Detection and Delineation of Depth of Subsurface Coalmine Fires Based on an Airborne Multispectral Scanner Survey in a Part of the Jharia Coalfield, India*

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ABSTRACT: In India, active fires burning for quite a few decades in underground coal mines have created serious hazards to life and coal property. A daytime and predawn Multispectral Scanner Survey was conducted over the Jharia coalfield, Bihar, to detect and delineate subsurface fires. Pixel temperature data converted from digital number values were used to generate isothermal maps and temperature profiles along scan lines which were subsequently cross-checked with selective ground thermometric data. The anomalous zones of isothermal maps have been correlated with known fires and have also indicated possible fireprone areas. Depth of the source of fire delineated at different locations on the basis of the equation for linear heat flow in a semi-infinite medium has been correlated with underground mining information and was found to be very encouraging for all future activities and monitoring.

INTRODUCTION

JHARIA COALFIELD, the only source of prime coking coal in India, has a mining history dating back to 1890. Coal mines in this coalfield have been plagued for many years by the effects of subsurface fires. Such fires, many of which have been burning for over five decades, are currently spread over 70 some locations in nearly 40 collieries. Mine fires have not only resulted in a considerable loss of the country's limited coking coal resources, but also have affected the minability of coal from the adjoining areas, polluted the environment, and endangered surface structures. Coal mine fires of various kinds in different countries have been causing serious concern since the beginning of the century. Though much work has been done in attempting to solve the problem from different perspectives, a foolproof solution remains to be found.

Early detection of fireprone areas and monitoring the fire's progress may make it possible to plan fire-fighting operations and select the optimum strategy for combating underground fires. Thermal studies may turn out to be of immense help in those cases where the situation cannot be perceived by conventional methods.

Studies on problems of fires in mine refuse banks were initiated in the Scranton and Wilkes Barre, Pennsylvania coal mining areas (Slavecki, 1964). Subsequently, a few workers attempted similar studies in other areas (Fisher *et al.*, 1968; Ellyett and Fleming, 1974; Guan Hai-yan, 1984).

Mine fires in coalfields have necessitated further studies, particularly in the detection and delineation of depth of subsurface fires. The present study deals with the application of airborne multispectral scanner data to this problem in the Mukunda area in the eastern part of the Jharia coalfield (Figure 1).

COAL MINE FIRES IN THE JHARIA COALFIELD

The Jharia coalfield, comprised of Permian coal bearing rocks, is located in an E-W trending morpho-tectonic half graben extending over an area of about 450 sq km. The coal bearing Barakar Formation (Lower Permian) which overlies the basal non-coal bearing Talchir Formation, is exposed all along the northern and northeastern half of the basin and dips towards the south/southwest. The Ranigunj Formation, another coal bearing horizon, overlies the Barakar Formation and non-coal bearing Barren Measure Formation in the southwestern part.

Nearly 46 coal horizons varying in thickness from 0.9 to 22.5 m have been recorded within a 1250-m thick section of the Barakar Formation. However, only 18 coal horizons have persistent regional extent, and are known as I to XVIII in ascending order. The upper 12 seams (IX/X to XVIII) contain prime coking coal whereas the lower seams contain medium to weakly coking coals. The overall quality of these seams is best in the eastern part of the coalfield and gradually deteriorates from the eastern part to the central and western parts. The mine fires are mostly confined to the upper group of seams which produce the best quality coal. The fires are also mostly in the eastern part of the coalfield and decrease gradually towards the central part.

All coal mine fires so far reported for the Jharia coalfield are restricted to the younger coal seams of the Barakar Formation under an overburden of less than 80 metres. The majority of fires are shallow (i.e., less than 40 m). The history of these fires can be traced back to as early as 1916. Most of these fires probably originated from spontaneous combustion occurring either underground or along the outcrops. In those days most of the mines were limited to shallow depths where a number of thick contiguous seams were mined by the "room-and-pillar" system with caving. As a result, large quantities of coal were bypassed (in the form of small pillars, stocks, etc.) and subsequently caught fire when surface subsidence opened cracks to the surface, allowing air passage. The maximum time of burning of underground fires in the study area appears to have been about 15 years (Sharma, 1989).

