Study on Minimizing CO_2 Emissions in Clinker Unit of Cement Plant in Sultanate of Oman

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Abstract

The design project of Chemical Engineering focus on solving the problem related to a chemical or process industry. The aim of the research paper is to establish study on gaseous emission in cement industry of Sultanate of Oman. The study was concentrated on testing numerous options that may help in dropping the amount of emission from cement plants especially carbon dioxide emission. As per the investigation the suggested technology was CO_2 capture and it was effective in terms of cost and maintain the production amount. According to energy and mass balance of the plant it has been found that 8700 tons/day of clinker produces and 5206.08 tons /day of CO_2 was generated. The analysis includes the design aspect for cyclone separator that has an efficiency of 42.7%.In addition, according to the feasibility study of this study it has been noticed that FCI of making plant produce 3.17 million ton/year was 4.2 million OMR. Moreover, according to the present investigation it has been identified that the solution for minimizing the emission couldn't depend not only in method of production but also some alternative substitution for the parameters, raw material and process equipment used for production of cement.

Keywords- Cement, Mass Balance, Carbon Dioxide, Cyclone Separator, Gaseous Emission and Environment

I. INTRODUCTION

Engineering is the main branch which contributes in the construction and operating the industries. It plays the role of sustainable development for these industries by updating and creating modern technologies that will develop any process involve in the industry. From that perspective, this study has been carried out for minimizing CO_2 emission in clinker unit in cement plant to improve the environmental aspect existed in cement industry. It is focusing on solving the gaseous emission generated by cement production process and also consider CO_2 emission at calcination unit because the amount of CO_2 produces at this stage is high and need to be control. As per the investigation it provide the possible effective solutions for this issue and developed the concept of using separating equipment's which is the only thing use to limit the emission. In addition, it is necessary to maintain the production amount under any additive technology and that has been showed in the results of the project. The current study is applicable in a direct way to cement production plant comparing to other industries due to high amount of CO_2 generated by cement sector alone and it represent 5% of global emission. The following key aspects has been focused on this present investigation are to examine various options for reducing CO_2 emission in cement industry, stoichiometric calculation with energy and mass balance calculations, design & simulation of cyclone separator at clinker production unit and economic feasibility for the plant as per the intervals of time.

II. EXPERIMENTAL INVESTIGATION

A. To Examine Various Routes for Reducing CO_2 Emission in Cement Industry & Analyze the Effects on Production

The issue of CO_2 emission from cement industries and how it's a serious case that need to be taken under consideration. It has been observed over the years beside the sustainable developments how the industries trying to reduce the emission of greenhouse gases by using different technologies. One of the main objective on that aspect is to focus in improving the energy efficiency, using alternative energy sources rather than fossil fuel and increase the use of additive in the manufactured cement. Moreover, CO_2 capture and storage has been presented nowadays as one of the opportunities for emission reduction in cement industries. The CO_2 capture is consider as a good choice because the concentration of these gasses is relatively high (2.5 mole% dry bases) and represent 60% of total emission from mineral decomposition in modern cement plants which means that this amount cannot be reduced only by changing the energy source. Process raw materials are ground in water while in dry process the raw materials will be dried and ground before feeding to preheaters and kiln. The favored one is the dry process because it requires less energy comparing with the wet process. The growth rate in cement production is rapidly increase due to the increment in the demand and simultaneously the CO_2 emission is increase as well.

- Separating CO_2 from flue gas by post combustion capture
- Burning the fuel in oxygen instead of air. (Oxy-combustion)

- Making a reaction between fuel, oxygen and steam in which the produced mixture will be a separated CO_2 and H_2 as a fuel for the process (pre-combustion capture)
- The comparison will be between Post-combustion and Oxy-combustion technologies

By using technology there will be no effect on the core of cement production, but there will be several additions to the plant like:

- The plant will require solvent scrubber and regenerator.
- To transport the produce CO_2 through the pipeline, a compressor will be require.
- Provide the needs to get the purity of flue gas as required.
- Steam will be need it for the regeneration of CO_2 capture solvent.

The functioning of plant based on flue gas will have high CO_2 concentration comparing with plants that work based on coal fired power plants by 25 mole% and 14 mole % respectively. This method has been used for different industries that work based on this principle with a specific production amount. In case of cement plants it's almost suitable for the production of 1 Mt/y of cement. In addition, this type of CO_2 capture techniques generate a CO_2 stream with high purity that can reach 99% dry basis. For the analysation purpose, there are some concerns need to be consider to achieve the required objectives. One of them is that CO_2 need to be compressed at 11MPa for the transportation through the pipeline into the storage site. The other one is that 95% of CO_2 will be captured for each tone of CO_2 produced. There is an issue for this mechanism which is the supplying of low pressure steam for the CO_2 capture solvent regeneration. The issue is occur because the process will be supplied by the power from coal-fired and power plants that basically includes high pressure steam generation. The use of coal because that some cement plants already using it which make the process of combined it with flue gases and fed it to the CO_2 capture plants easier. The plant performance before and after capture mechanism was shown in table 1 & cost estimation after applying CO2 capture technology was shown in table 2.

