Characterization of coal mine panels in bord and pillar workings in respect of their proneness to spontaneous heating—a prediction model

by T.R. Roy*

Synopsis

A prediction model, developed by Central Mining Research Institute (India) for evaluation of fire risk rating of underground coal mine panels in bord and pillar working in respect of their proneness to spontaneous heating, is presented in this paper. The concept used in this model is innovative and user friendly. This model may be applied to a panel where extraction is carried out using any of the techniques: i) depillaring with formation of small pillars as final operation, ii) extraction by broadening of galleries, iii) depillaring with hydraulic sand stowing, and iv) depillaring with caving.

Here, major fire risk parameters are short-listed and divided into three broad groups in accordance with the nature of their contribution to the spontaneous heating of a mine panel. The paper describes the procedure for estimating the fire risk rating of individual groups using separate objective type models developed for this purpose. Then it evaluates the overall fire risk rating of the panel by combining the fire risk ratings of all the three broad groups. The model is tested with the field data collected from different collieries spreading across the country and with the laboratory data for critical assessment of fitness.

Keywords : prediction model, fire risk rating of panel, spontaneous heating of coal, underground panel, bord and pillar working.

Introduction

Spontaneous heating is often found to be the cause of fire in underground coal mine panels. Due to this phenomenon, an enormous amount of coal is reduced into ashes every year and in the process the working environment is disturbed. Many a time mines are closed down for safety reasons.

It is well established that spontaneous heating of coal depends mainly on two types of parameters: intrinsic and extrinsic. Parameters associated with nature of coal (i.e. its physico-chemical characteristics, petrographic distribution and mineral make-up) are intrinsic. On the other hand, extrinsic parameters are related to atmospheric, geological and mining conditions. Scope of leakage of air, status of ventilation, wetness of mines, gassiness of seam, geological disturbances, system of extraction, size of panel etc. are examples of extrinsic parameters.

There are two prediction models for evaluation of fire risk potential of coal mine panels that we have come across, one model has been developed by Feng *et al.*[1] in Canada, and the other one by Olpinski and his colleagues Banerjee[2] in Poland. Besides these models, the works of Banerjee[3] and Singh *et al.*[4] in India, Didari and Kaymakci[5] in Turkey, deserve sincere attention.

As the above models are either difficult to use or oversimplified, it triggered the Mine Fire Department of CMRI to develop a new model that is easy to use, effective and universally applicable to underground panels. Since most of the mines in India are worked by the bord and pillar method of mining, our model has been designed for this method to serve a maximum number of mines. Among the systems of extraction in the bord and pillar method, depillaring with formation of small pillars as final operation, extraction by broadening galleries, depillaring with hydraulic sand stowing, and depillaring with caving are very common in Indian mines and so this prediction model is applicable to these systems of extraction only.

This model was developed sometime back, and a part of it was also published by the author Roy[6]. Thereafter, this model has undergone a significant improvement on the basis of the experience gained through subsequent applications. Here, we present the improved version of the model.

Major fire risk parameters and building modules

To describe a mining scene in a bord and pillar working, about twenty major fire risk parameters have been short-listed and, in accordance with the nature of contribution to the causes of spontaneous heating, these

* *Central Mining Research Institute, Jharkhand, India*

 SA ISSN 0038–223X/3.00 + 0.00. Paper received Jun. 2002; revised paper received Oct. 2003.

parameters have been divided into three broad groups, viz. *i)* panel specifics, ii) environment, and iii) coal and seam characteristics. To determine the fire risk rating of an individual group, separate objective type models have been developed using respective constituent parameters. These models, referred to as 'building modules', have been later selectively used to form the desired prediction model for evaluation of the overall fire risk rating of the panel.

Panel specifics

The parameters taken into this group are i) system of depillaring, ii) state of extraction, iii) seam thickness, iv) parting, v) nature of extraction, vi) scope of accumulation of coal fines, vii) state of consolidation of coal mass, viii) size of panel, and ix) heat dissipation by conduction.

This group of parameters has three modules. Module 1a, which is applicable to the panels where depillaring is done with the formation of small pillars as the final operation or coal is extracted by broadening of galleries, is given in Table Ia. Two other modules, applicable to i) depillaring with hydraulic sand stowing (Module 1b), and ii) depillaring with caving (Module 1c), are also given in Tables Ib and Ic respectively.

