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Study of Real-Time Dry Bulb and Relative Humidity Sensors in Underground Coal Mines

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Abstract As the depth of mines increases, the temperature in the mine workings also increases due to the geothermal gradient. A questionnaire was prepared and sent to a number of mine ventilation engineers, consultants and academics in order to gain an understanding of their experiences and current views on real-time dry and relative humidity temperature monitoring practices. Eighteen persons provided a response to the questionnaire. The answers were compiled and analyzed. This paper presents and analyzed the results obtained from the survey.

Keywords Humidity · Queensland · Real time · Survey · Temperature · Underground coalmine

1 Introduction

Accurate measurement of dry bulb temperature and relative humidity at different critical locations/areas of underground coal mines is a challenge to the underground coal mining industry. A small change in dry bulb temperature and relative humidity can cause human fatigue, mine hazards, equipment failures and decreased production. Insufficient information and uncertainties associated with measurement of under-

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ground temperatures can cause difficulty in managing mine safety issues such as, spontaneous combustion, fires and ventilation problems all of which can jeopardize mine safety and efficient production. All these issues necessitate the implementation of an Intrinsically Safe (IS) approved automated real-time temperature monitoring system for underground coal mines, particularly for relative humidity measurements.

In Australian underground coal mines, the dry bulb and the wet bulb temperatures are measured using a psychrometer or whirling hygrometer. Currently, these temperatures are spot measurements and are manually recorded in various locations of the mine workings at different time intervals. The objectives of this work were to (a) review the current state of the art for real-time temperature instrumentation and monitoring practices applicable to underground coal mines (b) identify challenges associated with the implementation of real-time dry and wet bulb temperature monitoring systems, and determine the problems which are preventing or discouraging their use in underground coal mines and (c) compare and validate the real-time temperature data with an existing temperature measurement system in the laboratory.

There are a number of real-time temperature monitoring devices on the market which require minimum human intervention when compared to the conventional whirling hygrometer measurement device. Real-time temperature monitoring instruments can provide accurate, reliable, representative and continuous dry bulb temperature and relative humidity measurements in various critical sections of mines, and this information can then be used to control and improve the mine working environment as well as to derive various psychometric properties, such as, relative humidity, dew point temperature, specific enthalpy, mixing ratio and specific volume on a real-time basis.

The researchers consulted with the relevant personnel from Australian underground coal mines in order to identify the pertinent issues associated with implementing a real-time underground temperature monitoring system. They reviewed state-of-the-art temperature monitoring systems currently available and identified a suitable type for use in underground coal mines. The advantages of an intrinsically safe real-time temperature monitoring device were evaluated against the challenges associated with its implementation. The project also compared and contrasted the accuracy of the real-time temperature monitoring system in comparison with the current non-real-time measurement devices and practices.

Queensland Coal Mining Safety and Health Regulation [1] under the sections on heat stress management (369 and 370) deal with managing risk from heat and methods of calculating the effective temperature. Section 370 refers to monitoring the atmosphere and provides guidelines for managing effective temperature at the coal face. To effectively achieve the safety compliance of the underground workings, it is necessary to have continuous monitoring of temperatures at all times. This can be fulfilled by implementing a real-time temperature monitoring system.

This project focused on improving the production and safety in underground mines by accurately measuring real-time temperature within critical areas of an underground mine. To the best of our knowledge, there is not a single Australian mine that uses a real-time relative humidity monitoring system in underground workings. The key questions are: (i) why the Australian underground coal mines are not using real-time temperature monitoring systems (ii) what challenges mines would face in implementing real-time

temperature monitoring devices and (iii) what needs to be done to facilitate their use in Australian underground coal mines.

In mining, the importance of real-time monitoring has been highlighted by various researchers [2–6]. In contrast to real-time monitoring research performed in other areas of underground coal mines, the research on real-time dry bulb temperature and relative humidity monitoring has been neglected.

Real-time temperature monitoring systems are very common in a range of manufacturing and processing industries, with powder handling, paper, drying, steel and pharmaceuticals industries being notable examples. These devices are well developed and used to scrutinize humidity and confirm the quality of processing operations in challenging but sensitive environments. The real-time sensors can be either wired or wireless. A key benefit of real-time sensors is that they allow appropriate actions to be taken immediately or even automatically adjust a mode of operation, depending on the circumstances [7].