Table 1: Plant performance before and after capture mechanism

Plant performance				
	unit	*No capture*	*Post combustion capture*	*Oxy- combustion*
Fuel and power				
Coal	*tone/yr*	*63.3*	*291.6*	*72.1*
Average power consumption	*MW*	*10.2*	*42.1*	*22.7*
CO_2 capture and emitted				
CO_2 capture	*tone/yr*	*-*	*1067.7*	*465*
CO_2 emitted	*tone/yr*	*728*	*188.4*	*282.9*
CO_2 emission avoided	*%*	*-*	*74*	*61*
CO_2 overall emission	*tone/yr*	*770.4*	*176.6*	*373.7*

Table 2: Cost estimation after applying CO_2 capture technology

Cost estimation				
	unit	*No capture*	*Post combustion capture*	*Oxy- combustion*
Capital cost	*€M*	*263*	*558*	*327*
Cement production cost	*€/t*	*65.6*	*129.4*	*81.6*
Cost/tone of cement produced	*€/t*	*-*	*63.8*	*16*
Cost/ton of CO_2 captured	*€/t*	*-*	*59.6*	*34.3*
Cost/tone of CO_2 emission avoided	*€/t*	*-*	*107.4*	*40.2*

B. Performance Evaluation of Post Combustion Capture Process

It was noticed that the results shown that 74% is the CO_2 emission avoidance by the cement plant and its 77% when it is counted with CO_2 avoided due to electricity consumption. The avoidance percentage can be increased and reach up to 93% if the percentage capture is also increased. Cost of this method is very high and it's effected by CO_2 variation in concentration because the equipment and power need to be modified based on the change in the gas concentration.

C. Performance Evaluation of Oxy-Combustion Capture Process

As per the study it was observed that 61% of CO_2 could be avoided by oxy-combustion at pre-calciner only. This percentage could be increase if re-capturing done for CO_2 that emitted from CO_2 purification vent stream using a membrane or scrubber. For the power consumption it provides a significant increase that mainly done for oxygen production, CO_2 purification & compression. The overall reduction of CO_2 including the amount emitted during power generation is equal to 52%. For the cost aspect, the avoidance of CO_2 emission by this method is less comparing with post-combustion method. One of the main results has been reached is that this mechanism is much suitable for cement plants than post-combustion and that is because of capturing require only oxygen for CO_2 by the fuel combustion and it's not required for mineral decomposition. While in the post combustion CO_2 will not be captured from the mineral decomposition and that will not give a sufficient result for CO_2 minimization because its account $1/3^{rd}$ of total CO_2 emitted in modern cement plants.

D. Mass & Energy Balance

Based on Oman cement factory the following percentages were used for manufacturing of Portland cement. The percentage raw material used in OCC was shown in table 3.

Table 3: Percentage raw material used in OCC

Name of raw material	*Short form*	*Its source*	*% involved in total cement composition*
Calcium oxide (CaO)	*C*	*limestone*	*CaO 45-56%* *$CaCO_3$ 85%*
Silica (SiO_2)	*S*	*QPH*	*10%*
Alumina (Al_2O_3)	*A*	*Kaolin*	*3%*
Ferric oxide (Fe_2O_3)	*F*	*Iron ore*	*2%*
			Total 100%

The main reaction involved during the cement production is: $CaCO_3 \rightarrow CaO + CO_2$

The total amount of raw material used to produce that amount of clinker in tone per day is = 8700 × 1.6= 13920 tons/day of raw material. Because they are using 85% of limestone in the raw material that is mean amount of entering CaCO3 =85% × 13920= 11832 ton/day.

So mass of CaO is (11832× 56) ÷100 = 6625.92 ton/day

And mass of CO2 is (11832 × 44) ÷ 100 = 5206.08 tons /day

For heat balance the following equation can be used:

$$\Delta H^oT=\Delta HoT1+ \Delta \alpha (T-T1) + ½ \Delta \beta (T2 –T12) + 1/3 \Delta \gamma (T3 –T3) \quad (1)$$

$$\Delta H^oT = 178+ -1.011(1173-298) + ½ (-1591.557) (1173\ 2 – 298\ 2) + 0 = -1.86 \times 106 \quad (2)$$

Negative enthalpy indicates that heat was released during the course of a reaction. It was an exothermic reaction and that can be predict because the reaction temperature was extremely high.