Procedure for estimation of fire risk rating of a group

Most of the parameters of the group 'panel specifics' possess more than one fire risk aspect. To estimate the fire risk value of a module, we first determine the fire risk number of every individual parameter. It is done by assigning a set of suitable digits such as (0,1,2), (1,2,3,4) etc. against each parameter, where an individual digit corresponds to a particular fire risk aspect of the parameter. The lowest digit stands for the aspect that has least risk of spontaneous heating, while the highest one corresponds to the aspect that has maximum risk. In a case study, an appropriate fire risk aspect with an assigned digit is selected from the list given with every individual parameter. We call the assigned digit the 'fire risk number of the parameter' and it is denoted by N_i ('i' stands for the ith parameter). However, it is to be remembered that this fire risk numbering technique is purely subjective. When the fire risk numbers of all the concerned parameters are added, the total number ($\sum N_i$) is called the 'fire risk number of the module'. For the group 'panel specifics', it varies from 0 to 10. Thereafter, a qualifying value of 0.1 is attached to every unit of the fire risk number of the module, and so the quantity ($0.1 * \sum N_i$) varies from 0 to 1.0. We call it 'fire risk value of the module'.

In the case of the group 'coal and seam characteristics', the total fire risk number of the module may vary up to 25. When it is multiplied by 0.04, the fire risk value of the module may go up to 1.00.

Environment

The constituent parameters of this group are i) geological disturbances (fault, dyke etc.) that facilitate leakage of air into a panel, ii) leakage of air from surface / through parting / through barrier pillar, panel barrier, isolation stopping etc. iii) ventilation of the panel during extraction of coal, iv) ventilation in undesired route outside an unsealed panel that may provoke risk of fire, v) ventilation in undesired route outside a sealed panel that may be a source of air leakage and vi) incubation period of coal seam. As given below, three auxilliary models have been prepared with these parameters.

i) Model 2a: This model is related to the leakage of air into an unsealed / sealed panel from the surface / through parting / due to the existence of geological disturbances.
ii) Model 2b: It is associated with the environment of an unsealed panel. Ventilation of a panel during extraction of coal, ventilation in undesired route that may provoke risk of fire, and incubation period of coal seam have been considered in this model.
iii) Model 2c : This model is related to the environment of a sealed panel. Leakage of air through barrier pillar, panel barrier, isolation stopping etc. and ventilation in undesired route outside a sealed panel that may be a source of air leakage are the parameters of this model.

Modules 2ab and 2ac

A list of causes that make the environment of an unsealed panel fire provocative has been prepared by combining Models 2a and 2b. The group 'environment' is then characterized into three different fire risk ratings: low (E), high (E), and very high (E) in accordance with the nature of the cause(s), where 'E' signifies environment. As it will not lose much significance, Models 2a and 2b are not presented here. But, the list of causes with assigned fire risk ratings (Module 2ab) is given in Table II.

For a sealed panel, Models 2a and 2c are combined to prepare a list of fire provocative causes. Without losing much relevance we are omitting the model 2c, but the list of fire provocative causes with fire risk rating (Module 2ac) is given in Table III.

Coal and seam characteristics

The parameters falling in this group are independent of mining and environmental conditions. The constituent parameters are: i) category of coal in respect of its proneness to spontaneous heating (crossing point temperature), ii) wetness of mines, iii) inherent moisture of the coal, iv) existence of pyrite band in coal seam, v) particle size distribution in coal fines, and vi) gassiness of seam. The building module of this group (Module 3) is presented in Table IV.

Evaluation of overall fire risk rating of mine panels

As seen from the nature of the constituent parameters, all the three groups of parameters have their own roles in underground fires. So, the overall fire risk rating of an underground panel may be obtained by combining the fire risk ratings of Module 1a or 1b or 1c, Module 2ab or 2ac, and Module 3.

Hence, the overall fire risk rating of a selected panel ⇒ a combination of (the fire risk rating of the group 'panel specifics' (obtained by using Module 1a or 1b or 1c)), (the fire risk rating of the group 'environment' (obtained by using Module 2ab or 2ac)), and (the fire risk rating of the group 'coal and seam characteristics' (obtained by using Module 3)) ⇒ Low (O) / High (O) / Very high (O).

Table Ia

Module 1a: Building module of the group 'panel specifics'

(Applicable to depillaring with formation of small pillars as final operation or to extraction by broadening of galleries)

