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An onshore gas well blow-out and its impact observations using satellite data

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The blow-out of the ONGC Gas Well-19 located at Pasarlapudi in East Godavari District, Andhra Pradesh, attracted lot of concern on its impacts. The blow-out site has been monitored by satellite-based data sets from Indian Remote Sensing Satellite (IRS-P2) and Landsat-5 for impact assessment studies. The satellite data sets showed signature variation in 200 m surrounding the well site. The water umbrella formed over the blow-out site and the resultant temperature and humidity variation measured on the ground were significant up to 200 m radius. Satellite-based optical data have been used for estimating the well temperature. The gas well temperature estimated from satellite data has been found to be around 1100°C. The methodology adopted for estimating the gas well temperature and the results on impact assessment studies are discussed.

THE blow-out of ONGC onshore Gas Well-19 located at Pasarlapudi near Devarlanka in Amalapuram Taluk of East Godavari District, Andhra Pradesh, occurred on 8 January 1995. At about 6.50 PM on that day, there was a sudden increase of gas pressure and the casting was pushed out, with the result that the well caught fire. Initially for about 30 days only the vertical spread of the flame was noticed and subsequently due to damage in the blast of preventor (BOP), which is a vertical structure containing equipment for closing the well in case of exigency, the fire in horizontal direction also increased. Satellite data sets over the region were continuously monitored to obtain cloud-free data over the region and first cloud-free coverage was observed in Indian Remote Sensing Satellite (IRS-P2) pass of 27 January 1995. Spaceborne sensors due to synoptic and repetitive coverage provide data over large regions and have the advantage of providing data over inaccessible regions. The sensors onboard natural resources monitoring missions operate mostly in visible and near-infrared regions of the electromagnetic spectrum. The Landsat satellite data in India are acquired with thematic mapper (TM) sensor having a band in thermal IR region of the electromagnetic spectrum. The thermal band data can be used to study temperature variations below 60°C (ref. 5). In the present study, optical data from IRS-P2 and Landsat TM have been analysed with a view to study the impacts due to blow-out, and ground-based measurements have been collated with the satellite-based observations. IRS-P2 optical data has been analysed with a view to estimate the well temperature and the methodology adopted has been discussed in detail.

IRS-P2 Linear Imaging Self-Scanning System (LISS-II) digital data of 27 January 1995 and Landsat TM data of 2 February 1995 over the blow-out region have been obtained. Biophysical parameters like leaf temperature, photosynthetically active radiation (PAR), leaf level transpiration and intercellular CO_2 were measured using a leaf chamber analyser (LCA-3); temperature and humidity at different points from the well site were also measured. The vertical profiles of temperature and humidity were measured, respectively, with mercurial thermometer having a sensitivity of 0.1°C in the 0–100°C range and with hygrometer using a stack.

The IRS-P2 LISS-II sensor operates in four bands at 0.45–0.52 μm, 0.53–0.59 μm, 0.63–0.69 μm, 0.77–0.86 μm and Landsat TM operates in seven spectral bands (six in 0.45–2.35 μm region and one in 10.4–12.5 μm thermal IR region).

Satellite data sets recorded in various bands can be analysed for vegetation vigour by ratioing the data of infrared and red bands. The ratio is normally called normalized difference vegetation index (NDVI) and is given by the formula NDVI = (IR-Red)/(IR+Red) (refs 1,4).

The thermal IR data of Landsat are used mainly for studying temperatures below 60°C. In the present study an alternate method for estimating the temperature of the gas well has been adopted[5]. The short wavelength region of 0.4–3.0 μm is not commonly used for monitoring the normal thermal regime of the earth's surface as it emits a very small quantity of radiation in this spectral region. In the case of gas well burning, the observed high-temperature region acts like a source of radiation and the radiance values recorded by satellite-based sensors correspond to the emitted radiation. This concept enables the use of Planck's function for estimating the temperature over the gas well. Similar studies have been reported in the literature over volcanic regions[2,3,5].