2 Questionnaire Analysis

A questionnaire was prepared and sent to a number of mine ventilation engineers, consultants and academics in order to understand their recent experiences and current views on real-time dry and wet bulb temperature monitoring practices. Eighteen persons provided their responses to the questionnaire. The answers are compiled and analyzed as follows.

1. At what locations do you measure temperature and humidity in the underground coal mines?

In general, temperature and humidity measurement are conducted as a part of the monthly statutory survey conducted by deputies, typically on a shift basis but often when and where problems occur. Measurements are conducted at all specified ventilation measurement stations as per the mining regulations and where deemed necessary by ventilation officers. Detailed measurements are required to develop a heat model for underground coal mines. The measurements are also required to monitor for heat from spontaneous combustion and in accordance with the heat management plans. More typically, hotter regions of underground old workings are measured for temperature and humidity.

The respondents mentioned that the areas where personnel are working are critical locations to measure temperature and relative humidity in underground coal mines. Temperature and humidity measurements are required at all monthly survey points, statutory locations and all ventilation stations. Locations such as, entries to exhaust shafts, intake and exhaust ducts, all district regulators, longwall face areas (maingate, middle and tailgate), development face and return, tailgate outbye, intakes, last open cut through, driveheads and key areas in belt roads, upcast shafts, bottom of the cooling shaft, shaft collar, main returns to fans, panel entries and returns, and ventilation split regulators are critical locations to obtain temperature and humidity data. The explosive risk zone (ERZ, located at boundary and face) and surface weather station are also important locations to measure temperature and humidity in the mines. In order to monitor heat from spontaneous combustion, measurements are also performed at

regular intervals at the rear-leg of longwall chocks, longwall goaf stream and goaf seal traps.

The temperature measurements are very critical in hotter and gassy mines of Queensland (for example, Bowen Basin) compared to the New South Wales mines, except for the very deep mines of the south coast (for example, Appin, Westcliff).

2. What is the current method of measuring temperature and humidity in the underground coal mines?

Dry bulb temperature, wet bulb temperature and relative humidity are currently interpreted from manual readings using various hand held devices and a psychrometer chart. Some mines use conventional thermal expansion thermometers and mine approved infrared spot temperature meters to measure the dry bulb temperature. Several mines use a system involving thermographic cameras and spot measurements. One of the mines uses real-time monitoring of dry bulb temperature using the Redline software logging system. One of the mines uses remote measurement of dry bulb temperature at main fan exhaust air. In other mines, monthly ventilation surveys are conducted where temperature and relative humidity are measured.

3. What instrument/s do you currently use to measure temperature and humidity in the underground coal mines?

The following instruments are commonly used in the underground coal mines to measure temperature and humidity.

- Psychrometer chart
- Conventional thermal expansion thermometer
- Surface weather station
- Whirling hygrometer (dry and wet bulb)
- Brannan Sling psychrometer (dry and wet bulb)
- Infrared spot temperature meters
- Thermographic cameras
- Digital temperature probes
- Real-time monitoring (dry bulb) by Redline Software logging system
- Kestrel Instrument
- Bacharach Sling psychrometer (wet and dry bulb)
- Real-time and/or remote monitoring of dry bulb temperature
- Fixed thermocouples mounted in surface mine fan ducts for measuring dry bulb temperature

4. Currently, how frequent do you measure temperature and humidity in the underground coal mines?

In working areas, the measurements are obtained during every shift, and in ventilation stations, panel entries and return splits measurements are obtained every month. As per statutory ventilation reporting requirements, all mines perform measurement/surveys on a monthly basis. Similarly, shift measurements are performed in each panel by the deputy as per statutory inspections. Measurements are also performed as required to monitor potential spontaneous combustion, and in accordance with the heat management plan in order to determine the "effective temperature," where hot and humid

conditions exist. These measurements can activate the Trigger Action Response Plan (TARP) when limits are likely to be or have been reached. In hot and humid conditions and when approaching TARP limits, measurements would be done several times during each shift. The temperature measurement information is managed under a principal hazard management plan which uses TARPs to trigger corrective action. Depending on the mine conditions, 4 h to 6 h measurements are also performed. Some operations perform continuous monitoring of the temperature on the surface of the underground coal mine.