Parameters	Fire risk number of individual parameters (N_i)
State of extraction *(With the assumption that there is no coal in roof)*	**(1,2,3)**
i) Developed panel (extraction not started)	(1)
ii) Depillaring panel	(2)
iii) Extraction not completed, loose coal cleared from the floor, panel sealed temporarily	(2)
iv) Extraction incomplete, loose coal lying on the floor, area left unattended	(3)
v) Extraction complete (entirely depillared panel)	(2)
Nature of extraction with due consideration of seam thickness *(Developed / completely depillared / depillaring panel)*	**(0,1)**
i) Extraction in single lift	(0)
ii) Extraction may be carried out in more than one lift (Panel area has a top section, virgin or otherwise)	(1)
Existence of coal in roof *(Developed / completely depillared / depillaring panel)* *(Coal in upper seam separated by a narrow parting may also be taken into account)* *[In case of a developed panel, coal left in roof during development is measured / in case of a completely depillared panel, coal left in roof after depillaring is measured / in case of a depillaring panel, coal left in roof is measured either in the developed area or in the depillared area (as prevailing in the major portion of the panel)]*	**(0,1)**
i) Less than 1.5 m coal in roof	(0)
ii) If it is 1.5 m or above	(1)
Frequency of roof fall *(Developed / completely depillared / depillaring panel)* *[In case of a developed panel, coal left in roof during development is measured / in case of a completely depillared panel, coal left in roof after depillaring is measured / in case of a depillaring panel, coal left in roof is measured either in the developed area or in the depillared area (as prevailing in the major portion of the panel)]*	**(0,1)**
i) When coal in roof is less than 1.5 m (No roof fall / occasional roof fall / frequent roof fall) (For any state of the panel as mentioned earlier)	(0)
ii) When coal in roof is 1.5 m or more (No roof fall / occasional roof fall) (For any state of the panel as mentioned earlier)	(0)
iii) When coal in roof is 1.5 m or more (For any state of the panel as mentioned earlier) (Frequent roof fall. It has two options)	
a) Not heavy roof fall Max. height of roof fall: not more than 1.5 m or so (As understood from earlier roof fall incidents in the area)	(0)
b) Heavy roof fall Max. height of roof fall: sometimes even more than 1.5 m or so (As understood from earlier roof fall incidents in the area)	(1)
Existence of crushed or cracked pillars in the panel *(It may be due to heavy overburden, intensive mining etc.)*	**(0,1)**
i) Such a pillar does not exist	(0)
ii) This type of pillar exists	(1)
Size of panel *(Developed / completely depillared / depillaring panel)* *(Sealed / unsealed panel)*	**(0,1,2)**
i) up to 30 pillars	(0)
ii) 31 to 50 pillars	(1)
iii) above 50 pillars	(2)
Heat dissipation by conduction *(Developed / completely depillared / depillaring panel)*	**(0,1)**
i) Coal exists neither in the roof nor in the floor	(0)
ii) Coal exists either in the roof or in the floor	(0)
iii) Coal exists in the roof as well as in the floor (In case of extraction in single lift / more than one lift)	(1)
Therefore, total fire risk number of Module 1a	**= ΣN_i**
Corresponding fire risk value of Module 1a	**= ΣN_i * 0.1**
Hence, the fire risk rating of Module 1a : Low(P) / High(P) / Very high(P), depending on the fire risk value as given below: It is Low (P), (for fire risk value up to 0.4) High (P), (for fire risk value from 0.5 to 0.7) Very high (P), (for fire risk value from 0.8 to 1.0)	

Table Ib

Module 1b: Building module of the group 'panel specifics'

(Applicable to depillaring with hydraulic sand stowing)

