Preliminary Investigation on Using IS Approved Real Time Dry Bulb and Relative Humidity Sensors in Underground Coalmines

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Abstract

A review of various real time temperature monitoring devices available for use in underground coal mines in Queensland was conducted. To investigate the *fit-for-purpose* of the intrinsically safe (IS) instrument, laboratory experiments were performed. The obtained results were compared to the calibrated reference instrument readings and sling psychrometer data under variation in air flow velocity, moisture content and dust content.

Keywords: Underground coalmine, temperature, humidity, real time.

Introduction

Accurate measurement of dry bulb temperature T_{dbt} and relative humidity at different critical locations/areas of underground coal mines is a challenge to industry. A significant change in T_{dbt} and relative humidity can cause human fatigue, mine hazards, equipment failures and decreased production. Insufficient information and uncertainties associated with underground temperature data 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 measurement to determine the wet bulb temperature T_{wbt}.

In Australian underground coal mines, T_{wbt} is manually measured using a psychrometer or whirling hygrometer at various locations of the mine workings at different time intervals. The use of a real time temperature monitoring system can provide reliable, representative and continuous records of the temperature of various mine workings. Various psychometric properties, such as, relative humidity, dew point temperature, specific enthalpy, mixing ratio and specific volume can be derived from the temperature readings on a real time basis.

The aim of monitoring various parameters on real time basis in underground workings is to provide safe, efficient and productive working environment. 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. In mining engineering the importance of real time monitoring has been highlighted by various studies [1–4]. In contrast to real time monitoring research performed in other areas of underground coal mines, research on real time dry bulb temperature and relative humidity monitoring has been neglected due to the non- availability of IS monitors.

Real time temperature monitoring systems are very common in a range of manufacturing and processing industries, for example, powder handling, paper, drying, steel and pharmaceuticals. These devices are well developed, and used to scrutinize humidity and confirm the quality of processing operations in challenging but sensitive environments. These 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 [5]. The pertinent issues associated with the lack of use of real time T_{dbt} and relative humidity measuring instruments in the Australian underground coal mines were surveyed and presented [6].

The current work reviewed the availability of state of art real time temperature monitoring systems which could be deployed in Queensland underground coal mines, and investigated how accurate temperature measurements could be obtained to assist in the control of heat and temperature related issues experienced at various critical locations within an underground coal mine. The project also compared and contrasted the accuracy of the real time temperature monitoring system in comparison to the current non real time measurement devices and practices.

1. Experiment

The real time IS approved temperature sensor and real time IS approved humidity sensor were selected with the aim of comparing and contrasting their relative humidity RH_{rt} and temperature T_{rt} readings with those obtained using digital calibrated relative humidity and temperature sensors, which is termed as reference instrument R in this paper. A thermo-anemometer was selected to measure various air flow velocities. A room humidifier was used to produce various levels of humidity in a small experimental room. A medium sized electric fan was used to generate various air flow velocities. The reference instrument has an ISO 9001 quality management system with laboratories operating under ISO/IEC 17025. Before the project measurements began the reference instrument was thoroughly checked at the supplier's laboratory, where the unit showed 33.7% RH and 83.6% RH at the reference relative humidity of 33.86 and 85%, respectively.

The experimental room was 2.8 m long by 1.8 m wide by 2.3 m high. Experiments were conducted at various relative humidity, temperature, airflow velocity and dust concentration in order to investigate the effect of environmental parameters on real time measurement of temperature and relative humidity. The instruments were also remotely monitored and the data readings were recorded on a PC. Data transfer was facilitated using an RS485 to USB converter and a Modbus enabled programmable sensor controller supplied for the duration of the project. Figure 1 shows the experimental setup at the Mines Testing and Research Station (SIMTARS)'s dusty environment laboratory.

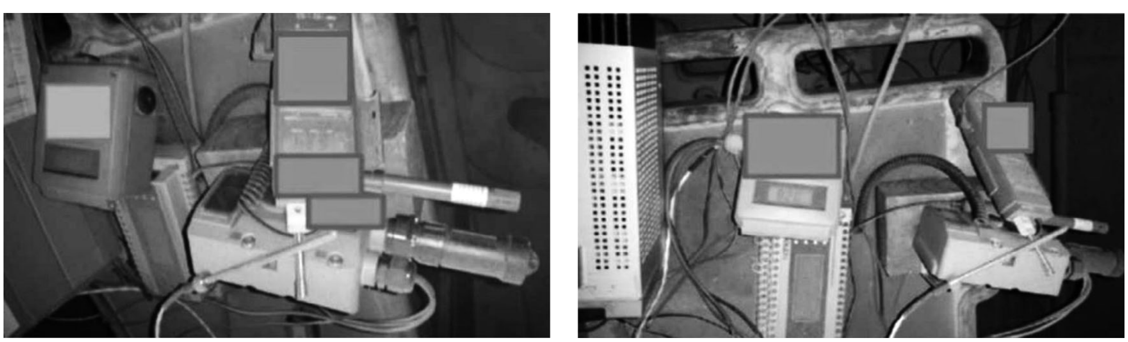

Fig. 1. Experimental plant under dusty conditions of laboratory.

