CHEMICAL ENGINEERING TRANSACTIONS

VOL. 31, 2013

Guest Editors: Eddy De Rademaeker, Bruno Fabiano, Simberto Senni Buratti

ISBN 978-88-95608-22-8; ISSN 1974-9791

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at: www.aidic.it/cet

DOI: 10.3303/CET1331124

The Minimum Ignition Energy of Coal Dust in an Oxygen Enriched Atmosphere

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In oxy/fuel combustion of coal, the pulverised coal is burned with oxygen at concentrations greater than the currently allowed value of 21 %. This may well provide advantages in carbon sequestration against other technologies such as pre- and post-combustion capture. However the risk of dust explosions increases significantly with increasing oxygen concentration and temperature. In this study the influence of enriched oxygen concentrations is researched on the dust explosion characteristics of Indonesian (Sebuku) coal dust and of Pittsburgh coal n°8. First the ignition sensitivity characteristics (minimum ignition energy and minimum ignition temperatures) and explosion severity characteristics (maximum explosion pressure, Pmax, and maximum rate of pressure rise, Kst) are determined in air. Thereafter the minimum ignition energy is determined of both coals in an oxygen enriched CO_2 atmosphere. The minimum ignition energy in air of the Sebuku coal was equal to 55 mJ, while the minimum ignition energy of the Pittsburgh coal was higher than 1000 mJ. The ignition sensitivity in a 30 vol% O2 in CO_2 mixture was in good agreement to the ignition sensitivity in air. In a 50 vol% O2 in CO_2 mixture the ignition energy decreased significantly to a value of 1.4 mJ for the Sebuku coal and 4.7 mJ for the Pittsburgh coal n°8.

1. Introduction

The work reported here is part of the European FP7 project RELCOM (Reliable and Efficient Combustion of Oxygen/Coal/Recycled Flue Gas Mixtures, www.relcomeu.com). In this project the full scale deployment of oxy-coal firing is researched both by experimental studies and by combustion modelling. Design rules and methods are generated which can be employed for scaling up results from pilot and laboratory studies to the full-scale. The mixing of coal dust with increased oxygen concentrations provides advantages in oxy/coal fired systems for the burners and also for the capture of CO_2. It is known that increasing the oxygen concentration will make the dust cloud more sensitive to ignition compared to a dust cloud in an atmosphere of pure air. In the literature some experimental data can be found on dust explosion characteristics for oxygen poor mixtures, which are important for inerted conditions. However, only very scarce data can be found on dust explosion characteristics in oxygen enriched mixtures.

2. Experimental methods

Dust explosion tests were performed on pulverized Sebuku and Pittsburgh coal n°8 according to the European standards EN 13821, VDI 2263 and EN 14034. The maximum explosion pressure, the maximum rate of pressure rise and the lower flammability limit are measured by means of a standardized test sphere with a volume of 20 L. The minimum ignition energy is determined by means of the MIKE3 apparatus and of a modified Hartmann tube. The thermal behaviour of the coal is measured by means of a Grewer oven. The ignition temperature of the dust in contact with a hot wall is determined by means of a BAM oven. A description of the equipment to determine the explosion characteristics of dusts can be found in e.g. Lees (1990). Because the particle size has a major influence on the explosion

Please cite this article as: Norman F., Berghmans J. and Verplaetsen F., 2013, The minimum ignition energy of coal dust in an oxygen enriched atmosphere, Chemical Engineering Transactions, 31, 739-744 DOI: 10.3303/CET1331124