Parameters	Fire risk number of individual parameters (N_i)
State of extraction (With the assumption that there is no coal in roof)	**(0,2,3)**
i) Entirely depillared and fully stowed panel (Extraction complete)	(0)
ii) Depillaring panel	(2)
iii) Extraction not completed, loose coal cleared from the floor, panel sealed temporarily	(2)
iv) Extraction incomplete, loose coal lying on the floor, area left unattended	(3)
Nature of extraction with due consideration of seam thickness *(Completely depillared / depillaring panel)*	**(0,1)**
i) Extraction in single lift	(0)
ii) Extraction may be carried out in more than one lift (Where upper section is virgin)	(0)
iii) Extraction may be carried out in more than one lift (Where upper section is not virgin)	(1)
Existence of coal in roof *(Completely depillared / depillaring panel)* *(Coal in upper seam separated by a narrow parting may also be taken into account)* *[In case of a depillaring panel, coal left in roof is measured either in the developed or in the unstowed depillared area (as prevailing in the major portion of the panel) / in case of a completely depillared and stowed panel, this factor need not be considered]*	**(0,1)**
i) Less than 1.5 m coal in roof	(0)
ii) If it is 1.5 m or above	(1)
iii) Completely depillared and stowed panel	(0)
Frequency of roof fall (*Completely depillared / depillaring panel)* *[In case of a depillaring panel, coal left in roof is measured either in the developed or in the unstowed depillared area (as prevailing in the major portion of the panel) / in case of a completely depillared and stowed panel, this factor need not be considered]*	**(0,1)**
i) When coal in roof is less than 1.5 m (No roof fall / occasional roof fall / frequent roof fall) (For any state of the panel as mentioned earlier)	(0)
ii) When coal in roof is 1.5 m or more (No roof fall / occasional roof fall) (For any state of the panel as mentioned earlier)	(0)
iii) When coal in roof is 1.5 m or more (Frequent roof fall. It has two options) (For any state of the panel as mentioned earlier)	
a) Not heavy roof fall Max. height of roof fall: not more than 1.5 m or so (As understood from earlier roof fall incidents in the area)	(0)
b) Heavy roof fall Max. height of roof fall: sometimes even more than 1.5 m or so (As understood from earlier roof fall incidents in the area)	(1)
Existence of crushed or cracked pillars in the developed area of a depillaring panel *(It may be due to heavy overburden, intensive mining etc.)* *(In case of a completely depillared and stowed panel, this factor need not be considered)*	**(0,1)**
i) Such a pillar does not exist	(0)
ii) This type of pillar exists	(1)
Size of panel *(Unsealed depillaring panel)*	**(0,1,2)**
i) up to 30 pillars	(0)
ii) 31 to 50 pillars	(1)
iii) above 50 pillars	(2)
(Completely / partially depillared, stowed and sealed panel)	
i) up to 50 pillars	(0)
ii) above 50 pillars	(1)
Heat dissipation by conduction *(Completely depillared / depillaring panel)*	**(0,1)**
i) Fully stowed panel with or without coal in roof	(0)
ii) Coal exists neither in the roof nor in the floor	(0)
iii) Coal does not exist in the roof, but may exist in the floor	(0)
iv) Coal exists in the roof, it may or may not exist in the floor (In case of extraction in single lift / more than one lift)	(1)

The fire risk rating of Module 1b may be obtained in the same way as in the case of Module 1a.

Table Ic

Module 1c: Building module of the group 'panel specifics'

(Applicable to depillaring with caving)

Parameters	Fire risk number of individual parameters (N_i)
State of extraction *(With the assumption that there is no coal in roof)*	**(3,4)**
i) Entirely depillared panel (Extraction complete)	(4)
ii) Depillaring panel	(3)
iii) Extraction not completed, loose coal cleared from the floor, panel sealed temporarily	(4)
iv) Extraction incomplete, loose coal on the floor, area left unattended	(4)
Nature of extraction with due consideration of seam thickness *(Completely depillared / depillaring panel)*	**(0,1)**
i) Extraction in single lift	(0)
ii) Extraction may be carried out in more than one lift (Panel area has a top section, virgin or otherwise)	(1)
Existence of coal in roof *(Completely depillared / depillaring panel)* *(Coal in upper seam separated by a narrow parting may also be taken into account)* *[In case of a depillaring panel, coal left in roof is measured either in the developed area or in the depillared area (as prevailing in the major portion of the panel) / in case of a completely depillared panel, coal left in roof after depillaring is measured]*	**(0,1)**
i) Less than 1.5 m coal in roof	(0)
ii) If it is 1.5 m or above	(1)
Size of panel *(Completely depillared / depillaring panel)* *(Unsealed / sealed panel)*	**(0,1,2)**
i) up to 30 pillars	(0)
ii) 31 to 50 pillars	(1)
iii) above 50 pillars	(2)
Heat dissipation by conduction *(Completely depillared / depillaring panel)* *[In case of a depillaring panel, coal left in roof is measured either in the developed area or in the depillared area (as prevailing in the major portion of the panel) / in case of a completely depillared panel, coal left in roof after depillaring is measured]*	**(0,1,2)**
i) Coal exists neither in the roof nor in the floor	(0)
ii) Coal exists in the roof (1.5 m of coal or more)	(1)
iii) Coal exists both in the roof as well as in the floor (In case of extraction in single lift or the thickness is not enough for more than one section)	(1)
iv) Coal exists in the floor and there is a top section (virgin or otherwise)	(2)

The fire risk rating of Module 1c may be obtained in the same way as in the case of Module 1a.