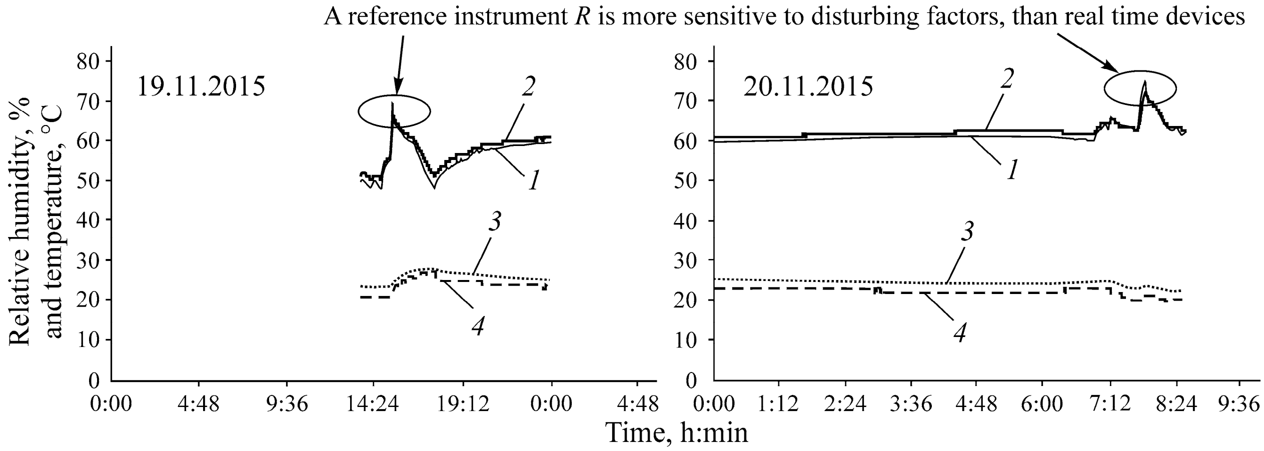

Fig. 2. Continuous readings of real time IS approved and reference sensors of temperature and relative humidity: *1*, *3*—reference sensors for measuring relative humidity and temperature, respectively; *2*, *4*—real time sensors for measuring relative humidity and temperature, respectively.

Numerous experiments were conducted in a wide variety of simulated environments. In all of the environmental combinations, the relative humidity and the temperature readings were observed on the monitoring instruments and the results were noted. The experiments were conducted on various days and readings were taken at a minimum interval of two minutes. Figure 2 shows the continuous readings recorded over two days of monitoring using real time IS approved relative humidity and temperature sensors, and a reference.

2 Results of observations

The T_{rt} and RH_{rt} readings in real time were similar to *R* when measuring temperature and relative humidity. *R* temperature sensor is more sensitive than the T_{rt}; hence, with the introduction of a disturbance the *R* temperature responded faster to an incremental change in relative humidity as shown by the circled segment (Fig. 2). The T_{rt} and RH_{rt} readings usually display slightly higher relative humidity and slightly lower T_{dbt} readings when compared to the reference instrument.

Figure 3 shows the spot measurement comparison of temperature and relative humidity readings observed for the two instruments at an air velocity of approximately 0 m/s with a dust concentration of 0 g/m^3 in a certain number of time intervals.

The Table presents the comparison results of IS approved sensors and reference sensors at various airflow velocities and dust concentration of 0 g/m^3.

