

## ABSTRACT

The present invention relates to an apparatus for analyzing and characterizing spalling behavior of coal during underground coal gasification. The apparatus comprises a furnace (1) having a lid (2) with an opening (3). A heat source (4) is located at the bottom surface of the furnace (1). A coal block holder (5) with a coal block (6) is suspended within the furnace (1). The coal block holder (5) has an open bottom (7) facing the heat source (4). The apparatus comprises a device (10), for monitoring weight of the coal block (6), placed outside the furnace (1) and comprising a suspension means (11) for suspending the coal block (6) with the coal block holder (5), wherein the suspension means (11) passes through the opening (3) of the furnace lid (2). The present invention further relates to a process for analyzing and characterizing spalling behavior of coal during underground coal gasification.

We claim:

1. An apparatus for analyzing and characterizing spalling behavior of coal during underground coal gasification comprising

a furnace (1) having a lid (2) with an opening (3);

5 a heat source(4) located at the bottom surface of said furnace (1);

a coal block holder(5) for holding a coal block (6) within said furnace (1), wherein the coal block holder (5) has an open bottom (7) facing the heat source (4);

10 at least one inlet tube (8), for supplying gas to said furnace, placed between the heat source and open bottom of coal block holder;

at least one outlet tube, for removing gas from said furnace (1), placed between the heat source(4) and open bottom (7) of coal block holder (5);

15 a device (10), for monitoring weight of the coal block (6), placed outside the furnace (1) and comprising a suspension means (11) for suspending the coal block (6) with the coal block holder (5) in the furnace (1), wherein the suspension means (11) passes through the opening (3) of the furnace lid (2).

2. The apparatus as claimed in claim 1, wherein the furnace (1) is an insulated furnace.

3. The apparatus as claimed in claim 1, wherein the furnace (1) is made of material selected from stainless steel, inconel, superalloys and/or tantalum based compounds or alloys.
- 5       4. The apparatus as claimed in claim 1, wherein the heat source (4) is in the form of a plate or a disc.
- 5       5. The apparatus as claimed in claim 1, wherein the open bottom (7) of the coal block holder (5) comprises at least two projections (14) in order to prevent the 10       coal block (6) from falling down from the coal block holder (5).
- 5       6. The apparatus as claimed in claim 7, wherein the projections (14) comprise a slidable metal strip.
- 15       7. The apparatus as claimed in claim 1, wherein the gas passed through the inlet tube (8) into the furnace (1) is selected from air, oxygen, nitrogen, carbon dioxide and/or steam.
- 20       8. The apparatus as claimed in claim 1, wherein the device (10) for monitoring weight of the coal block (6) is a load cell.
- 25       9. The apparatus as claimed in claim 11, wherein the load cell is attached to a data logger (12).

10. The apparatus as claimed in claim 1, wherein the suspension means (11) is selected from a rod and/or a spring.

11. The apparatus as claimed in claim 1, wherein the rod for suspending and 5 weighing the coal block is made up of stainless steel, inconel, superalloys and/or tantalum based compounds or alloys.

12. A process for analyzing and characterizing the spalling behavior of coal during underground coal gasification, wherein the process comprises the steps 10 of

- a) Placing a coal block (6) within a coal block holder (5);
- b) suspending the coal block holder (5) with the coal block (6) from a device (10) for monitoring weight of the coal block (6) at any given point of time; wherein the device (10) comprises a suspension means (11) for suspending the coal block holder (5) with the coal block (6);
- c) placing the device (10) for monitoring weight of the coal block (6) outside 15 a furnace (1) such that the suspension means (11) passes through an opening (3) in lid (2) of the furnace (1) with the coal block (6) within the coal block holder (5) suspended from the device (10) for monitoring weight of the coal block (6) and being placed within the furnace (1);
- d) passing a mixture of gases into the furnace (1) through an inlet tube (8);

- e) raising the temperature in the furnace to 700 to 900°C by heating a heat source (4) placed in the furnace (1); and
- f) recording weight profile of the coal block (6) with respect to weight and time.

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13. The process for analyzing and characterizing the spalling behavior of coal during underground coal gasification as claimed in claim 12, wherein the gases passed through the inlet tube (8) is selected from air, oxygen, nitrogen, carbon dioxide and/or steam.