Table II

Module 2ab: Fire provocative environment and characterization of the causes

(Applicable for characterizing the environment of an unsealed panel)

1) When there is a substantial leakage of air into a depillaring panel (there is loose coal affected by the leakage), fire risk rating ⇒ **Very high (E)**
2) When there is a substantial leakage of air into a depillaring panel (depillared area is affected by the leakage, but there is no loose coal), fire risk rating ⇒ **High (E)**
3) When the quantity of air flow in a depillaring panel is insufficient (sluggish ventilation), fire risk rating ⇒ **Very high (E)**
4) When the loose coal on the floor of a depillaring panel is exposed to the ventilating air and the panel is unattended, fire risk rating ⇒ **Very high (E**)
5) When the depillared area of a running panel is left exposed to the ventilating air, fire risk rating ⇒ **High (E)**
6) When a completely depillared and unsealed panel with sufficient coal in it is at close proximity to a ventilating route, fire risk rating ⇒ **High (E)**
7) When there is a subsidence or cracks on the surface (in case of shallow overburden of width less than 50 m or so), fire risk rating ⇒ **High (E)**
8) When a depillaring panel is affected by a geological disturbance, fire risk rating ⇒ **High (E)**
9) When depillaring time exceeds the incubation period of a seam, fire risk rating ⇒ **High (E)**
10) When a cause of air leakage / heating is supplemented by another cause making the situation more prone to heating, fire risk rating ⇒ **Very high (E)**
11) When a panel is free from any of the above listed causes of fire, fire risk rating ⇒ **Low (E)**

Table III

Module 2ac: Fire provocative environment and characterization of the causes

(Applicable for characterizing the environment of a sealed panel)

1) When there is a substantial leakage of air and there is loose coal affected by the leakage, fire risk rating ⇒ **Very high (E)**
2) When there is a substantial leakage of air and the panel has sufficient coal in it, fire risk rating ⇒ **Very high (E)**
3) When there exists a cause posing a threat of air leakage, fire risk rating ⇒ **High (E)**
4) When there is a subsidence or crack on the surface (in case of shallow overburden of width less than 50 m or so), fire risk rating ⇒ **High (E)**
5) When a panel is affected by a geological disturbance and there is sufficient coal in it, fire risk rating ⇒ **High (E)**
6) When a cause of air leakage / heating is supplemented by another cause making the situation more prone to heating, fire risk rating ⇒ **Very high (E)**
7) When a panel is free from any of the above listed causes of fire, fire risk rating ⇒ **Low (E)**

Table IV

Module 3: Building module of the group 'coal and seam characteristics'

(Independent of mining and environmental conditions)

Parameters	Fire risk number of individual parameters (Ni)
Crossing Point Temperature (CPT)	**(1,2,3,4,5,6,7,8,9)**
i) CPT is less than 110°C	(9)
ii) 110°C or more but less than 120°C	(8)
iii) 120°C or more but less than 130°C	(7)
iv) 130°C or more but less than 140°C	(6)
v) 140°C or more but less than 150°C	(5)
vi) 150°C or more but less than 160°C	(4)
vii) 160°C or more but less than 170°C	(3)
viii) 170°C or more but less than 180°C	(2)
ix) 180°C and above	(1)
Wetness of mines *(In the case of the floor as well as both sides of galleries being fully or partially wet, the mine / panel is taken to be wet. Otherwise, it is considered dry. This assessment of wetness is purely subjective)*	**(1,2)**
i) Dry mine	(1)
ii) Wet mine	(2)
Inherent moisture of the coal *(Obtained by proximate analysis)*	**(0,1,2)**
i) Moisture content is less than 2%	(0)
ii) It is 2–5 %	(1)
iii) It is more than 5%	(2)
Existence of pyrite band	**(0,1,2,3,4,5,6)**
(For dry mines)	
i) No pyrite band exists	(0)
ii) Pyrite bands exist and total thickness is less than 0.25 m	(1)
iii) Total thickness: 0.25 m or more but less than 0.5 m	(2)
iv) Total thickness: 0.5 m or more but less than 0.75 m	(3)
v) Total thickness: 0.75 m or above	(4)
(For wet mines)	
i) No pyrite band exists	(0)
ii) Pyrite bands exist and total thickness is less than 0.25 m	(3)
iii) Total thickness : 0.25 m or more but less than 0.5 m	(4)
iv) Total thickness : 0.5 m or more but less than 0.75 m	(5)
v) Total thickness : 0.75 m or above	(6)
Particle size distribution in coal fines *(Sampling from the heap of loose coal is done following a technique called 'cone and quartering')*	**(1,2,3)**
i) When -BS40+BS72 size fraction is > -BS72 size fraction + a margin of 25% of this size fraction	(1)
ii) When -BS40+BS72 size fraction is < -BS72 size fraction - a margin of 25% of this size fraction	(3)
iii) When -BS40+BS72 size fraction is ≤ -BS72 size fraction + a margin of 25% of this size fraction & ≥ -BS72 size fraction - a margin of 25% of this size fraction *[The size fractions are expressed in weight percentage (wt%)]*	(2)
Gassiness of coal seam	**(1,2,3)**
i) Degree I	(1)
ii) Degree II	(2)
iii) Degree III	(3)