DATA ACQUISITION

An aerial multispectral scanner survey was carried out in collaboration with the National Remote Sensing Agency, Hyderabad, India. The survey covered about 500 sq km of the fire-affected area of the Jharia coalfield during February and March 1989 employing an AADS 1268 Daedalus Multispectral Scanner System on board a Superking B-200 aircraft. The survey was flown at an average altitude of 685 m above sea level, during both predawn and daytime periods. The scanner was adjusted for 50 scans/sec, 2.5 m rad IFOV; and a 0.125 velocity/height

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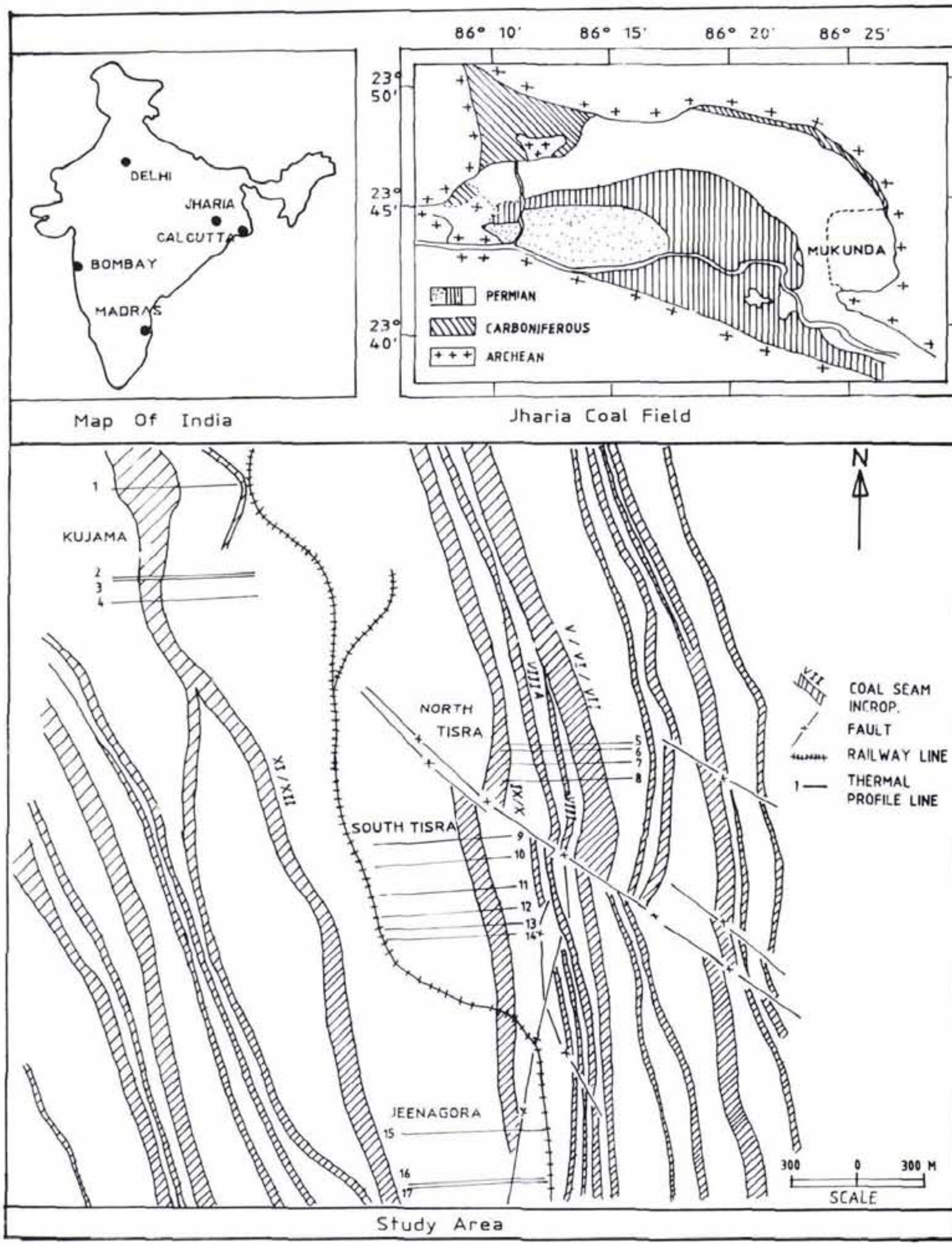

FIG. 1. Location map of the Jharia Coal Field, coal seams, and thermal profile lines.

ratio. Out of 11 channels in the multispectral scanner, eight channels cover the range from 0.42 to 1.05 μm in the visible/near infrared region, two channels cover from 1.55 to 1.77 μm and 2.08 to 2.35 μm in the middle infrared region, and one channel with normal and high gain covers from 8.5 to 13.0 μm in the thermal infrared region. The system has a thermal sensitivity of less than 0.3°C noise equivalent temperature change. The raw data were recorded on high density digital tapes (HDDT) at 10,000 bits per inch and were converted to computer compatible tapes (CCT) at 1600 bits per inch in the Earth Resources Laboratory Application Software (ELAS) format.

Conventional black-and-white photography, taken with an RMK 8.5/23 camera, was acquired simultaneously during daytime scanning.

A concurrent ground thermal infrared survey employing an Infrared Gun was carried out during both the daytime and predawn flights for generating ground truth data to supplement the airborne scanner data interpretation.