The false colour composite of the study area generated from TM bands 4, 3, 2 (RGB) is shown in Figure 1 *a* and that from TM bands 4, 5, 7 is shown in Figure 1 *b*. The enlarged false colour composites corresponding to these are shown in Figures 1 *d* and 1 *e*, respectively. The blow-out region can be clearly seen as a bright yellow spot in Figure 1 *d*, which is an enlarged image of Figure 1 *a*. In Figure 1 *b*, severe stress over the vegetation due to heat from blow-out is indicated by bluish grey area around the well site as the TM bands

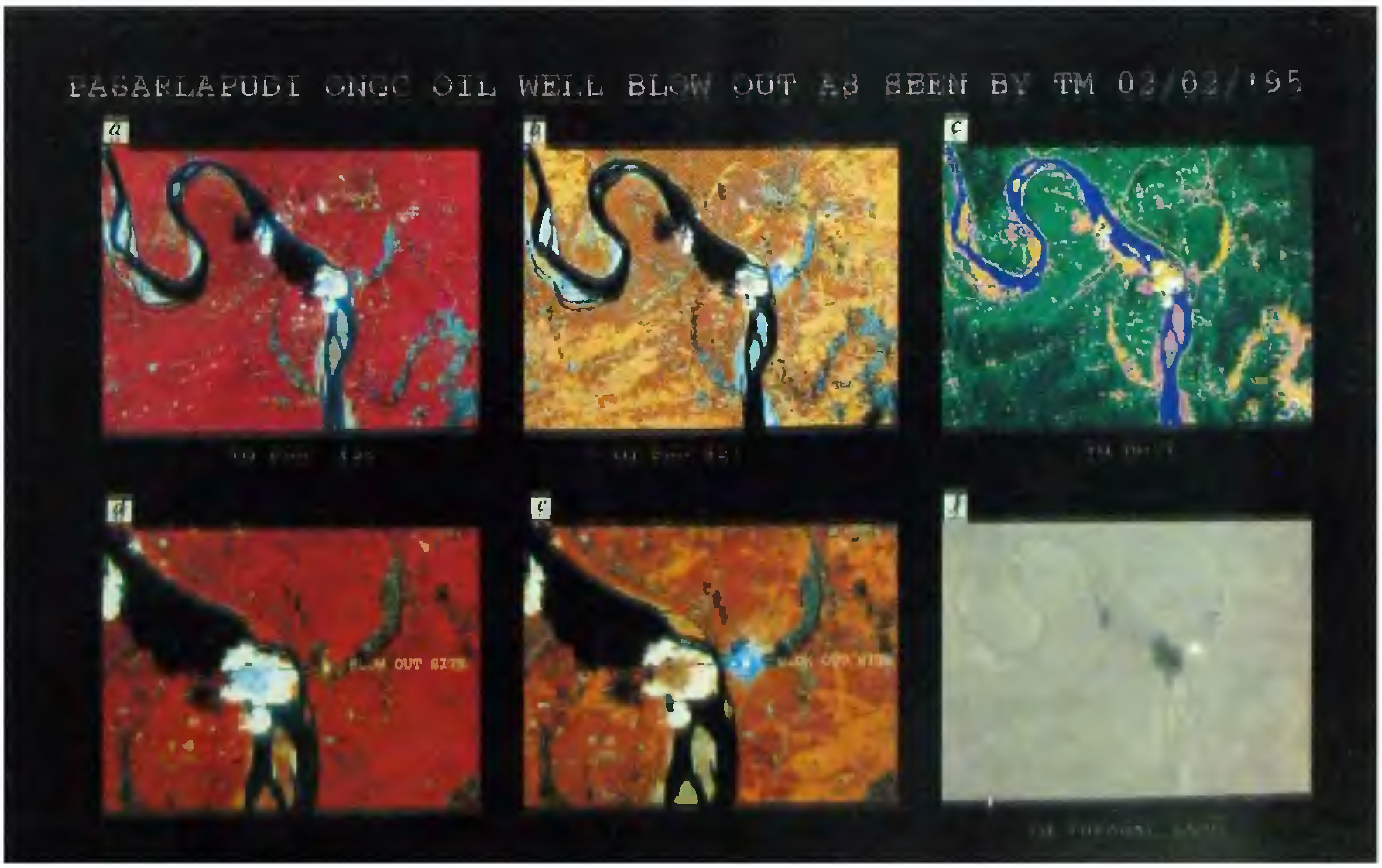

Figure 1. Thematic mapper data of the study area on 2 February 1995. ***a***, False colour composite (FCC) of bands 4, 3, 2; ***b***, FCC of bands 4, 5, 7; ***c***, normalized difference vegetation index (NDVI); ***d***, enlarged FCC of bands 4, 3, 2; ***e***, enlarged FCC of bands 4, 5, 7; ***f***, thermal IR image.

4, 5, 7 (0.77–0.86 μm, 1.55–1.75 μm and 2.08–2.35 μm) are sensitive to vegetation stress. The NDVI image generated from bands 4 and 3 (0.77–0.86 μm and 0.63–0.69 μm) is shown in Figure 1 *c*, wherein the nongreen area around the blow-out site indicates the stressed area. The thermal image of TM band 6 (10.4–12.5 μm) is shown in Figure 1 *f* and it can be observed that due to saturation of thermal radiance values above 60°C, the blow-out site region appears bright and it is difficult to pinpoint the well site.

The satellite observations of localized vegetation stress around the well site were cross-checked with ground observations. Ground measurements of air and soil temperature, humidity, crop photosynthetic rate, transpiration and radiation near the well site were made using the LCA-3 instrument. Further, discussions with Revenue, Agriculture and ONGC officials were made to understand the economic impacts.