5. How do you interpret and use the measured temperature and humidity data in the underground coal mines?

The measured data are used to monitor legislative limits and to gauge current working conditions. Hotter mines use the data to substantiate heat modeling and analysis, but in colder mines the measurements are for information only. The data are used to determine the effective temperature from wet bulb, dry bulb and air flow measurements. The data are also used to monitor goaf stream and goaf oxidation levels in gassy mines. Apart from using the interpolated standard nomograms for monthly or incidental temperature, humidity recording, trending, comparison and historic purposes, the data are used as part of the TARP for temperature, heat mapping after vent surveys and carbon emissions reporting. The data are also used to report greenhouse gas emissions from the bottom of the upcast. Surface heat trends are used to forward project for other ambient conditions.

6. What are the practical and technical problems you are encountering at the moment in measuring temperature and humidity in the underground coal mines?

The readings are prone to human error associated with the location identification, interpretation and noting the temperature from the thermometer. The limited data points and placement of the instrument (close or far from the human body which may also record/add additional human introduced heat), crude instruments, limited ways to measure wet bulb temperature, represent/record and time taken to prepare data in a statistical report are the technical limitations experienced by the ventilation officers/deputies.

Due to the lack of continuous monitoring, the readings can be inconsistent due to human interpretation and how/where the readings are taken. Some of the survey participants also mentioned that due to an inability to remotely measure the temperature and the difficulty in accessing returns, goaf stream areas and some other measurement spots, not enough measurements can be conducted in the time available.

A snapshot measurement may not be representative of the actual conditions because heat loads will vary, particularly in areas where machines are in operation.

The above-mentioned problems arise from a lack of personal, and from the absence of portable, robust, cheap and intrinsically safe electronic temperature and humidity sensors suitable for use in underground coal mines. Due to these limitations and in accordance with the heat management plans, deputies sometimes have to withdraw workers to a place of safety until the effective temperatures are confirmed below TARP limits. This means that due to the use of non-real-time devices the delay in determining the effective temperature using a manual psychrometer can impede coal production

and increase the environmental risk to workers. Further, current fugitive emission (GHG) legislation requires mines to monitor for fugitive mine gases as well as for relative humidity.

7. What are the instrumental problems you are encountering at the moment in measuring temperature and humidity in the underground coal mines?

At the moment, the instruments are manual and analogue which require manual interpretation and calculation of results; hence, in an underground environment the older deputies sometimes struggle to read the fine gradations on a psychrometer (for example, Brannan psychrometer). Most of the electronic instruments would provide a digital readout with higher accuracy and repeatability, but they are not intrinsically safe to use in underground coal mines.

Limited data points (measurement locations), hard to read (for example, the sling psychrometer), not able to recalibrate (for example, Kestrels), low accuracy and different measurement techniques between persons are instrumental limitations; the deputies and ventilation officers are encountering. The instruments are also very prone to damage, and there is limited availability of coal mine approved wet/dry bulb and relative humidity sensors, limitations in using the same sensors at various spots (for example, RT sensors used in the intake cannot be used in ERZ1) as well as human error involving location identification and misreading the true temperature are some problems experienced when using the instruments.

8. Ideally, what type of instrument and output do you want for the measurement of temperature and humidity in the underground coal mines?

An instrument capable of digitally displaying results with one decimal point resolution of wet/dry bulb temperature and relative humidity, and which displays the results in desired units (for example, degree centigrade, percentage of relative humidity) would be an ideal instrument. For the portable unit, an integrated anemometer/psychrometer displaying dry/wet bulb temperature, relative humidity and effective temperature to an accuracy of one decimal point. An instrument which provides TARP multi-level alarms is capable of logging and includes a trend display would be a preferred choice.