Therefore, total fire risk number of Module 3 = $\sum N_i$

Corresponding fire risk value of Module 3 = $\sum N_i$ * 0.04

Hence, the fire risk rating of Module 3 : Low(C) / High(C) / Very high(C),
depending on the fire risk value as given below:
It is Low (C), (for fire risk value up to 0.44)
High (C), (for fire risk value from 0.48 to 0.64)
Very high (C), (for fire risk value from 0.68 to 1.0)

The procedure for estimation of the overall fire risk rating of a panel may be found in the article by Roy[6]. It is an average of the fire risk ratings of Module 1a/1b/1c, Module 2ab/2ac, and Module 3. To estimate the overall fire risk rating of a panel, we first attach three equidistant integer values 1, 2, and 3 respectively to the possible fire risk ratings 'low', 'high' and 'very high' of each group. For a particular panel, the fire risk rating of each of the selected modules is determined separately, and then the arithmetic mean of the integer values, associated with the fire risk rating of each group, is calculated and rounded off to the nearest integer value. This value, when expressed as 'low' or 'high' or 'very high', gives the overall fire risk rating of the panel.

Worked example

A worked example is given below to help the readers to have a better understanding of the prediction model.

Details of the panel

Durgapur-Rayatwari Colliery / WCL (subsidiary of CIL)/Rayatwari (seam)/16.87m (seam thickness at the bore hole D-24) / I in 5 (inclination)/Grade C & D (coal) / No fire panel existed in the nearby area / Extraction in lower section / Bord and pillar working / Hydraulic sand stowing / Part-panel 8 / Fire in depillaring panel.

Response of the panel to Module 1b

State of extraction

iv) Extraction incomplete, loose coal on the floor, area left unattended (3)

Nature of extraction with due consideration of seam thickness

ii) Extraction may be carried out in more than one lift (where upper section was virgin) (0)

Existence of coal in roof

ii) It was 1.5 m or above (1)
(11.0 m or so coal left in the roof during development)

Frequency of roof fall

iii) Coal in roof is 1.5 m or more (frequent roof fall)
b) Heavy roof fall (1)
Max. height of roof fall: sometimes even more than 1.5 m or so
(as understood from earlier roof fall incidents in the area)

Existence of crushed or cracked pillars in the panel

i) Such a pillar did not exist (0)

Size of panel

ii) 31 to 50 pillars (1)
[40 pillars (22 m x 22 m)]

Heat dissipation by conduction

iii) Coal existed in the roof as well as in the floor (1)
[11 m (approx.) coal in the roof and 2.5m (approx.) coal in the floor left during development]

Therefore, total fire risk number = 7
Corresponding fire risk value = 7 * 0.1 = 0.7
Hence, the fire risk rating of the group 'panel specifics' : High(P)

Response of the panel to Models 2a and 2b

Surface cover: 140 m approx. / No subsidence above the panel / No geological disturbances affecting the panel / Ventilation status: normal / Work on preparatory isolation stopping was being carried out as usual / Incubation period of the seam: 1 to 1.5 years, depillaring started approximately three months before it caught fire / Due to the presence of pyrite band in coal seam and moist atmosphere of the mine, the coal is very susceptible to spontaneous heating / Loose coal, exposed to ventilating air, was lying on the floor for several hours.

Response of the panel to Module 2ab

4) Loose coal on the floor of a depillaring panel is exposed to the ventilating air and the panel is unattended, fire risk rating ⇒ Very high (E)

Response of the panel to Module 3

Crossing Point Temperature (CPT)

iv) 130°C or more but less than 140°C (6)
[CPT : 136°C (bottom section)]

Wetness of mines

ii) Wet mine (2)

Inherent moisture content of the coal

iii) It is more than 5% (2)
[inherent moisture : 9.4 % (bottom section)]

Existence of pyrite band

iii) Total thickness : 0.25 m or more but less than 0.5 m (wet mine) (4)

Particle size distribution in coal fines

i) When -BS40+BS72 size fraction is > -BS72 size fraction + a margin of 25% of this size fraction (1)
[-BS40 +BS72 size fraction: 3.38% of sample size
-BS72 size fraction: 0.95% of the sample size
Sample size (-12.5 mm to -BS200): 2.005 kg]

Gassiness of coal seam

i) Degree I (1)

Therefore, total fire risk number = 16
Corresponding fire risk value = 16* 0.04 =0.64
Hence, the fire risk rating of the group 'Environment' : High(C)
Therefore, the overall fire risk rating of the panel ⇒ a combination of the fire risk rating of the group 'Panel specifics', the fire risk rating of the group 'Environment' and the fire risk rating of the group 'Coal and seam characteristics',
that is, a combination of High (P), Very high (E) and High (C)
⇒ High (O), as explained in an earlier section.