The satellite data analysis indicates localized damage of around 200 m close to the well site, as can be seen in Figure 1, and is in conformity with ground observations. The ground observations showed that the temperature was around 40°C at 24–30 f height close to the well site (150 m) and the ground temperature was at 32°C. The temperature was uniform with surroundings beyond 150 m, mainly due to the heat protection by coconut plantations. The well site (BOP) was totally provided with water umbrella by ONGC using jet pumps. The moisture thus generated formed a localized cloud and can be seen as a cloud patch appearing in bright white in Figure 1. The biophysical parameters showed normal values in standing paddy crops close to the blow-out site (150 m) as the ground temperatures were normal and sufficient stagnated water was available in the fields. The coconut trees within 200 m radius showed damage signs as the temperatures were high above ground level due to the gushing flames. The coconut saplings facing BOP at 150 m distance showed yellowing and browning due to damage of leaves. In the leeward side of BOP, healthy coconut saplings are observed. The persistent high temperature of above 40°C at the coconut crown led to falling of fruits near the BOP site (200 m). The heat-tolerant Ficus sp. plant was found to be in healthy state even at a distance of 150 m from the well site.

The observations made by A. P. Pollution Control Board, Rajahmundry, indicated that no poisonous gases were present due to burning in the atmosphere. The physiological process level changes due to exposure to high temperature and humidity in the less impacted area were also shown to be normal. Noise pollution was in the range of 100–140 dB close to the well site and 55 dB (normal) around 2 km radius, as reported by A. P. Pollution Control Board.

The temperature of the well site was estimated to be around 1100°C; this value is close to the reported values. The effect of emitted gases and water vapour on the satellite-derived radiance values has not been considered while calculating the temperature. The ground temperature and humidity variation at different heights from the well site is shown in Figure 2. It can be observed that the temperature values are increasing with height, due to the gushing flames spreading above ground level. Due to water umbrella, the humidity values were found to be high in the windward direction away from the well site.