Design & Simulation Of Cyclone Separator

It is one of the common devices used in many industries for air pollutant separation. The principle behind this equipment is to employ a centrifugal force generated by providing a spinning gas stream from a special inlet in the cyclone separator. The gas stream will separate the particles from the carrier gas. Moreover, there are many features that make this device as one of the wide particle removal device .The simple design, low maintenance cost, has different range of efficiency, has the ability to work with different particle size and flow rates and the easy to be operated. By using suitable materials and methods of construction, cyclones may be adapted for use in extreme operating conditions: high temperature, high pressure, and corrosive gases.

The simulation for cyclone separator using HYSYS has been done to indicate the quantities of material and gas in the inlet and outlets of the device. The observed quantities were in weight fraction & material composition was in mole fraction. The material stream table for cyclone separator simulation were shown in table 4 & the detailed Composition quantities from inlet and outlet stream were shown in table 5.

Table 4: Material stream table for cyclone simulation

Material stream				
		Pollutant air	*Top product 1*	*Bottom product 2*
Vapor fraction		*0.9141*	*0.9489*	*0*
Temperature	*^oC*	*25*	*25*	*25*
Pressure	*Kpa*	*101.3*	*93.68*	*93.68*
Molar flow	*Kmole/h*	*1.578e+004*	*1.520e+004*	*578.8*
Mass flow	*Kg/h*	*5.893e+005*	*5.314e+005*	*5.788e+004*
Liquid volume flow	*m^3/h*	*573.8*	*552.5*	*21.36*
Heat flow	*KJ/h*	*-9.491e+008*	*-9.491e+008*	*0*

Table 5: Composition quantities from inlet and outlet stream

Composition			
Composition mole fraction	*Pollutant air*	*Top product 1*	*Bottom product 2*
CO_2	*0.1528*	*0.1528*	*0*
Air	*0.7613*	*0.7903*	*0*
$CaCO_3$	*0.0859*	*0.0511*	*1*

III. RESULTS & DISCUSSION

As per the investigation the main objectives of the study has been achieved with different level of accuracy. It was noted that the most optimum value has been reached with clear justification for selection. In addition to this, it was comprising confirmations which indicates the availability choosing particular parameter of using specific value. The following discussion was explaining the results for major objectives:

In addition cyclone design calculation was fit with the standard conditions. It was also proved that if the particle size has range of < 5µm, the efficiency will be less than 50%. (Rao, 2006), where the calculated d_p= 4.69 µm & efficiency was 42.7%.

In simulation studies the inlet used as raw material $CaCO_3$ mixed with pollutant air. In cyclone separator the main two outlet were the gas/clean air from the top & dust/influent material from the bottom. The normal temperature and pressure were used for the operation. The quantities used were the one which calculated from mass balance. In the top outlet the major product was air mixture 0.7903, 0.1528 of CO_2 & very small amount of $CaCO_3$ .This was an indication of sensible separation of the

process. In addition to this bottom outlet, the product component was fully $CaCO_3$ and that is exactly the require amount. The following key results were identified from the investigation:

- According to the above values, the design calculation were fit with the standard conditions. It was proved that if the particle size has a range of < 5µm, efficiency was less than 50 % (Rao, 2006).
- The calculated d_p= 4.69 µm and the efficiency= 42.7 %
- In simulation part the inlet was raw material $CaCO_3$ mixed with pollutant air. In cyclone the main two outlet was the gas or clean air from the top and dust or the influent material from the bottom.
- The conditions used was at normal temperature and pressure. The quantities used are the one that calculated from mass balance.
- In the top outlet the major product is air mixture (0.7903), (0.1528) of CO_2 & very small amount of $CaCO_3$ (0.05).That was indicates for a sensible separation from the process.
- In the bottom outlet, the product component was fully $CaCO_3$ & was exactly the require amount for the process.

IV. CONCLUSIONS

Comprehensive study on minimizing CO_2 emission in clinker unit of cement plant has been carried out. The study was mainly focused on cement industry & specifically in production process. It has been recognized the working as well as CO_2 emission during the production and at which equipment/process the emission was occurs. It was proved that CO_2 capture process was one of the most effective mechanisms for emission reduction. Cement production involved in reaction of $CaCO_3$ for the mass & energy balance with the amount of CO_2 produced was 5206.08 tons /day for each 11832 tons/day of $CaCO_3$ utilization. Moreover, a cyclone separator has been designed with specific parameter and simulated using HYSYS. It was also highlighted the feasibility study to determine the cost require for constructing cement plant with (3.17 million ton/year) and its found that 4.2 million R.O for the capital investment & 5.4 million R.O as total production cost.

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