Similarly, for fixed plant (for example, mine surface and underground fans) the relatively inexpensive instrument capable of providing accurate, precise, digital display in desired units, hazardous zone approved, not subject to output level drift, nor fouling from airstream contaminates would be an ideal instrument.

In general, more robust instruments taking real-time measurements (reporting to control center) for wet bulb, dry bulb and humidity and with telemetric monitoring, Group I approved, 4 mA to 20 mA and accurate sensors with limited drift seem to be the ideal instrument. The instrument should be capable of measuring in real time at shafts and entry to the pit, conveyor belts, panel returns and at the base of shafts. The instrument should be Intrinsically Safe (IS) equipment with digital display, capable of continuously recording and storing data, and able to provide trend data and feature an analysis tool, similar to a real-time gas monitoring system. One of the respondents would like to have a single device capable for measuring temperatures and air velocities.

9. Are you aware of any real-time temperature and humidity measurement device/system which can be used in the underground coal mines?

The respondents provided a mixed response to this question. One of the ventilation officers of Queensland mines is aware of the availability of a real-time temperature and relative humidity measurement system and has ordered one. Similarly, a handheld device for dry bulb temperature and relative humidity is available but not approved for general underground use and can only be used in a controlled environment. Trolex brand seems to be a common name in underground coal mines; however, until recently it was not approved to be used in Queensland underground coal mines. Likewise, Kestrel brand is also known to mining personnel; however, it is not IS approved to take underground for real-time measurement. The respondents seem to be aware of other devices, but their status with regard to approval for use in underground coal mines has not been researched in detail by the respondents.

10. Are you aware of any real-time temperature and humidity measurement device/system which are used in metalliferous mines?

A mixed response of *yes and no* was noted from the participants. Even if they are available in the metalliferous mines, generally due to the restrictions in hazard zones in underground coal mines they are not applicable. The loading and drift from airborne contaminant would still preclude some applications in underground coal mines. VAISALA brand seems to be a known brand in metalliferous mines for temperature and humidity measurement.

11. If there is an availability of real-time temperature and humidity monitoring device/system to be used in the underground coal mines, would you prefer using it rather than continuing with the current method?

Depending on the mine location and heat issues, the respondents showed a mixed response. Most of the mines in NSW are doubtful about using the real-time temperature monitoring devices due to their minimal issues with heat in underground coal mines. It would be hard to justify the change in measurement system, where heat is not a real issue in mines, especially in current economic climate if it involves an additional investment. However in QLD underground coal mines, due to the higher heat issues, the mines will consider using the instrument, particularly at the longwall face, main intakes and upcast fans. One of the mines in QLD is in the process of purchasing and trying the device. Mine personnel would be instructed to use it in addition to the existing system. The real-time monitoring system can also be used when preparing monthly vent surveys. There is a scope for a robust, reliable, real-time portable and fixed psychometric instrument which can be used in hazardous zones.

If the available devices are practically and technically robust, reliable, real time, portable and IS approved to use in hazardous zones, then that would be useful in the underground coal mines. An instrument with these characteristics will also help to conduct more detailed monitoring of the heat status assessment and improve the determination of heat loads in hot and gassy mines.

12. If there is an availability of real-time temperature and humidity monitoring system to be used in the underground coal mines, what sort of problems do you expect in using real-time measurement device/system?

The problems are expected to be related to approvals for underground use, robustness, reliability, susceptibility to damage, accuracy, maintenance, integrity testing and calibration. The availability of labor to run cables and cables damage, reliability in gassy and dusty environment, as well as integration into the mine gas monitoring systems could be problems encountered when installing the instrument. Similar to real-time gas sensors, loss of communications and false readings are other anticipated issues. In a portable personal system, robustness, maintainability and cost, and in a fixed system, drift (both electronic and from fouling), precision and accuracy could be possible problems.

Likewise, training in the use of the real-time system, obtaining assistance from the electrical department to implement and connect to the existing electrical and communication networks, and dust and moisture ingress could be another set of problems the respondents mentioned.

13. What are the restrictions you think or expect in using real-time temperature monitoring system in the underground coal mines?