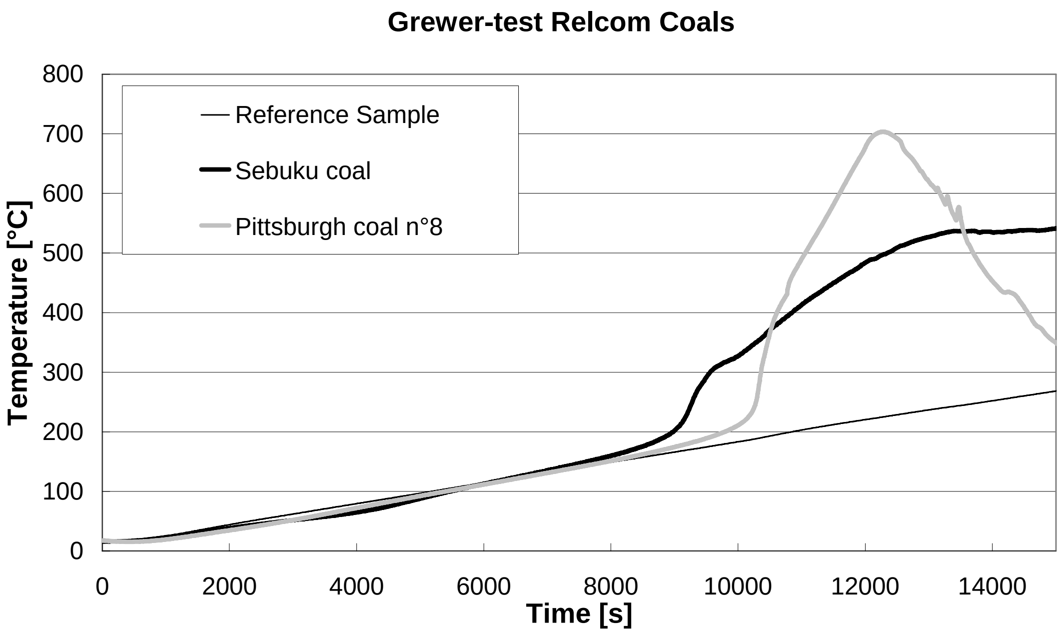

Figure 1: Results of the Grewer test, determination of the relative auto-ignition temperature.

characteristics, see Di Benedetto (2010a), both coals were milled and sieved < 63 µm. The particle size distribution of the tested coals is determined by means of a laser diffraction analysis and the median values were 14.9 µm and 11.8 µm for the Sebuku and the Pittsburgh coal respectively. Because the explosion characteristics also depend on the moisture content of the dust sample, the coals are dried by means of a vacuum dry oven for the determination of the minimum ignition energy until the moisture content of the coal samples was below 3%. A halogen moisture balance is used for this purpose.

3. Experimental results in air

The minimum layer ignition temperature (MLIT) or the lowest plate temperature at which a 5 mm thick layer of coal deposited on the plate ignites is 260°C for both coals.

The results of the Grewer oven test or determination of the relative auto-ignition temperature are shown in Figure 1. It is found that the Indonesian coal (Sebuku) has more volatile components which are released at lower temperatures than the Pittsburgh coal. Sebuku is a bituminous coal rich in volatile components.

The minimum cloud ignition temperature (MCIT), see Di Benedetto (2010b), of airborne dust in contact with a hot surface is determined by means of the standardised BAM-oven (VDI 2263, Blatt 1, 2.6.). The lowest temperature of the heated impact plate in the oven at which the dust blown into the oven ignites or decomposes producing flames or explosion in less or equal than 5 seconds is stated as the minimum ignition temperature. This test is performed on the fraction of the sample with a particle size less than 63 µm. It is found that the MCIT of the Sebuku coal is 540°C. For the Pittsburgh coal a value of 590°C was obtained. This result is in agreement with the results of the Grewer tests. High volatile coals have a lower MCIT than non-volatile coals.

Figure 2 shows the results of the tests in the 20 L sphere for the Sebuku coal. It is found that, over the whole range of concentrations the maximum pressure is 6.6 bar, the maximum rate of pressure rise is 418 bar/s and the K_{st} value is 114 bar m/s. The lower explosive limit is 60 g/m^3.

The results obtained for the Pittsburgh coal are presented in Figure 3. It is found that, over the whole range of concentrations the maximum pressure is 6.5 bar, the maximum rate of pressure rise is 290 bar/s and the K_{st} value is 79 bar m/s. The lower explosive limit is 60 g/m^3.

The results of the 20 L sphere test are in agreement with those of the tests mentioned above. Small particle size and high volatility lead to faster combustion and thus to higher dP/dt and K_{st} values.

