Spontaneous Heating Hotspot: A key to Temperature Profile of Coal Stockpile

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***Abstract* — This paper provides the information of how a coal fire in a stockpile takes. Stockpiles are meant for storage to meet the demands of the industries at need. They can be store for few days to one year and above. Self-heating of coal takes place if the accumulation period of coal is increased to a longer duration. The point where the accumulated heat inside the pile is more than dissipation can be termed as hotspot. Gradually, it reaches beyond the crossing point of coal and goes for spontaneous combustion. When it comes to surface it comes as fire. Therefore an early detection can prevent spontaneous combustion of coal and a large amount of coal reserve can be saved.**

Keywords – stockpile, accumulation, dissipation, hotspot

I. INTRODUCTION

Spontaneous heating is a common phenomenon when coal are storing for longer periods of time. Large amount of coal are stored in coal stockyard, in ports, refineries, power plants etc. Due to storage, a major loss in coal quality gross calorific value (GCV) is seen. Therefore, the focus is typically on timely delivery and timely discharge of coal to and from yard. On basis of discharge, Stockpiles can be classified into two types. Stockpiles stored for shorter duration and the other for longer duration. Short term duration stockpile are being operated within short period of time and are smaller in capacity and dimension. They are basically situated near to conveyor, reclaimers and wagons and are unloaded to trains, ship and get transferred within few weeks. The coals of these stockpiles are of high calorific value with high carbon content and mineral matter. Long duration stockpile are stored for more than (9 months and above). The short term duration stockpiles are called as operational coal stockpile and the piles for longer duration as strategic coal stockpile.

II. MECHANISM

Coal oxidation is an exothermic process that evolves heat. The heat released further accelerates the oxidation of coal. If the heat from the coal oxidation is trapped it will continue to self-heat and will eventually rise above the ignition temperature. Once it reaches higher temperature the risk of spontaneous combustion becomes extremely high. The chemical reactions involved in the atmospheric oxidation process are complex and have been the focus of decades of research. It has been said that these oxidation processes occur at the surface of the coal particles, primarily at the surfaces of the macropores, which are large enough to allow for the free diffusion of atmospheric oxygen into the pore.

III. FORMULATION OF MODEL

Several mathematical models have been developed to predict the conditions under which coal in a pile could undergo spontaneous combustion and to determine the influence of factors contributing to the spontaneous heating. Numerical solution of these models enables predicting of the dynamic behaviour of the coal stockpile, investigating the affecting limits on the process and determining the safe storage conditions and period. One of the more complete models belongs to Nordan (1970). This model consists of the equations for oxygen, water vapour and energy conservation and includes particular transport terms for convection, diffusion or conduction. This kind of modelling efforts has been continued and more developed models have been obtained (Brooks et al. (1988), Schmal (1989), Edwards (1990), Arisoy and Akgun (1994)). However, it is still necessary to develop a model considering all of the affecting parameters sufficiently and to give more realistic results for practical applications. Models solely in one - dimensional can consider only the vertical or the horizontal variations of parameters in the pile. However, actual processes are at least two - dimensional. But the numerical solution of two - dimensional model equations requires much more computer time due to large scale of the pile and time dependency of the process. It may therefore be necessary to make an acceptable assumption to avoid time consumption. Buurn (1981) assumes that heat conduction in the coal pile is effective only in the vertical direction and he solves the one - dimensional energy equation analytically in this direction. He investigated critical ignition conditions depending on coal reactivity. A sinusoidal temperature distrubution is assumed in the vertical direction in Baums model. These entire models provide information that there is a significant role of hotspot. Considering this, a model is been prepared in Transient thermal Analysis (ANSYS).

1. Simulation model outline

A heat-generation simulation of a coal pile (hereinafter "pile simulation") has been designed to accurately reproduce the heat generation behavior inside piles. The following three behaviors were studied in detail and were modeled:

i) The behavior of air flowing inside the pile,
ii) The low-temperature oxidation behavior of coal inside the pile, and
iii) These models were incorporated into the software for general-purpose thermal fluid analysis (ANSYS Transient Thermal Anlaysis), which makes it possible to perform unsteady analysis taking into account the heat transfer, flow and reaction in a large-scale pile. As a result, the heat generation characteristics of various coals during storage can now be predicted by simply obtaining their physical properties from small-scale tests. This eliminates the need for measuring the temperatures of large test piles.