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14. The process for analyzing and characterizing the spalling behavior of coal during underground coal gasification as claimed in claim 12, wherein the heating and passing of gases is continued till the weight change is negligible with respect to time.

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15. The process for analyzing and characterizing the spalling behavior of coal during underground coal gasification as claimed in claim 12, wherein the product gas is continuously removed from the furnace (1) through an outlet tube (9).

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Dated this 19<sup>th</sup> day of November 2013

  
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## **FIELD OF THE INVENTION**

The present invention, in general, is directed to an apparatus and a process for analyzing and characterizing the physical and chemical processes occurring in underground coal seams during UCG process. More specifically, the present invention relates to the spalling behavior of coal during underground coal gasification.

## **BACKGROUND**

Underground coal gasification (UCG), is an in-situ conversion process of coal which is present in deep underground seams, to combustible product gas. During the process of UCG, a cavity is formed inside the coal seam due to coal consumption by chemical reactions. The temperature inside the cavity is around 700-1000°C and at this temperature, the coal present at the roof of the cavity develops cracks in it, due to its drying and pyrolysis. These cracks grow with time until a piece of coal breaks from its parent material and falls on the floor of the cavity. This phenomenon is called spalling. The extent of spalling for a particular type of coal is an important input to UCG process model that predicts the product gas calorific value. Till date, there is no equipment or methodology available for the analysis, characterization and/or quantification of spalling behavior of coal.

Spalling is conceptualized as something which occurs in regular manner. However, as yet no apparatus or process is known for the characterization of spalling behavior of coal. There has been a long-felt need to study the spalling process in detail in order to predict and/or estimate the product gas value in an UCG process.

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The present inventors have solved this long-felt need by developing an apparatus for studying and quantifying the spalling behavior of coal and a process of use of the apparatus.

## 10 **DESCRIPTION OF THE INVENTION**

The invention relates to an apparatus for analyzing and characterizing spalling behavior of coal during underground coal gasification comprising a furnace (1) having a lid (2) with an opening (3); a heat source(4) located at the bottom surface of the furnace (1); a coal block holder (5) for holding a coal block (6) within the furnace 15 (1),wherein the coal block holder (5) has an open bottom (7) facing the heat source (4);at least one inlet tube (8), for supplying gas to the furnace (1), placed between the heat source (4) and open bottom (7) of the coal block holder (5);at least one outlet tube (9), for removing gas from the furnace (1), placed between the heat source (4) and open bottom (7) of the coal block holder (5);a device (10), for monitoring weight 20 of the coal block (6), placed outside the furnace (1) and comprising a suspension means(11) for suspending the coal block (6) with the coal block holder(5) in the

furnace (1); wherein the suspension means(11) passes through the opening (3) of the furnace lid (2).

Another aspect of the invention relates to a process for analyzing and characterizing  
5 the spalling behavior of coal during underground coal gasification, wherein the process comprises the steps of

- a) Placing a coal block (6) within a coal block holder (5);
- b) suspending the coal block holder (5) with the coal block (6) from a device(10) for monitoring weight of the coal block (6) at any given point  
10 of time; wherein the device (10) comprises a suspension means (11) for suspending the coal block holder (5) with the coal block (6);
- c) placing the device(10) for monitoring weight of the coal block (6) outside a furnace (1) such that the suspension means (11) passes through an opening (3) in lid (2) of the furnace(1) with the coal block (6) within the  
15 coal block holder (5) suspended from the device(10) for monitoring weight of the coal block (6) and being placed within the furnace (1);
- d) passing a mixture of gases into the furnace (1) through an inlet tube (8);
- e) raising the temperature in the furnace to 700 to 900°C by heating a heat  
20 source(4) placed in the furnace (1); and
- f) recording weight profile of the coal block (6) with respect to time.

## **BRIEF DESCRIPTION OF DRAWING**

**Fig. 1** illustrates a schematic diagram of the apparatus.

**Fig. 2** illustrates the weight profile of coal block versus time on heating of the coal block under air atmosphere and at a temperature of 700°C.