DATA PROCESSING

In order to facilitate rational handling of the data at the initial stage and also to extract optimum information, the CCTs were generated for channels 3 (0.52 to 0.60 μm), 5 (0.63 to 0.69 μm), 8 (0.91 to 1.05 μm), and 11/12 (8.50 to 13.00 μm, normal and high gain) of daytime data and channels 11/12 of predawn data. Systematic digital analyses have been carried out with the help of EASI/PACE (V 4.1) image processing software on a PC AT 80386 microprocessor and a 512 by 512 by 32 bit display image processing unit.

Pixelwise digital number (DN) values were converted into temperature data using the housekeeping data of the scanner's two internal black-bodies. The converted temperature values were randomly checked with the ground truth data. Such pixelwise temperature data were used to generate temperature contours using a contour algorithm (MINEX-GPC INT Software of ECS Australia) on a VAX 11/780 computer and a XYNETICS 1201 (58 by 27 inch) plotter.

Temperature profiles were generated along scanlines from the digitally recorded pixelwise temperature data.

DATA INTERPRETATION

The purpose of the digital analyses was to enhance thermally anomalous pixels with respect to the surrounding pixels. The general techniques followed were

- Visual classification of imagery,
- Density slicing,
- Alphanumeric printouts,
- Digital color composites,
- Principal component enhancement (selective frames),
- Spatial frequency filtering (selective frames),
- Unsupervised classification, and
- Supervised classification.

Of the above enhancement techniques, Density Slicing of the predawn thermal channel data provided excellent thermal contrast. The scene was then analyzed for conversion of digital numbers to temperature.

A surface isotherm map derived from relative radiance values of predawn thermal infrared data aided by selective field data is shown in Figure 2. The isotherm map depicts the temperature differential with a contour interval of 5°C. The output temperature range was adjusted to a maximum 68°C, above which all the data are saturated.

By superimposing the density sliced color-coded thermal predawn data, digital color composite of daytime data, and isothermal contour maps on the mine working plan, the anomalous thermal zones were found to be well correlated with the known fires and also indicated possible fireprone areas.

The following equation for linear heat flow in a semi-infinite medium is used to determine the measured temperature increase (T) at distance "x" with respect to the heat source (T_i), at $x = 0$ and time $t = 0$; that is,

$$T = T_i \left[\frac{2}{\pi} \int_0^{x/\sqrt{4\alpha t}} e^{-\beta^2} \, d\beta \right] \tag{1}$$

where α is the thermal diffusivity and $\beta = \frac{1}{2} x(\alpha t)^{-\frac{1}{2}}$

It is apparent from the above relationship that the time required to reach a certain temperature at the measuring point from a fire source may be dependent on the diffusivity value of the media.

Representative values of diffusivity (measured from core samples of a borehole in the Jharia coalfield; see Ingersoll *et al.* (1948) and Moscicki, (1987)) for coal, sandstone, and air are considered to be 0.002 $cm^2 \, sec^{-1}$, 0.012 $cm^2 \, sec^{-1}$, and 0.178 $cm^2 \, sec^{-1}$, respectively, for the interpretation.

Theoretical computations of temperature anomalies produced by a constant fire source through different media for various

FIG. 2. Contour map of the thermal data for the Mukunda area.

length of time and plotted on a semi-log graph are shown in Figure 3.

The maximum alarming temperature for the ignition of coal is considered to be about 160°C as observed by Banerjee *et al.* (1972) for a number of Indian coal samples.

Considering the maximum duration of a constant fire to be about 15 years (as in the present study area) and the temperature anomaly of about 160°C produced by conduction through coal, the location of the constant fire source is computed to be at a depth of about 15 m. On the other hand, when the heat is conducted through a sandstone formation for the same distance, the time required to raise the corresponding temperature is much shorter, and the zone facilitating air entry entails higher incidences of spontaneous fires.

Thermal profiles of digitally recorded temperature data along scan lines in the Mukunda area were studied across a known geologic section in order to correlate them with anomalous temperatures associated with the fires. The locations of temperature profiles are shown in Figure 1. Two typical temperature profiles, along with the section of fire-affected coal seams, are shown in Figure 4. The temperature profiles depict distinct anomalous zones with respect to the background temperature. The average ambient temperatures is on the order of 12°C. The fluctuations along the profiles seem to be due to variations in temperature associated with the inhomogeneity of the topsoil and sandstone. There may also be minor cracks and fractures. The background noise is thus separated by graphical smoothing for the calculation of the duration of the fire or the depth of the fire.

