW	% age	MW	% age
Coal	156190.89	60.37	67,166	58.13
Hydro	40867.43	15.80	30,135	26.08
Wind/RES	31692.14	12.25	2489	2.15
Gas	22971.25	8.88	11,840	10.25
Diesel	1199.75	0.46	1196	1.04
Nuclear	5780	2.24	2720	2.35
Total	258701.45	100	115,546	100