## **DETAILED DESCRIPTION OF THE INVENTION**

The description of the specific embodiments will so fully reveal the general nature of the embodiments herein that others can, by applying current knowledge, readily 10 modify and/or adapt for various applications such specific embodiments without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not 15 of limitation. Therefore, while the embodiments herein have been described in terms of preferred embodiments, those skilled in the art will recognize that the embodiments herein can be practiced with modification within the spirit and scope of the embodiments as described herein.

20 An embodiment of the present invention relates to an apparatus for analyzing and characterizing spalling behavior of coal during underground coal gasification. The apparatus comprises a furnace (1) having a lid (2) with an opening (3) and a heat

source (4) located at the bottom surface of the furnace (1). The condition inside the furnace (1) is maintained analogous to the condition in underground coal seams during UCG process. The furnace (1) can be made up of any material which can withstand high temperatures of upto 1300°C and withstand highly corrosive and/or 5 reducing atmosphere. The material can be selected from stainless steel, super alloys etc.

The walls of the furnace (1) is thermally insulated in order to ensure that the temperature within the furnace (1) is maintained and to minimize the heat loss.

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The furnace (1) comprises a heat source (4) placed preferably on the bottom surface thereof. This set-up mimics the underground coal gasification scenario. The heat source (4) is in the form of a plate or a disc. The heating may be electrical heating or heating can be carried out using any fuel. The heat source (4) is specifically a disc 15 type heating coil with an Inconnel plate at the top of heat source (4).

The apparatus comprises a coal block holder (5) for holding a coal block (6). The coal block holder (5) has an open bottom (7) with the coal block (6) facing the heat source (4). The open bottom (7) of the coal block holder (5) facing the heat source (4) 20 ensures that the coal block (6) gets directly heated from the bottom. This set-up mimics the condition in the underground coal seams during UCG process. The open bottom (7) of the coal block holder (5) has at least two projections (14) to help in

retaining/holding the coal block (6) within the coal block holder(5). The projections (14) can be flanges or metal strips. The metal strip may be a slidable/rotatable metal strip such that the coal block (6) is placed within the coal block holder (5) and the metal strip is slid/rotated inwards towards each other so that the coal block (6) is held/retained within the coal block holder (5).

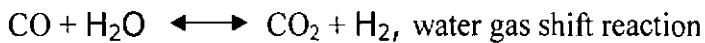
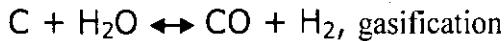
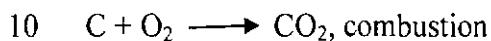
The apparatus further has at least one inlet tube (8) for supplying gas to the furnace (1). The inlet tube (8) is preferably placed between the heat source(4) and open bottom (7) of coal block holder(5). The gas supplied to the furnace (1) is selected from air, oxygen, nitrogen, carbon dioxide and/or steam depending on the reaction in the furnace. For e.g. for an analytical study of the spalling process during the UCG process, air, steam and/or oxygen is passed through the inlet tubes (8) into the furnace (1). Alternatively, in a study of the pyrolysis of coal, nitrogen can be passed through the inlet tubes (8).

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The apparatus further has at least one outlet tube (9) for removing gas from the furnace (1). The outlet tube (9) is placed between the heat source (4) and open bottom (7) of the coal block holder(5). The outlet tube (9) is used to remove the gas from the furnace (1). The gas removed is generally the product gas obtained after the reactions in the furnace including, but not limited to, combustible gases like carbon monoxide, hydrogen, methane, and traces of ethane and propane in varying compositions and inert gases like carbon dioxide and nitrogen. An analysis of the product gas enables

the study of the reactions occurring in the underground coal seams during UCG process.

The general reactions or processes taking place or occurring in the furnace include  
5 drying, pyrolysis and other chemical reactions. Drying is the evaporation of moisture present in the coal at high temperature. Pyrolysis is the breakdown of higher hydrocarbon components present in coal at higher temperature resulting in char or carbon in solid form and lighter components in gaseous form. The main chemical reactions are combustion, gasification and water gas shift reactions as given below:



The apparatus also comprises a device (10) for monitoring weight of the coal block  
15 (6) at any given point of time. The device (10) is placed outside the furnace (1) and comprises a suspension means (11) for suspending the coal block (6) with the coal block holder (5) in the furnace (1); wherein the suspension means (11) passes through the opening (3) of the furnace lid (2). The opening (3) in the lid (2) is packed around the suspension means (11) to ensure complete insulation in order to minimizing heat  
20 loss and gas leakage. The suspension means (11) can be selected from a rod or a spring. The device (10) for monitoring weight of the coal block (6) can be a load cell.