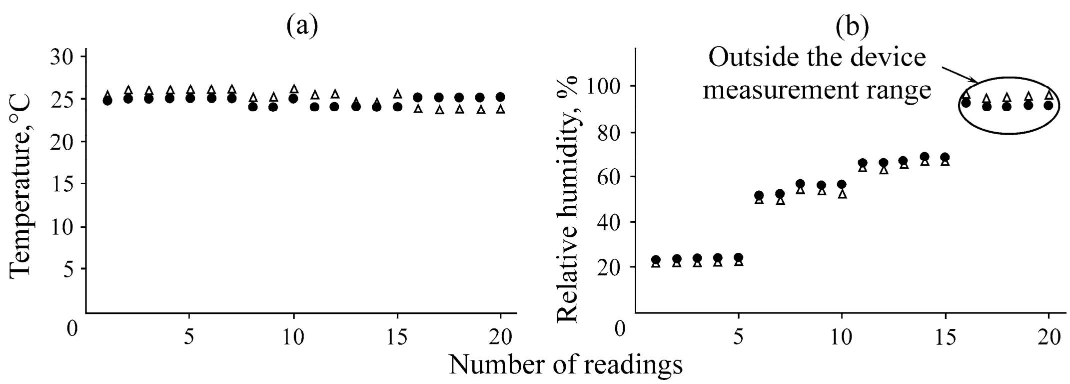

Fig. 3. Comparison of reference sensors (**Δ**) and real time sensors (**●**) readings at an air velocity of 0 m/s and dust concentration of 0 g/m^3: (a)—temperature; (b)—relative humidity.

Comparison results of readings of various sensors

Experiment no.	Airflow velocity, m/s	Deviation of RH_{rt} sensor readings relative to R, %	Deviation of T_{rt} sensor readings relative to R, %	Relative humidity, %
1	0	> 6	< 6	In case of humidity > 90 %, the results can be neglected
2	3.5	> 6	– 5 to 3	From 20 to 90
3	6.7	> 4	< 5	From 40 to 60
4	7.2	> 5	< 5	From 40 to 60
5	8.3	> 3	< 3	From 40 to 60

Figure 4 shows a comparison of temperature and relative humidity readings observed between the instruments at dust concentration of approximately 25 g/m^3. The dust chamber was not equipped with a dust concentration measuring instrument, but it was estimated from the quantity of dust spread in the chamber of known size. These graphs show that T_{dbt} and relative humidity readings observed for each instrument are very close to each other. The T_{rt} temperature readings are in close agreement with the readings noted from the standard instruments, T_{rt} temperature readings are up to 3% lower than the readings noted from the standard instruments, RH_{rt} readings are up to 2% higher when compared to the readings noted from the standard instruments.

3. Comparison with manual sling psychrometer

Figure 5 shows a comparison of the temperature and relative humidity readings obtained by three instruments (the sling psychromter, the real time IS instrument, and the non-IS instrument) at an air velocity of approximately 0 m/s with a dust concentration of approximately 0 g/m^3. The readings were taken in a single day at various time intervals in an external uncontrolled environment.

As follows from Fig. 5, the T_{rt} reading variations are –4 to 2%, and the readings noted from the standard instruments variations are –2 to 2% when compared to the sling psychrometer readings for identical environmental conditions. The RH_{rt} reading variations are –2 to 2%, and the readings noted from the standard instruments reading variations are –3 to 1% when compared to the sling psychrometer readings for identical environmental conditions.

Following points are to be considered while interpreting the experimental results from the instruments. The readings obtained from the real time and standard instruments were digitally displayed whereas the T_{dbt} and T_{wbt} readings from the sling psychrometer were manually noted, and may be subject to parallax error.

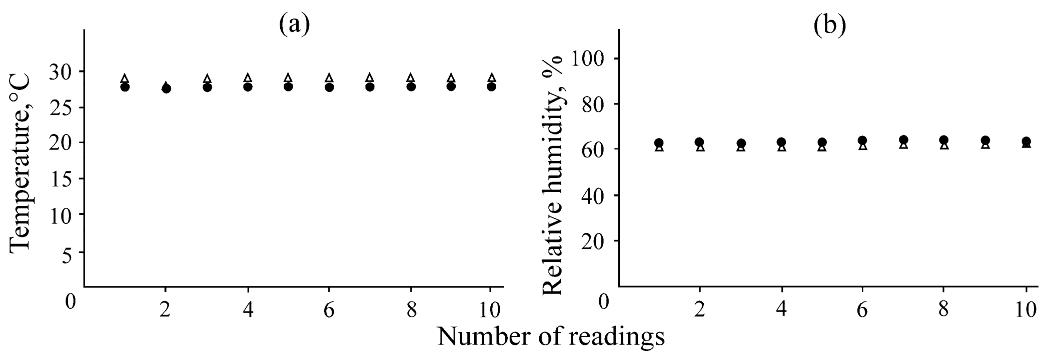

Fig. 4. Comparison of reference sensors (**Δ**) and real time sensors (●) readings at an air velocity of 0 m/s and dust concentration of 0 g/m^3: (a) temperature; (b) relative humidity.