Temperature anomalies of a magnitude of about 68°C along profile no. 11 at about 200 m and 400 m appear to correspond to fires in the IX/X and VIIIA seam at depths of about 45 m and 40 m, respectively. The age of the fire associated with the IX/X seam is computed to be about 8 years and that with the VIIIA seam to be about 7 years. The anomalies towards the extreme right of the profile seem to be from the fire in the workings of the VIII seam. The fires in the VIII seam were determined to be relatively younger and were found to progress down the dip of the seam.

The fire in the northwestern part of the study area was detected in the underground workings of the IX/X seam in early 1982. Accordingly, the depth of the fire was calculated to be about 55 m at about 500 m distance along temperature profile no. 1. This correlates well with the cross section (Figure 1) of the fire-affected coal seam.

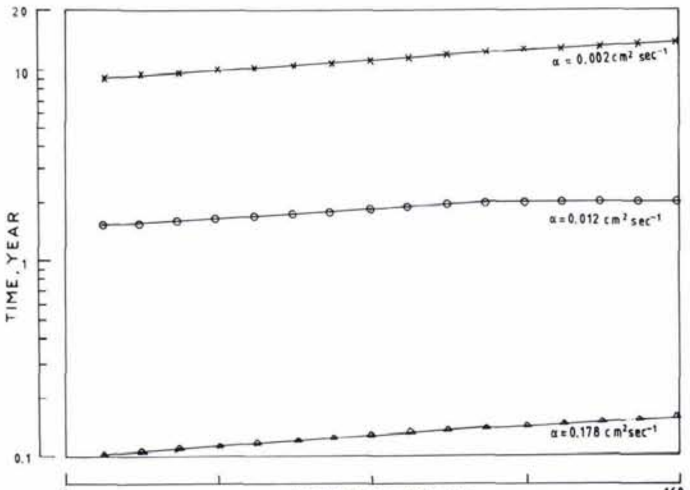

FIG. 3. Computed relationship between time and temperature rise for different diffusivity values from a constant fire source.

CONCLUSION

Airborne thermal infrared remote sensing has proved to be a very effective tool in rapidly acquiring information on the location and intensity of thermal anomalies caused by fires in coal mines.

The scanner survey over the Jharia coalfield has facilitated preparation of isothermal maps which reveal areas of high thermal anomalies.

The estimate of the depth of fire and its propagation through time, based on the equation for linear heat flow in a semi-infinite medium and utilizing temperature profiles drawn from a thermal scanner survey, was found to provide useful information. This technique could form the basis for the preparation, implementation, and monitoring of proper action plans for dealing with such fires in other areas as well.

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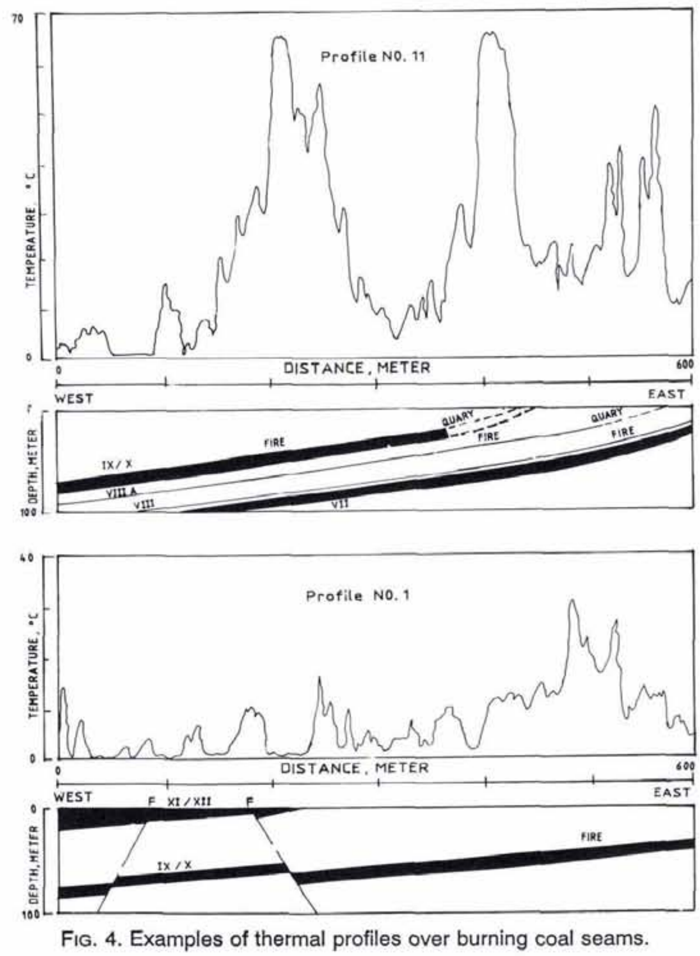

FIG. 4. Examples of thermal profiles over burning coal seams.

The views expressed in the paper are not necessarily those of the institution to which the authors belong.

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