2. Numerical Modeling of low-temperature coal oxidation

ANSYS software Transient thermal Analysis was used to simulate the physical processes involved in the self-heating phenomenon. ANSYS Transient thermal Analysis is a solver with capabilities ranging from transport equations to chemical reactions modeling applications. The spontaneous heating of coal was modelled as a surface chemical reaction, coal oxidation, occurring on the coal surface and internal heat is generated inside the coal stockpile. The heat generated from coal oxidation is dissipated by convection and conduction, while oxygen and oxidation products are transported by convection and diffusion.

The physical model of the stockpile was developed on the following assumptions:

a) Truncated pyramid shape with the following dimensions: length 120 m, width 30 m, height 20 m, angle of the side slopes 60 °;
b) Initial temperature within the stockpile constant at any location and equal to 22 °C;
c) Coal particles have regulated shape (sphere);
d) Temperature at the interface of the stockpile with the soil was 22 °C
e) Meteorological data (ambient temperature, wind velocity and direction, air humidity) Wind Velocity was 5 W/m^2. °C
f) Natural Convection flow within the stockpile and surrounding.

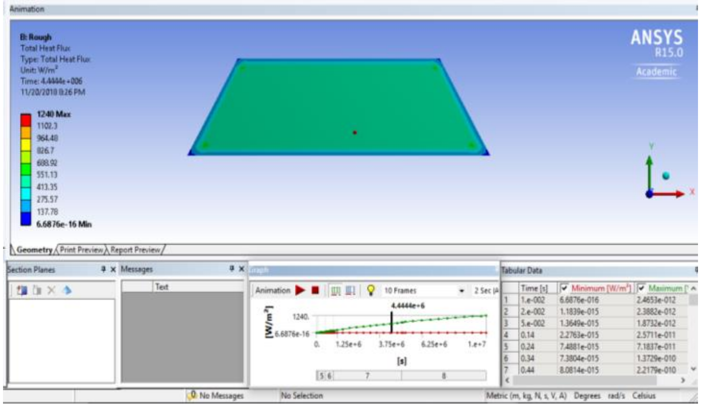
For- a first approximation the following basis was taken:

1. the model is non-steady, 2dimensional;
2. only the heat effects of oxidation are taken into account, the dependence of reaction rate on temperature being described by means of the Arrhenius equation and the dependence of reaction rate on oxygen gas concentration being assumed to be first order but capable of being varied;
3. in heat transfer, both conduction and convection are considered;
4. in the transport of oxygen, both diffusion and convection are considered;
5. it is assumed that gas flow velocity and porosity in the pile are independent of time and space;
6. the local temperatures of the coal and gas phase are assumed to be equal;
7. Accumulation of heat in the gas phase is neglected, because it is much smaller than in the coal.
8. The value of few parameters that are considered for the analysis of coal are presented in Table. 1.

TABLE I. COAL VALUES THAT ARE TAKEN FOR SIMULATION

Properties	Values
Density	1400 kg m^-3
Specific Heat	1680 J kg^-1 C^-1
Thermal Conductivity	0.33 W m^-1 C^-1
Vaporization Temperature C	126.85
Boiling Point C	126.85
Binary Diffusivity	4.e-005
Volatile Fraction	0.129
Combustible Fraction	0.791
Swelling Coefficient	1.4
Emissivity	0.9