The restrictions the respondents are expecting while using real-time temperature monitoring system are:

- The existing approvals regime (particularly QLD and NSW mine's approval) for use in ERZ1 locations
- Practicality and cost
- High maintenance and calibration
- Labor to run cables and cable damage
- Compatibility with existing systems
- Access within in shaft collar
- Dust and moisture ingress
- Identification of mobile head sources/variation in environment
- Calibration process.

14. Have you come across any mines in Queensland using a real-time temperature monitoring system?

The respondents unanimously responded that no mine in Queensland is using a real-time temperature monitoring system. However, the real-time system is available to measure other parameters (for example, air velocity) but for only use in "as approved" and nonhazardous zone applications.

Why is it not being used in your mine at the moment?

The main reason is the unavailability of an IS approved real-time temperature monitoring system. The respondents have also mentioned that budget, difficultly in maintaining the device, labor resources and problems with electrical approvals would be other issues for not using real-time temperature monitoring systems.

However, one of the mines in Queensland indicated that an instrument has been recently ordered. In NSW mines, due to the fact that heat is not a major issue, they are not in real need of it.

Is it because of the difficulty in maintaining the system?

Due to the unavailability of the IS approved real-time temperature monitoring system, the respondents are not aware of any maintenance required.

Any other reason?

Generally temperature is not a primary issue when compared to ventilation and gas management; hence, the IS approved temperature monitoring systems for use in underground coal mines does not attract significant attention. In addition, the overall cost of purchasing and maintaining a system is another reason for not implementing an IS approved temperature monitoring system.

15. What are the challenges and advantages you can envision when implementing and using a real-time temperature and humidity measurement system in an underground coal mine?

The challenges are approval, robustness, maintenance, electronic/fouling drift (particularly for fixed system), calibration, labor resources and cost. In addition, choosing appropriate locations, control of data, implications of incorrect readings and possible cross contamination due to dust and moisture would be additional challenges when implementing the system. Installation into the mine ventilation network could also be an issue.

Selection of appropriate locations, and changing sensor positions in main drives during outbye activities or during diesel intensive outbye work, is another challenge.

The advantages with portable systems would be instantaneous electronic detection and display (ideally, integration of air flow and temperature display/alarming of effective temperature) for heat management and TARP levels.

Similarly, the advantages for fixed systems would be accurate and precise long-term data for mine environmental monitoring, mine planning, assessment of fugitive emission, planning for personal heat load management, optimization and control of mine air conditioning systems, and spontaneous combustion monitoring and control. Presentation of data, trending and collation, and ease of interpretation would be an added advantage. The use of IS approved real-time temperature monitoring system would justify flow and calculation of bulk air cooling (eg, SCD/chilled water), heating and fire detection. Apart from managing heat issues in real time, the system would also provide a better understanding of heat loads, underground temperatures and assist in the design of cooling plant.

16. Any comment/suggestion on this topic?

One underground coal mine is in the process of installing an IS approved real-time temperature monitoring system and would like to include us in the review. A couple of respondents believe that in comparison with the benefits of installing real-time air velocity monitors for pressure and flow the installation of real-time monitoring of temperature and humidity would not be embraced by mines.

One respondent believes that intrinsically safe, optic fiber, Raman scatter based sensing system capable of distributed temperature sensing, and capable of sensing wet bulb temperature would be invaluable in heat management and air conditioning within many Bowen Basin underground coal mines. Such a system deployed at regular intervals across active longwall goafs and gateroad goaf margins would be a "*God-send"* for management/monitoring of spontaneous combustion.

3 Conclusions

The work has found that:

- In Queensland, there is no mine which uses a real-time temperature monitoring system for dry bulb and humidity measurements. One of the mines is in the process of installing a real-time relative humidity measurement device.
- The majority of the respondents from Queensland mines indicated that if a real-time instrument for measuring dry bulb, wet bulb and humidity was available, they would be interested to install such a device at their mine sites.

As a continuation of this project, a suitable IS approved instrument will be compared and contrasted against the current non-real-time measurement devices (reference instruments and sling psychrometer) and practices. The comparison will be performed in a laboratory under various simulated mine environmental conditions in order to find out the fit for purpose status of the IS approved real-time instrument to be used in Queensland underground coal mines.

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