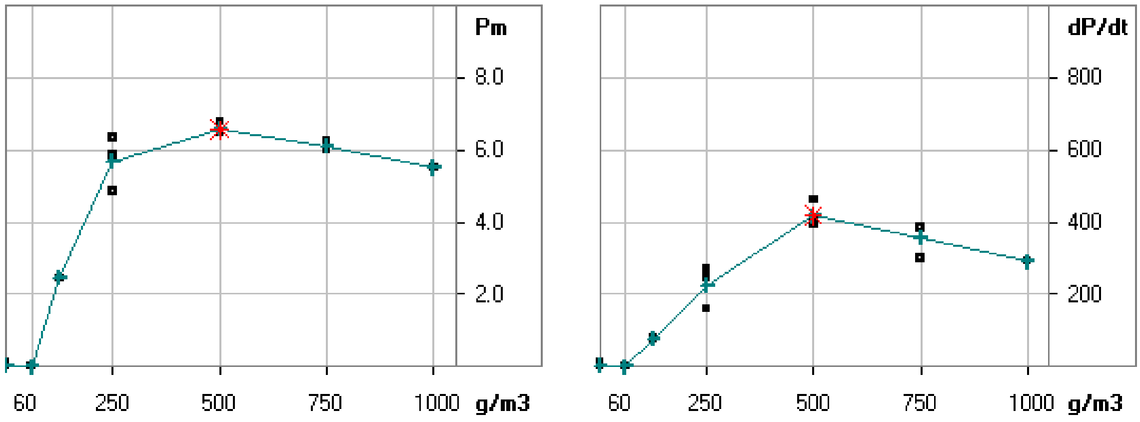

Figure 2: Maximum pressure Pm (bar) and maximum rate of pressure rise dP/dt (bar/s) as a function of dust cloud concentration for Sebuku coal.

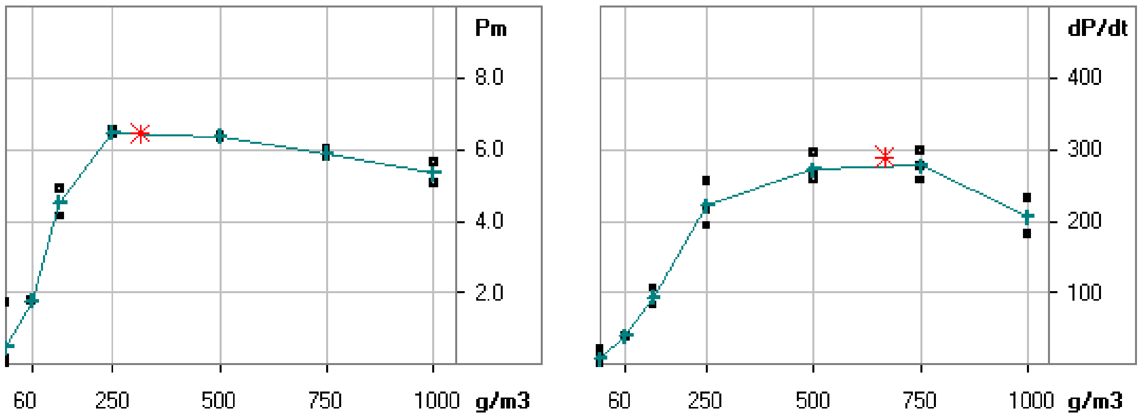

Figure 3: Maximum pressure Pm (bar) and maximum rate of pressure rise dP/dt (bar/s) as a function of dust cloud concentration for Pittsburgh coal.

4. Influence of oxygen

The amount of experimental data available in the literature about the effect of oxygen on the explosion characteristics on coal is very limited. An overview of this subject up to 2003 can be found in Eckhoff (2003). Most of the work in the past was connected to the technique of inertization. This technique aims at making dust clouds non-ignitable by adding an inert gas to the air in order to reduce the oxygen content of the air-dust mixture. From these studies it can be concluded in general that increased oxygen content will:

- Increase the flame temperature
- Increase the speed of combustion
- Lower the lower flammability limit
- Increase the maximum rate of pressure rise