2 D Analysis



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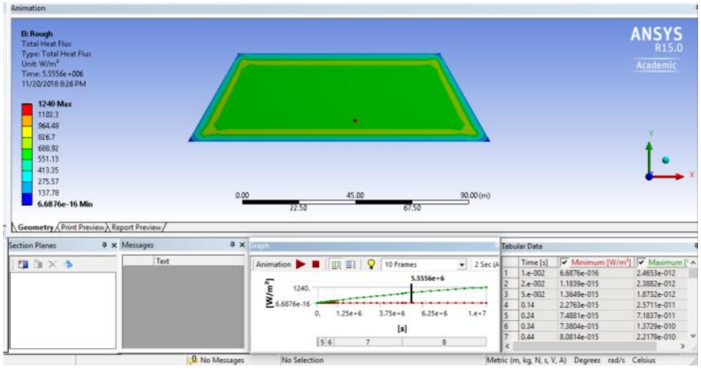
2	2.e-002	1.1839e-015	2.3882e-012
3	5.e-002	1.3649e-015	1.8732e-012
4	0.14	2.2763e-015	2.5711e-011
5	0.24	7.4881e-015	7.1837e-011
6	0.34	7.3804e-015	1.3729e-010
7	0.44	8.0814e-015	2.2179e-010



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3	5.e-002	1.3649e-015	1.8732e-012
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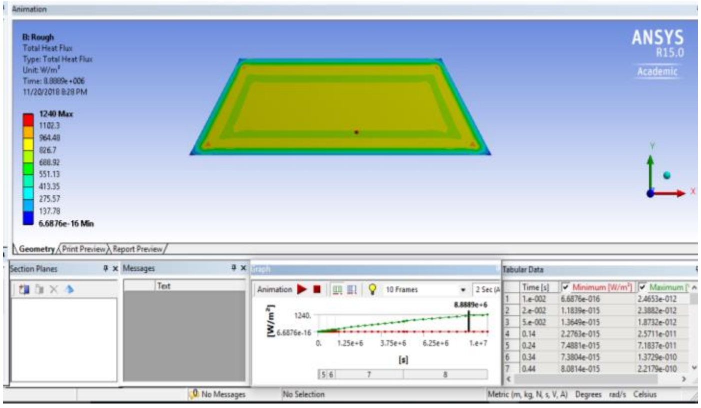

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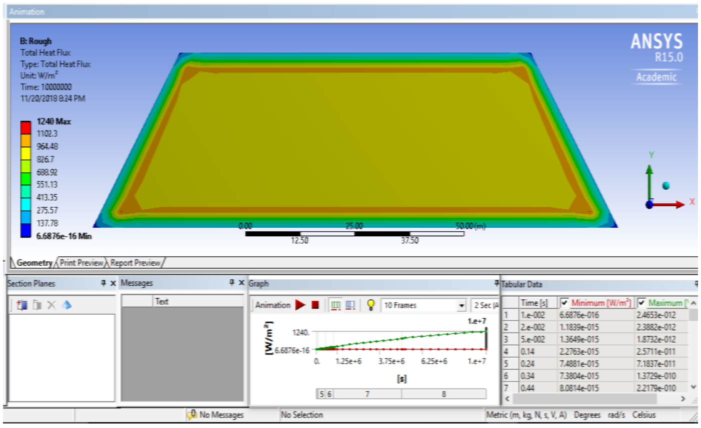

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3	5.e-002	1.3649e-015	1.8732e-012
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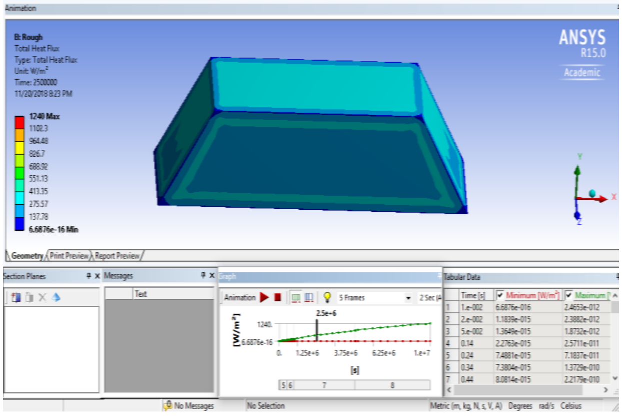
3D Analysis