The analysis of satellite data suggested localized effects (around 200 m regions) due to the oil well blow-out. The temperature values estimated from the optical data are in conformity with ONGC ground observations, suggesting the possible use of optical data for studying high-temperature phenomena. The noise pollution levels are high within 2 km region around the site. The damage to coconut plantations in down wind direction were

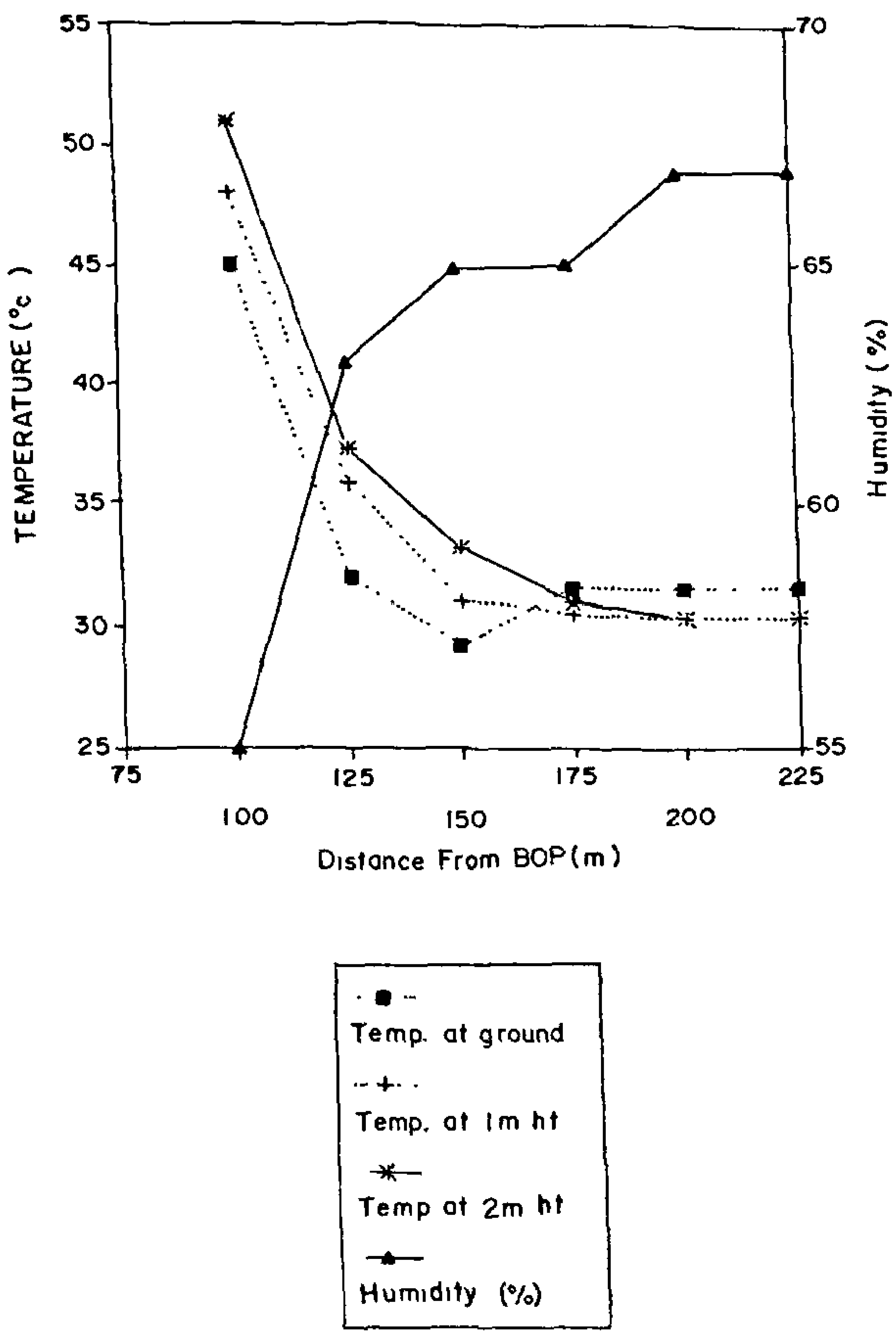

Figure 2. Temperature and humidity profiles at various points from the blow-out site.

observed within 200 m zone. The area under 200 m radius from BOP is the zone of influence of blow-out. The gas blow-out site was inaccessible and satellite data alone facilitated in observing the vent temperature synoptically during the blow-out condition. In addition, multi-temporal satellite data by virtue of repetitive coverage facilitated dynamic aspects of blow-out condition and the associated spatial changes resulting due to damage. Thus, satellite technology only could facilitate synoptic observation of such episodic events and could account spatially for the area of its influence.