Inference on the test results of the above panel

As the overall fire risk rating of the panel is found to be 'High (O)', it may be predicted that either it is a fire panel or there is a chance of fire breaking out in the panel. However, in the field we observed that it was a fire panel.

Efficacy of the prediction model

Literally, the overall fire risk rating of a panel is 'high' or 'very high' means that the panel is 'unsafe' from the point of catching fire. When it is 'low', the panel is 'safe' from fire. In case of unsafe panels, the scope of reaction in the system (coal and air combination) for spontaneous heating is high or very high, and an amount of time is required by the system to reach the critical stage of spontaneous heating. However, the scope of reaction can be arrested either by removing the loose coal or by cutting off the supply line of air. These remedial measures are taken within an appropriate time to avoid fire in unsafe panels.

During field verification of the prediction model, we were interested in fire panels having symptoms of fire, not in unsafe panels with a chance of possible fire break out, except one for demonstration, to avoid controversy and satisfy the readers. We also did not include those panels with an overall fire risk rating of high or very high, where remedial measures were taken before catching fire.

Efficacy of the prediction model has been tested with the data related to 27 selected panels in 12 different seams of 11 collieries, representing BCCL, CCL, ECL, MCL, SECL and WCL, the subsidiaries of Coal India Limited. The inference made on the basis of the model, have been found to agree with the exact physical status of the panels in 26 cases (some of these test results are given in Table V). Although the fire risk rating of the remaining panel was evaluated as high indicating that it was a fire panel. However, at the time of our visit to the colliery, we observed no sign of fire in the panel (please see the test results of Part-panel 6 in Table V). A quantity survey showed a considerable amount of leakage into the panel from the surface and so the panel could catch fire at any time, unless the affected coal was completely weathered or necessary remedial measures were taken.

Remarks and conclusions

Under each parameter, as in Modules 1a,b,c and 3, a number

Table V

Prediction results and observed status of some panels

Sl. No.	Panel/colliery/ subsidiary of CIL/seam/ system of extraction	Fire risk rating of the groups of parameters			Overall fire risk rating of the panel (obtained by using the prediction model)	Observed status of the panel
		Fire risk rating of the group 'panel specifics'	Fire risk rating of the group 'environment'	Fire risk rating of the group 'coal seam characteristics'		
1.	Part panel-8/ Durgapur Rayatwari Colliery/WCL/ Rayatwari/depillaring with hydraulic sand stowing	HIGH (Fire Risk Value: 0.7)	VERY HIGH (Following the list of causes of fire given earlier)	HIGH (Fire Risk Value: 0.64)	HIGH (As per the logic given earlier)	Fire in running panel
2.	Panel-5/ Methani Colliery/ECL/ Burradhemo/ depillaring with caving	LOW (Fire Risk Value: 0.4)	VERY HIGH (Following the list of causes of fire given earlier)	LOW (Fire Risk Value: 0.44)	HIGH (As per the logic given earlier)	Fire in sealed panel
3.	Panel-B/Chirimiri Colliery/SECL/ Seam 3/ extraction by broadening of galleries	LOW (Fire Risk Value: 0.3)	LOW (Following the list of causes of fire given earlier)	LOW (Fire Risk Value: 0.32)	LOW (As per the logic given earlier)	Non-fire sealed panel
4.	Panel-RP-4/ Deulbera Colliery/MCL /Talcher seam No.1 (bottom)/ depillaring with formation of small pillars as final operation	HIGH (Fire Risk Value: 0.5)	VERY HIGH (Following the list of causes of fire given earlier)	LOW (Fire Risk Value: 0.32)	HIGH (As per the logic given earlier)	Fire in unsealed panel
5.	Part-panel-6/ Methani Colliery/ ECL/Burradhemo/ depillaring with caving	LOW (Fire Risk Value: 0.4)	VERY HIGH (Following the list of causes of fire given earlier)	LOW (Fire Risk Value: 0.44)	HIGH (As per the logic given earlier)	Non-fire depillaring panel

Note : When the overall fire risk rating of a panel is 'Low ', the panel is predicted to be 'Safe (non-fire)'.
If it is 'High' or 'Very high', it is predicted to be a 'Unsafe (fire)' panel.

of distinct fire risk aspects with assigned fire risk numbers are given. During preparation of the modules, utmost care was exercised so that no major fire risk aspect of a parameter was left out. However, during the use of the prediction model, if a user finds a particular aspect is not available, he may judiciously choose an equivalent one with an assigned fire risk number from the list.