The maximum explosion pressure may experience a limited increase.
More recently experimental and theoretical studies have been made of coal combustion with emphasis on the behavior of the coal particle. An overview of this work can be found in a paper from Khatami (2012). It is found that there exists a critical particle size below which the volatiles and the char burn simultaneously on or near the surface of the particle. The type of combustion (simultaneous or consecutive volatiles combustion followed by char combustion) has a large impact on the speed of combustion and the speed of the pressure rise. The critical size depends upon the physical and chemical properties of the coal (size, composition…), the ignition temperature and the composition of the gas phase in which the combustion

occurs. Higher O_2 concentrations and smaller particle sizes tend to promote simultaneous combustion. The studies also point to the role of CO_2. If N_2 is replaced by CO_2 it is found that simultaneous combustion is promoted (the critical size increases). CO_2 on the other hand decreases the flame temperature and the stability of the flame.
The impact of CO_2 is important because of the fact that in order to reduce CO_2 emission in an oxy-combustion process, CO_2 has to be re-circulated into the flame. Assessing the impact of O_2 in the context of oxy-combustion therefore also will require the study of the impact of CO_2 on the process and on its safety parameters. Based upon the impact of O_2 and CO_2 on the combustion of coal particles described above, the expected impact of increased CO_2 and of O_2 is listed in Table 1.

Table 1: Impact of increased O2 and CO2 on the main explosion characteristics of coal. (+ increase, - decrease)

	O_2	CO_2
Flame temperature	+	-
Speed of combustion	+	-
Lower flammability limit	-	+
Maximum rate of pressure rise	+	-
Minimum ignition energy	-	+
Minimum ignition temperature	-	+

5. Minimum ignition energies in oxygen enriched atmospheres

The minimum ignition energy of the Sebuku coal in air lies between 30 mJ and 100 mJ. 30 mJ is the highest energy at which no ignition is being observed in 10 successive tests for each concentration and ignition delay time and 100 mJ is the lowest energy at which at least one ignition occurs, see Figure 4. The statistic minimum ignition (E_S = 60 mJ) is calculated by the probability of ignition and can be used for comparison between different apparatus.

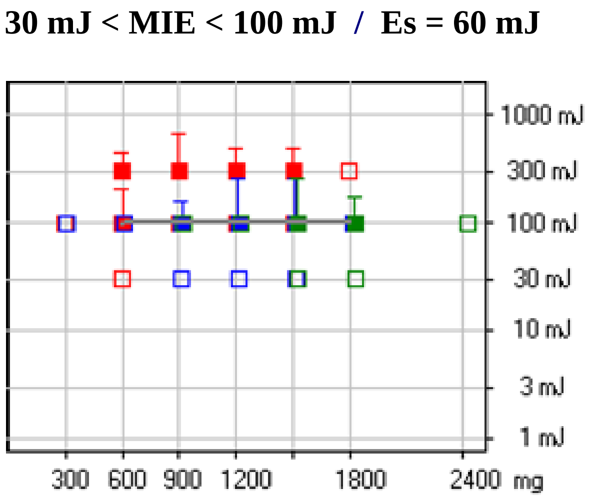

Figure 4: Determination of the minimum ignition energy of the Sebuku coal.

The minimum ignition energy of the Pittsburgh coal could not be determined with the Mike3 apparatus. The coal can be ignited in the Hartmann tube however by means of a continuous spark from a high voltage transformer, equivalent energy = 10 J. For this reason the minimum ignition energy of this coal is estimated as to be between 1000 mJ and 10000 mJ.

These values were determined with an inductance of 1 mH in the discharge circuit. The minimum ignition energy without inductance of the Sebuku coal lies between 100 mJ and 300 mJ (E_S = 160 mJ). Since the most conservative or lowest ignition energy is determined with inductance, the following test results are also determined with an inductance of 1 mH. The coals were dried and the moisture content was maximum 3% for the tests. Since the oxy/coal combustion consists of the combustion of pulverized coal in a mixture of pure oxygen with the recycling clean flue gas, it is important to research the dust explosion characteristics in an oxygen enriched (> 21 vol%) CO_2 atmosphere.

First both coals were tested in a 20 vol% O_2 in CO_2 mixture and did not result in an ignition in the MIKE 3 apparatus with ignition energy of 1000 mJ. The minimum ignition energies in a 30 vol% O_2 in CO_2 are for both coals in good agreement with the values obtained in air. This is also confirmed by Flower (2009). This implies that CO_2 is a better inertant than N_2, due to its higher molar heat capacity, higher radiation and chemical effect in combustion. The minimum ignition energy of the Sebuku coal decreased from 82 mJ, 3.5 mJ to 1.4 mJ in a 28 vol%, 38 vol% and 48 vol% O_2 in CO_2 mixture respectively. The minimum ignition energy of the Pittsburgh coal decreased from 79 mJ, 8.2 mJ to 4.7 mJ in a 35 vol%, 42 vol% and 49 vol% O_2 in CO_2 mixture respectively. This is represented graphically in Figure 5. It can be concluded that for Sebuku coal which is sensitive for electrostatic ignition in air becomes extremely sensitive in a 50 vol% O_2 in CO_2 mixture and for the Pittsburgh coal wich is almost insensitive for electrostatic ignition in air becomes very sensitive.