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3	5.e-002	1.3649e-015	1.8732e-012
4	0.14	2.2763e-015	2.5711e-011
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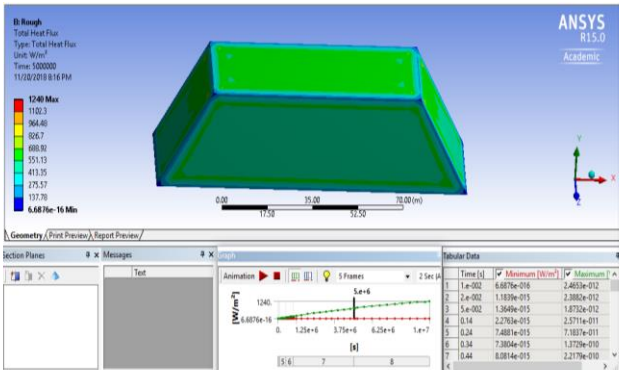

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3	5.e-002	1.3649e-015	1.8732e-012
4	0.14	2.2763e-015	2.5711e-011
5	0.24	7.4881e-015	7.1837e-011
6	0.34	7.3804e-015	1.3729e-010
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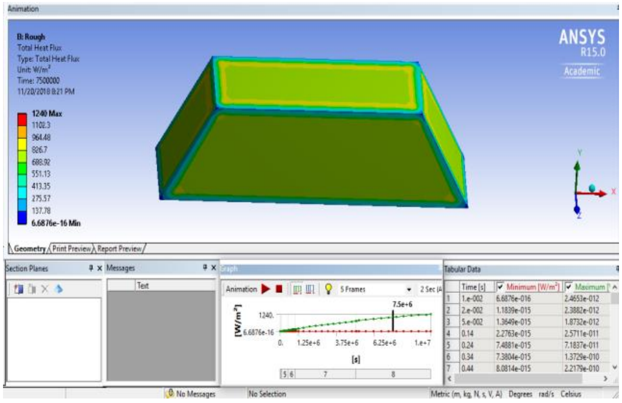

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3	5.e-002	1.3649e-015	1.8732e-012
4	0.14	2.2763e-015	2.5711e-011
5	0.24	7.4881e-015	7.1837e-011
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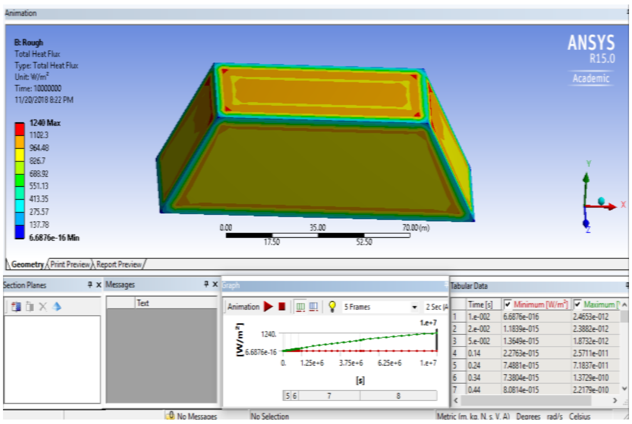

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2	2.e-002	1.1839e-015	2.3882e-012
3	5.e-002	1.3649e-015	1.8732e-012
4	0.14	2.2763e-015	2.5711e-011
5	0.24	7.4881e-015	7.1837e-011
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7	0.44	8.0814e-015	2.2179e-010

IV. ANALYSIS AND INTERPRETATION

Based on the study, the following things can be drawn:

(a) The existence of “Hotspot” of maximum temperature of the coal piles is not located at centerline, but typically about 2m in from the sides.

(b) The Hotspot migrates from center toward periphery.

(c) The temperature of the Hotspot increases steadily with time.

Both 2 D model and 3 D model are considered from nine months. Convection and Internal Heat generation are the major factors for heat generation in stockpile.

V. CONCLUSIONS

The results of spontaneous combustion(coal stockpile fire) are serious and can cause adverse environmental effect, nation’s reserve loss, economic loss and many more. The heat build-up in stored coal can degrade the quality of coal, cause it to weather, and lead to a fire. To prevent these the processes that lead to coal self-heat must be understood and precautions must be taken to avoid fires caused by spontaneous combustion. Accordingly, if sufficient information and adequate safety measures are adopted, the chances of occurrences of the accident can be reduced. The model study can provide enough information about the time duration and rate of reaction.

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