Since the colliery managers or mine safety officers keep proper information of underground panels, and also of the irregularities that may affect the safety of panels such as accumulation of loose coal, existence of unconsolidated coal mass, leakage of air from outside a panel, status of ventilation, undesired exposure of extracted area to ventilating air etc., they are probably the most suitable persons who can make best use of this model and take necessary remedial measures to reduce the fire risk potential of a panel in accordance with the demand of the situation. However, modification of this type of model is always a continuing process and this prediction model, too, has this scope for further improvement while dealing with more and more panels, probably by introducing new parameters or fire risk aspects. In fact, a parameter such as 'Ignition Point Temperature' could have been included in the model, particularly in the group 'coal and seam characteristics' as a new parameter. We could not accommodate this parameter in this report, since it would require collection of fresh coal samples from the collieries and further laboratory investigations for this purpose.

Finally, it is necessary to mention that coal mining and environmental influences may be of more importance than the intrinsic spontaneous heating liability in initiation of fire in a mine.

Acknowledgement

This research work is based on an S&T project [No.(CMPDIL): MT / 90 / 96] funded by the Ministry of Coal, Government of India. The author wishes to thank the Central Mine Planning & Design Institute (Ranchi) of Coal India Limited, for their involvement in the project, particularly to D.K. Jain, CGM (S&T / Spl. projects) for his impeccable monitoring and co-ordination during this project. The author also expresses heartfelt appreciation to A.K. Rudra, Director General, DGMS (Directorate-General of Mines Safety), for his suggestions during a meeting of Coal Mine Companies / Institutions of India, held at CMRI under his chairmanship on 16 February 2002, for implementation of the outcome of this project in all underground coal mines in India. The author is very grateful to Prof. D. D. Misra, Director, CMRI, for his advice during this project. The contributions of Dr. V. K. Singh, S. K. Ghosh, D. D. Banerjee and Dr. R.V.K. Singh, Scientists; G. Sural, Tech. Officer: Mine Fire Department, in laboratory work and field data collection are thankfully acknowledged by the author. Hearty thanks are also due to K. L. Banerjee, Scientist, BDIL Services, for his co-operation during preparation of this paper.

References

1. Feng, K. K., Chakravorty, R. N. and Cochrane, T. S. Spontaneous combustion—a coal mining hazard. *C I M Bulletin,* vol. 66, no. 738, 1973. pp. 75–84.
2. Banerjee, S. C. *Spontaneous combustion of coal and mine fires.* Oxford and IBH, India, 1985. p. 60.
3. Banerjee, S. C. A theoretical design to the determination of risk index of spontaneous fires in coal mines. *Journal of Mines, Metals and Fuels.* vol. 30, no. 8, 1982. pp. 399–406.
4. Singh, R. N., Demirbilek, S. and Turney, M. Application of spontaneous combustion risk index to mine planning, safe storage and shipment of coal. *Journal of Mines, Metals and Fuels.* vol. 32, no. 7, 1984. pp. 347–355.
5. Didary, V. and Kaymakci, E. Research into the spontaneous combustion characteristics of Turkish coal seams. *Proceedings National Conference on Prevention and Control of Mine and Industrial Fires—Trends and Challenges.* Dhar, B. B. and Acharya, A. K. (eds.). Central Mining Research Institute, Dhanbad, India, 1996. pp. 124–134.
6. Roy, T. R. An objective model for evaluation of spontaneous fire risk potential of underground panels extracted by bord and pillar method of mining with hydraulic sand stowing. *Journal of Mines, Metals and Fuels.* vol. 47, no. 11, 1999. pp. 310–316. ◆

Gravity concentration and comminution conferences attract major international interest*

Two major minerals engineering conferences will be run back-to-back in Perth, Western Australia in March.

Gravity concentration '04, from March 22–23, has attracted authors from 10 countries. The event is being sponsored by two of the world's leading manufacturers of enhanced gravity equipment, Falcon Concentrators of Canada, and Gekko Systems of Australia, as well as Australia's Minerals Gazette.

Full details of the conference and technical programme, can be found on www.min-eng.com/gravityconcentration04.

Comminution '04 immediately follows the gravity conference, from March 24-26. Sponsored by Xstrata Technology, Limn: the Flowsheet Processor, and the Minerals Gazette, this conference has attracted around 50 high quality presentations from 17 countries. Full details of the conference and technical programme can be found on www.min-eng.com/comminution04.

Both conferences are being organized by Minerals Engineering International, UK. ◆

* *Issued by:* *Dr B.A. Wills,*
Direct Telephone: +44 (0) 7768 234121
E-mail: bwills@min-eng.com