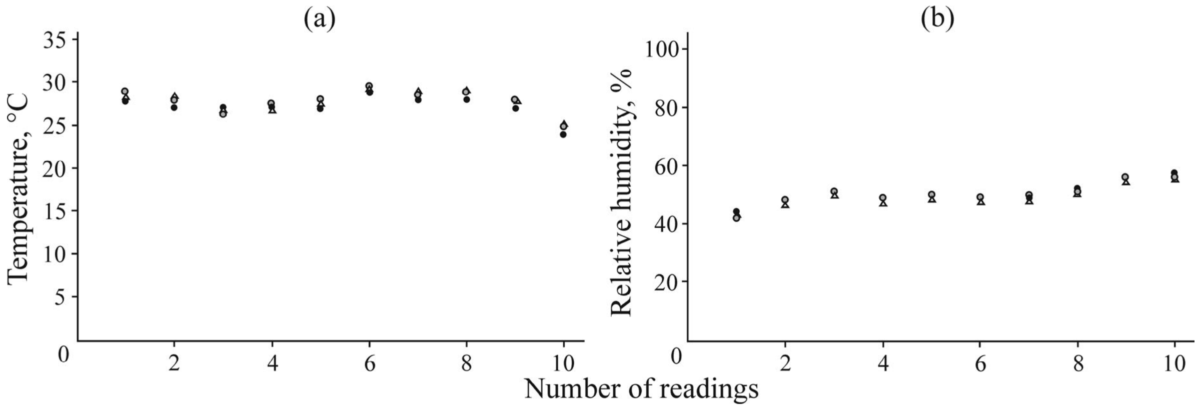

Fig. 5. Readings of temperature (a) and relative humidity (b) measured by reference instrument (▲), real time sensor (●) and sling psychrometer (◎).

In addition the calculation of relative humidity from the T_{dbt} and T_{wbt} readings obtained from the sling psychrometer was also prone to have parallax effect. Maximum effort was given to minimize such parallax effects while readings were taken and interpreted on the sling psychrometer. Similarly, low scale resolution and limited gradations may affect the interpretation of the readings obtained from the sling psychrometer. The sling psychrometer was held at arm's length while taking readings, whereas the real time and reference instruments were held at a farther distance, hence the psychrometer may be slightly influenced by the presence of a human body. From manufacturer's specifications, the sensing accuracy of the real time relative humidity is $\pm 5\%$ whereas the accuracy of the reference instrument's relative humidity is $\pm 2.5\%$. The accuracy of sling psychrometer relative humidity is $\pm 5\%$. Similarly, the accuracy of real time temperature is 1% and the accuracy of the reference instrument's temperature is $\pm 0.7^{o}$c.

4. Overall comparison and limitation

The comparison of readings obtained from the experiments under the simulated conditions between IS real time and reference devices that:

—IS relative humidity instrument consistently shows a slightly higher relative humidity readings up to 6% and IS temperature instrument shows a variation in temperature readings within –6% to +3% in comparison to the reference instruments;

—when compared to the relative humidity readings obtained using the sling psychrometer intervals in an external uncontrolled environment, the readings obtained from real time instruments are within $\pm 2\%$ and readings obtained from reference instrument are within –3%;

—the real time T_{dbt} reading variations are –4 to 2%, and reference instruments reading variations are $\pm 2\%$ when compared to the sling psychrometer T_{dbt} readings for identical environmental conditions.

Conclusions are based on a limited number of samples obtained in a known environment, where the temperature and relative humidity data obtained with the real time IS instrument were compared and contrasted with that obtained using a calibrated instruments and a sling psychrometer. A larger number of sample readings taken under more environmental scenarios and with a representative number of IS instruments, reference instruments and sling psychrometer would provide a better degree of confidence in using the tested IS instruments. As per the IS real time relative humidity sensor specifications, the instrument has a sensing range of relative humidity of 10 to 90% with sensing accuracy of $\pm 5\%$. This working range does not cover the whole spectrum of the relative humidity encountered in the underground coal mines. In some places in underground coal mines, the relative humidity measures up to 100%. The high humidity areas are the areas where the mine operators are most concerned.

Conclusions

It is found that the IS real time instrument exhibits a variation of dry bulb temperature by as much as –6% and up to +3% and always shows higher relative humidity readings by as much as +6% when compared to the standard calibrated non-IS instrument readings. Within the limitations of the current study, the tested IS real time relative humidity and temperature monitoring instruments could be considered. However, this conclusion is based on a limited sample size, limited number of instruments and the measurements were taken in a limited number of controlled environmental scenarios of temperature and relative humidity. A larger number of readings taken under more realistic underground environmental scenarios and with a representative number of IS instruments would provide a better measure of confidence. It can be inferred from the work that presently, there is a definite need for the development of a reliable IS real time humidity measurement system suitable for use in Australian underground coal mines. The underground coal mines operate in the relative humidity range spanning up to 80 to 100%. The only IS approved instrument at the moment measures up to 90% relative humidity (as per manufactureэs specification). It is valuable to investigate the possible development of a new IS approved instrument which can measure up to 100% relative humidity.

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