The load cell may be attached to a data logger (12) to record the weights at different time intervals.

Another embodiment of the invention relates to a process for analyzing and 5 characterizing the spalling behavior of coal during underground coal gasification comprising the steps of

- a) Placing a coal block (6) within a coal block holder (5);
- b) suspending the coal block holder (5) with the coal block (6) from a device (10) for monitoring weight of the coal block (6) at any given point of time; 10 wherein the device (10) comprises a suspension means (11) for suspending the coal block holder (5) with the coal block (6);
- c) placing the device (10) for monitoring weight of the coal block (6) outside a furnace (1) such that the suspension means (11) passes through an opening (3) in lid (2) of the furnace (1) with the coal block (6) within the 15 coal block holder (5) suspended from the device (10) for monitoring weight of the coal block (6) and being placed within the furnace (1);
- d) passing a mixture of gases into the furnace (1) through an inlet tube (8);
- e) raising the temperature in the furnace to 700 to 900°C by heating a heat source (4) placed in the furnace (1); and 20
- f) recording weight profile of the coal block (6) with respect to time.

The gases passed through the inlet tube (8) are selected from air, oxygen, nitrogen, carbon dioxide and/or steam. The process is continued till the weight change of the coal block is negligible with respect to time. The product gas in the furnace (1) is continuously removed from the furnace through an outlet tube (9). A graph is plotted 5 for the data obtained with regards to the weight of coal versus the time. The sudden drops in weight of coal block (6) observed in the weight vs. time data are identified as spalling events. Thus, the occurrence of spalling of coal block can be identified from the sudden drops in weight. One such figure is shown in figure2. On accumulating all these sudden weights, the rate of spalling can be calculated.

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The product gas is collected from the outlet tube and can be analyzed in a Gas Chromatograph (GC) for studying its components and thereby calculating its calorific value or understanding the reactions occurring in the underground coal seams. Other equipments like GC-MS, engine or downstream reactors (to convert the product gas 15 into other fuels) can also be integrated with our apparatus for the analysis or processing of product gas.

The apparatus and the process as defined hereinabove relate to study of the spalling behavior of coal in the underground coal gasification process. However, the present 20 apparatus can be modified for the study of other processes related to the UCG, like kinetics, heat and mass transfer phenomena and/or any physical and chemical process occurring in the underground coal seams during UCG process. The apparatus enables

the study of feasibility of a particular coal for UCG process. Further, it is also possible to characterize and analyze the kinetics and thermo-mechanical processes for other carbonaceous solid fuel biomass with slight modifications to the apparatus and the process for use thereof, which fall within the scope of the person skilled in the art.

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### Examples

The following experimental examples are illustrative of the invention but not limitative of the scope thereof.

- 10 A furnace was selected having a plate type heater at the bottom surface of its heating chamber. The dimension of the heating chamber was 380 x 280 x 215 mm. The internal openings of the inlet and outlet tubes were made in the heating chamber just above the heating plate. A box type coal block holder made of high temperature withstanding stainless steel, with its bottom face opened was placed inside the heating chamber. The dimension of the coal block holder was 300 x 200 x 140 mm.
- 15 The holder was thermally insulated on all its internal faces with a thickness of 15mm. The coal block was cut into a dimension suitable to fit into the holder. The thermal insulation between the coal block and holder surfaces causes the heating of the coal block to happen from the bottom exposed face of the coal block. This scenario is
- 20 analogous to the condition in underground coal seams during UCG process. After placing the coal block within the holder, four metal strips were attached to the holder such that it covered the coal block exposed surface 15 mm inward from all its sides.

This prevented the coal block from falling down through the bottom open face of the holder. Then this holder and coal block assembly was suspended from a load cell which was placed outside the furnace, using a stainless steel rod, to monitor the weight of coal block. The suspending rod was passed through the opening in the lid 5 of the furnace. Care was taken to prevent the load getting in contact with any solid object to have error free results.