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Oxygen linkages in neodymium heptamolybdate single crystals – An XPS study

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Single crystals of neodymium heptamolybdate ($Nd_2Mo_7O_{24} \cdot 27H_2O$) are grown in sodium metasilicate gel by the diffusion of neodymium nitrate (upper reactant) into the set gel impregnated with a mixture of molybdenum trioxide, ammonium hydroxide and concentrated nitric acid (lower reactant). Oscillation X-ray diffraction pattern shows that neodymium heptamolybdate is single-crystalline in nature, while infrared absorption spectrum establishes the presence of molybdate group and water of crystallization. X-ray photoelectron spectroscopic studies of neodymium heptamolybdate single crystals establish the presence of neodymium and molybdenum in their oxide states and the oxygens in the sample are shown to exist as (i) terminal oxygen (Mo=O), (ii) bridging oxygen (Mo–O–Nd) and (iii) oxygen of lattice water (H–O–H).

FERROELECTRIC and ferroelastic properties of rare-earth molybdates are of great interest in electro-optical and acousto-optical devices[1–3]. Barium molybdate tetragonal bipyramidal crystals are grown by the precipitation of alkaline-earth metal molybdate powders from neutral aqueous solutions[4]. Rare-earth molybdates, having the general formula $R_2(MoO_4)_3$, have been reported to be ferroelectric materials[5]. The growth of rare-earth molybdates (R = Pr, Nd, Sm, Eu, Tb and Dy) using the Czochralski technique has been studied by Brixner[6]. As this method involves elevated temperatures, thermal stresses released during the growth may make the crystals defective. Henisch and coworkers[7,8] have established the growth of crystals in gels and this method has been fully exploited in the case of calcium sulphate dihydrate single crystals[9–15]. Growth and characterization of rare-earth mixed single crystals of samarium barium molybdate have been reported by Isac and Ittyachen[16]. Studies on the growth of neodymium heptamolybdate (hereafter called NHM) single crystals in silica gels have been reported in the literature[17].

For the growth of NHM in gels in the test tube, acidified aqueous solution of sodium metasilicate (0.5 M, pH 5) is used as the reacting medium. The lower reactant (to be incorporated inside the gel before setting) is prepared as follows: 0.5 M molybdenum trioxide is completely dissolved in 15 N ammonium hydroxide using a magnetic stirrer, to which nitric acid (24 ml in 50 ml distilled water) is added. This lower reactant is mixed with the above gel and allowed to set undisturbed (gel age 96 h). On top of this set gel, as the upper reactant, a solution of 0.75 M neodymium nitrate is slowly added through the wall of the test tube, so as not to rupture the surface of the set gel. In about three weeks' time, platelets of NHM (of sizes 2 mm × 2 mm × 1 mm) appear below the thick white layer of the precipitate (of NHM) inside the gel.

The mechanism of chemical reactions leading to the formation of NHM is explained as follows:

$$MoO_3 + 2NH_4OH \rightarrow (NH_4)_2MoO_4 + H_2O. \quad (1)$$

When acidified, we get

$$(MoO_4)^{2-} + H^+ \rightarrow HMoO_4^- , \quad (2)$$

$$HMoO_4^- + H^+ + 2H_2O \rightarrow Mo(OH)_6 , \quad (3)$$

$$Mo(OH)_6 + HMoO_4^- \rightarrow (HO)_5MoOMoO_3 + H_2O, \quad (4)$$

$$(HO)_5MoOMoO_3^- + HMoO_4^- \rightarrow (HO)_4Mo(OMoO_3)_2^{2-} + H_2O, \quad (5)$$

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