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UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

deg	degree	mg/m^3	milligram per cubic meter
ft	foot	mm	millimeter
ft/min	foot per minute	µm	micrometer
ft^3/min	cubic foot per minute	m/s	meter per second
g	gram	m^3/s	cubic meter per second
gal/min	gallon per minute	oz	ounce
h	hour	pct	percent
in	inch	psi	pound per square inch
L/min	liter per minute	s	second

THE EFFECT OF WATER VAPOR AND WATER DROPLETS ON THE RAM-1 (PRELIMINARY RESULTS)

By R. P. Vinson,[1] K. L. Williams,[1] G. H. Schnakenberg, Jr.,[2] and N. Jayaraman[3]

ABSTRACT

The Bureau of Mines examined the effects of high humidity and water droplets on the GCA Corp. real-time aerosol monitor (RAM-1), which uses a 10-mm cyclone preseparator. Tests were conducted both in a laboratory and in a full-scale model mine entry. The laboratory tests were conducted in a test chamber saturated with moisture and water droplets. Under these extreme conditions, the RAM-1 responded by indicating dust concentrations of 1-1/2 to 2 mg/m^3, although the air was dust free. Within the first 2 h of each test, water accumulated in the cyclone and affected the cyclone particle separation characteristics, resulting in readings of 3 to 4 mg/m^3. In addition, condensation formed inside the RAM-1 case and affected the liquid crystal display (LCD). However, the full-scale mine entry tests revealed that the RAM-1 can function acceptably in an atmosphere of water vapor and water droplets similar to the most severe conditions found in an underground mine.

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INTRODUCTION

The RAM-1 real-time aerosol monitor (fig. 1) was designed and built by the GCA Corp. under contract (1)[4] to the Bureau of Mines. This instrument is one of the more recent results of the Bureau's effort to design reliable respirable dust monitors. The development of such instruments is vital for the elimination of the mining health hazard caused by respirable coal mine dust.

[4]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

The RAM-1 is often used in coal mines whose atmospheres contain dust particles coexisting with water droplets and high humidity. To measure somewhat quantitatively the response of the RAM-1 to water droplets and high humidity, an atmosphere at dewpoint was produced by injecting water droplets into an enclosed, dust-free chamber and sampling this atmosphere with the RAM-1. In addition, the RAM-1 was operated in a full-scale mine model to observe the effect of water droplets under moisture conditions similar to those found in mines.

FIGURE 1. - The RAM-1.

THE RAM-1

The RAM-1 is a commercially available, portable, real-time aerosol monitor, with a double airflow system. The primary system is used to sample dust-laden air. A pump in the instrument pulls air from the environment at 2 L/min through a 10-mm-diam nylon cyclone preseparator at the inlet. The cyclone separates out the respirable fraction of the dust. The dust-laden air then passes through the optics chamber where the dust particles scatter the near-infrared light emitted by a pulsed solid-state source. The scattered light is detected by a silicon photodiode. The resulting signal is processed to give a digital display in milligrams of respirable dust per cubic meter of air.

The secondary purge air system uses the same pump as the primary system uses but cleans and dries the air by pulling it through a filter and desiccator. A constant flow of this air continuously cleans the optical surfaces in the optical chamber. This air is also used to zero the RAM-1 when it is operated in the zero mode.

The RAM-1 can be set to one of three full-scale ranges: zero to 2, 20, or 200 mg/m^3. The measurement time constant can also be set to either 0.5, 2, 8, or 32 s. The 0.5-s time constant was used throughout this investigation. A convenient digital LCD on the top of the instrument presents the measured dust concentration reading in milligrams per cubic meter. Details of the RAM-1 can be found in various reports by the Bureau (1-3).

LABORATORY TESTS

EXPERIMENTAL PROCEDURE

The initial objective of the tests was to determine whether the RAM-1 would respond to an atmosphere containing water droplets and high humidity. The procedure used was as follows. A mist-producing humidifier was placed in a test chamber measuring 26 in deep, 28 in wide, and 26 in high (fig. 2). The humidifier continually added water vapor and droplets to the air in the chamber, so that the atmosphere in the chamber became saturated with water vapor. (The vapor content was measured with a psychrometer placed in the chamber.) These conditions were maintained while the RAM-1 was tested in a variety of configurations. The analog output of the RAM-1, representing the response of the instrument to aerosols, was continuously recorded on a strip chart recorder during the tests.