This apparatus generated the weight profile of coal block with time, maintaining the UCG like conditions inside the heating chamber, as shown in figure 2.

We claim:

1. An apparatus for analyzing and characterizing spalling behavior of coal during underground coal gasification comprising

a furnace (1) having a lid (2) with an opening (3);

5 a heat source(4) located at the bottom surface of said furnace (1);

a coal block holder(5) for holding a coal block (6) within said furnace (1), wherein the coal block holder (5) has an open bottom (7) facing the heat source (4);

10 at least one inlet tube (8), for supplying gas to said furnace, placed between the heat source and open bottom of coal block holder;

at least one outlet tube, for removing gas from said furnace (1), placed between the heat source(4) and open bottom (7) of coal block holder (5);

15 a device (10), for monitoring weight of the coal block (6), placed outside the furnace (1) and comprising a suspension means (11) for suspending the coal block (6) with the coal block holder (5) in the furnace (1), wherein the suspension means (11) passes through the opening (3) of the furnace lid (2).

2. The apparatus as claimed in claim 1, wherein the furnace (1) is an insulated furnace.

3. The apparatus as claimed in claim 1, wherein the furnace (1) is made of material selected from stainless steel, inconel, superalloys and/or tantalum based compounds or alloys.
- 5       4. The apparatus as claimed in claim 1, wherein the heat source (4) is in the form of a plate or a disc.
- 5       5. The apparatus as claimed in claim 1, wherein the open bottom (7) of the coal block holder (5) comprises at least two projections (14) in order to prevent the 10       coal block (6) from falling down from the coal block holder (5).
- 5       6. The apparatus as claimed in claim 7, wherein the projections (14) comprise a slidable metal strip.
- 15       7. The apparatus as claimed in claim 1, wherein the gas passed through the inlet tube (8) into the furnace (1) is selected from air, oxygen, nitrogen, carbon dioxide and/or steam.
- 20       8. The apparatus as claimed in claim 1, wherein the device (10) for monitoring weight of the coal block (6) is a load cell.
- 25       9. The apparatus as claimed in claim 11, wherein the load cell is attached to a data logger (12).

10. The apparatus as claimed in claim 1, wherein the suspension means (11) is selected from a rod and/or a spring.

11. The apparatus as claimed in claim 1, wherein the rod for suspending and 5 weighing the coal block is made up of stainless steel, inconel, superalloys and/or tantalum based compounds or alloys.

12. A process for analyzing and characterizing the spalling behavior of coal during underground coal gasification, wherein the process comprises the steps 10 of

- a) Placing a coal block (6) within a coal block holder (5);
- b) suspending the coal block holder (5) with the coal block (6) from a device (10) for monitoring weight of the coal block (6) at any given point of time; wherein the device (10) comprises a suspension means (11) for suspending the coal block holder (5) with the coal block (6);
- c) placing the device (10) for monitoring weight of the coal block (6) outside 15 a furnace (1) such that the suspension means (11) passes through an opening (3) in lid (2) of the furnace (1) with the coal block (6) within the coal block holder (5) suspended from the device (10) for monitoring weight of the coal block (6) and being placed within the furnace (1);
- d) passing a mixture of gases into the furnace (1) through an inlet tube (8);

- e) raising the temperature in the furnace to 700 to 900°C by heating a heat source (4) placed in the furnace (1); and
- f) recording weight profile of the coal block (6) with respect to weight and time.

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13. The process for analyzing and characterizing the spalling behavior of coal during underground coal gasification as claimed in claim 12, wherein the gases passed through the inlet tube (8) is selected from air, oxygen, nitrogen, carbon dioxide and/or steam.

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14. The process for analyzing and characterizing the spalling behavior of coal during underground coal gasification as claimed in claim 12, wherein the heating and passing of gases is continued till the weight change is negligible with respect to time.

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15. The process for analyzing and characterizing the spalling behavior of coal during underground coal gasification as claimed in claim 12, wherein the product gas is continuously removed from the furnace (1) through an outlet tube (9).

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Dated this 19<sup>th</sup> day of November 2013

  
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