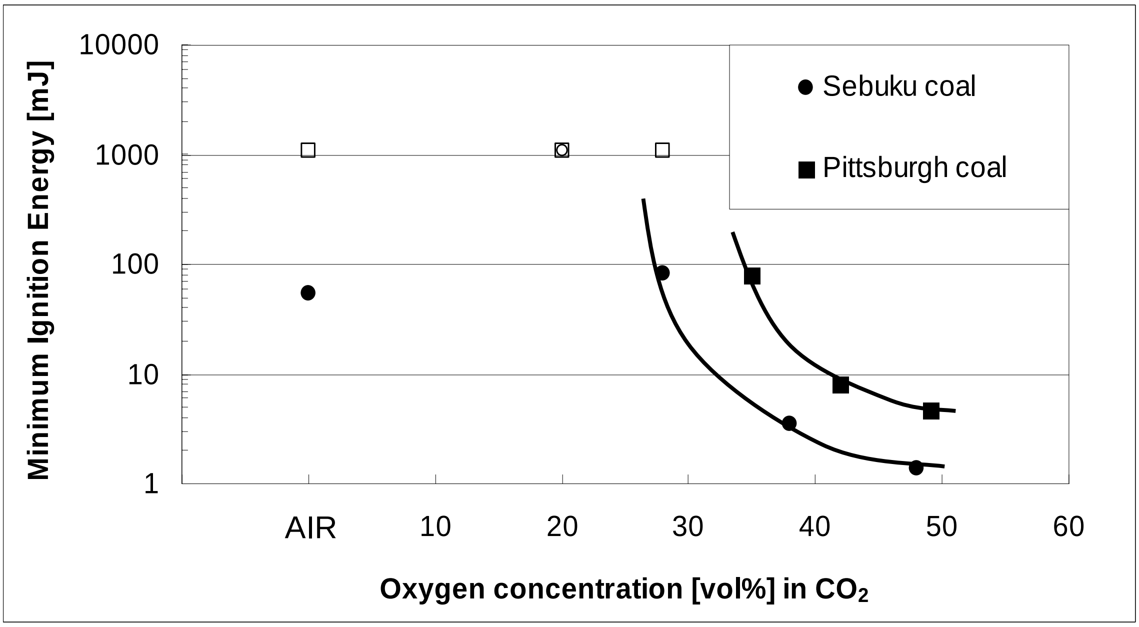

Figure 5: Influence of oxygen concentration on the minimum ignition energy of Sebuku coal and Pittsburgh coal n°8.

6. Conclusion

Knowledge of the phenomena occurring during coal combustion in oxygen enriched atmospheres is necessary for the reliable and efficient combustion of Oxygen/Coal/Recycled Flue Gas Mixtures. In order to identify the safe limits for oxygen use, the explosion characteristics (ignition sensitivity and explosion severity) are determined taking into account the specific atmospheres encountered in oxy/coal combustion. It is concluded that the minimum ignition energy decreases significantly with increasing oxygen concentration. The minimum ignition energy of the Sebuku coal, which is 55 mJ in air decreases to 1.4 mJ in a 50 vol% O_2 in CO_2 mixture. The minimum ignition energy of the Pittsburgh coal, which is higher than 1000 mJ in air decreases to 4.7 mJ in a 50 vol% O_2 in CO_2 mixture. The other explosion sensitivity and explosion severity characteristics of both coals are determined in air. It is observed that the Sebuku coals has the highest ignition sensitivity, e.g. lower ignition energy, lower cloud ignition temperature and lower auto-ignition temperature and the highest explosion severity characteristics, such as K_{st} and P_{max} in comparison with the Pittsburgh coal.

It is expected that the lower explosive limit and minimum ignition temperatures will decrease with increasing oxygen concentration while flame temperature and speed of pressure rise will increase. The addition of CO_2 during combustion is expected to have the opposite effects. These influences will soon be researched experimentally in the following part of the European FP7 project RELCOM.

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