RAM-1 INSIDE THE TEST CHAMBER

In the first test, the RAM-1 was placed inside the test chamber and operated in the "clear" mode to determine if it could be zeroed in the water-saturated environment. In the clear mode, only the clean, dry purge air enters the optical chamber. With fresh desiccant in the purge air inlet, the RAM-1 maintained zero reading while operating continuously for 5 h in this water-saturated atmosphere. However, it was found that if the purge air desiccant was removed or lost its ability to absorb water the RAM-1 drifted from zero, giving a false indication of dust. It is suspected that the water vapor condensed to droplets inside the RAM-1, where they were detected as they passed through the RAM-1's optical detection system. This first test showed that the purge air had to be kept clean and dry throughout the tests. Initially, this was accomplished by frequently changing the desiccant in the purge air inlet. In later tests, the purge air inlet (shown in figure 2*A*) was connected to a section of tubing and to another container of desiccant that was placed outside the test chamber. This ensured that the purged air would always be clean and dry.

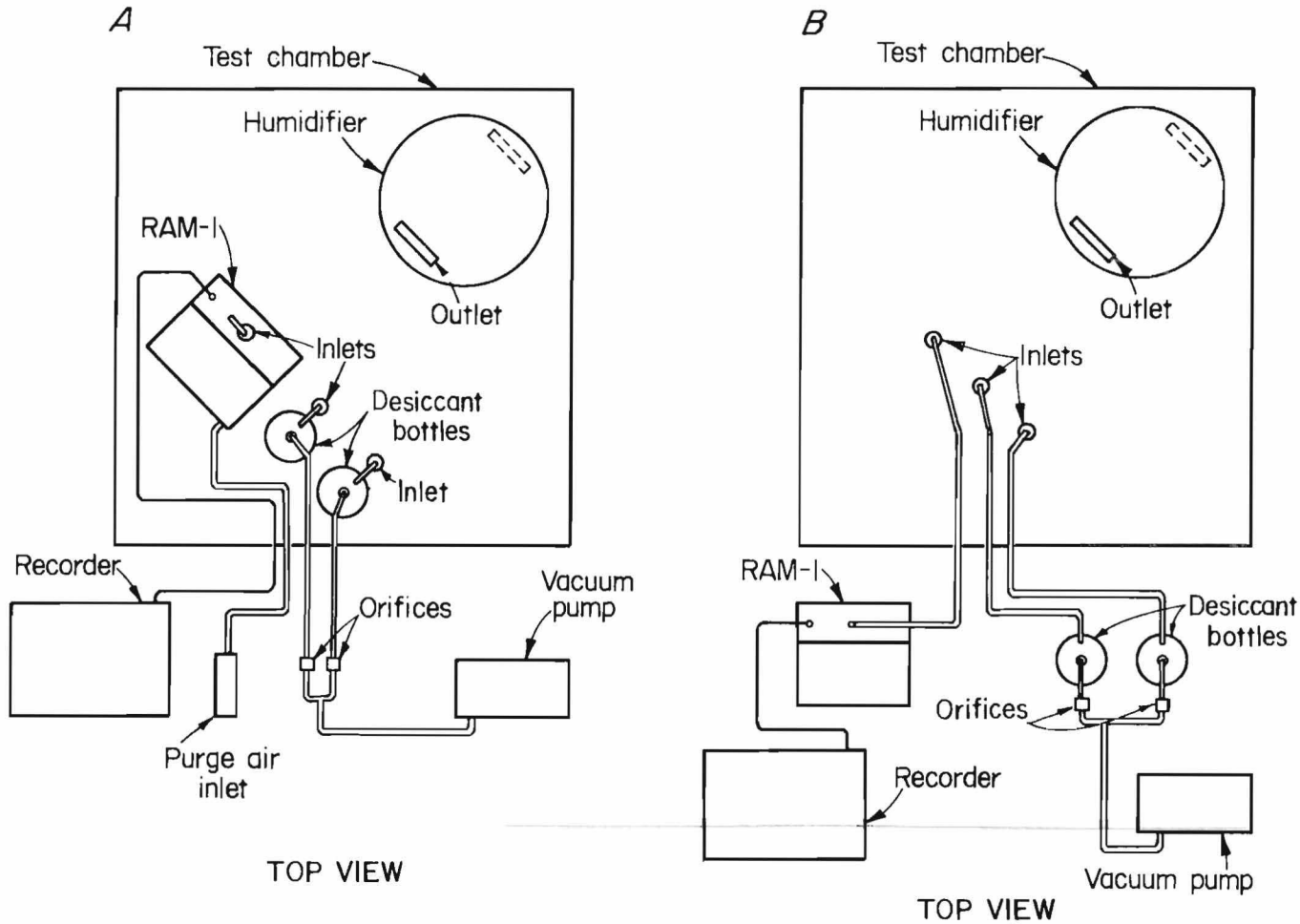

FIGURE 2. - Top views of test setup with RAM-1 inside (*A*) and outside (*B*) the test chamber.

To see if the RAM-1 responded to water droplets, it was placed in the test chamber with a 10-mm cyclone preseparator connected to its inlet and operated in its "sample" mode. The graph in figure 3 shows the RAM-1's response to water droplets from the humidifier, whose outlet was 17 in from and facing towards the cyclone inlet (fig. 2*A*). In this configuration, the RAM-1 received water vapor and a wide size range of water droplets, many of which were visible to the unaided eye. Under these conditions, the RAM-1 produced an initial reading of 1 mg/m^3, which increased to 2 mg/m^3 in the first half hour and then rapidly increased to about 4 mg/m^3, a doubling in the response.

The effects of the RAM-1 from water in the form of vapor and droplets not visible to the unaided eye were examined

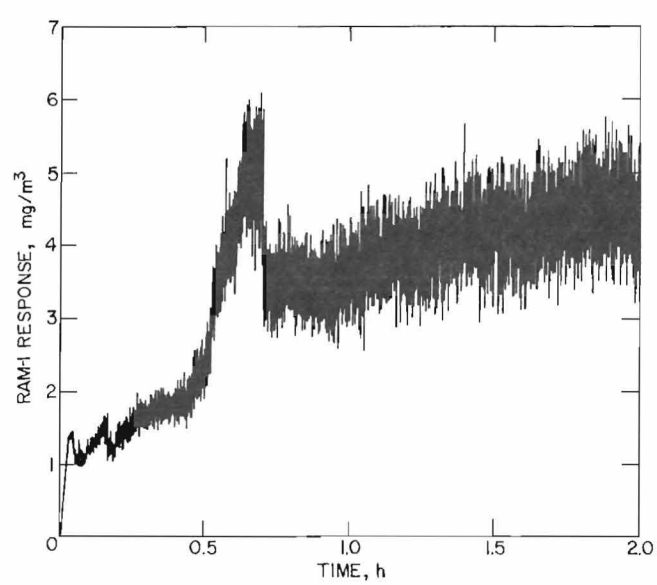

FIGURE 3. - RAM-1 response to water droplets with the humidifier outlet facing RAM-1 inlet.

next. The humidifier outlet faced toward the chamber wall opposite the RAM-1's inlet (outlet shown as dashed line in figure 2A). The visible water droplets impinged against the wall, leaving water vapor and nonvisible water droplets in the chamber's atmosphere. Once again, the RAM-1 immediately responded (fig. 4). Initially, the reading was 1 mg/m^3, which increased to 3 mg/m^3 and stayed between 2 and 3 mg/m^3 for the remainder of the test. Other repeated water droplet tests produced a similar response from the RAM-1 both in magnitude and in time.

The following observations were made when the RAM-1 was operated inside the test chamber. First, the RAM-1 responded to water vapor and water droplets; the RAM-1 indicated high dust concentrations when it was actually sampling air containing large amounts of water vapor and water droplets. Second, there was no significant difference in the RAM-1's response to visible and nonvisible water droplets. Third, the electronic components of the RAM-1 could be contaminanted by water as when, for example, water migrated inside the LCD laminations, causing improper displays.

This last finding made it necessary to operate the RAM-1 outside the test chamber while sampling the water-saturated air inside the chamber, to eliminate the influence of water contamination on the electronics so that the RAM-1's response was only from light scattering in the optics chamber.

This, in turn, required measuring the water volume sampled (1) to ensure that the RAM-1 sampled an equivalent amount of water outside the chamber as it sampled inside the chamber and (2) to determine if there was a correlation between the response of the RAM-1 and the water volume sampled.

WATER VOLUME MEASUREMENT METHOD

Two bottles were filled with desiccant and connected to an air pump (figs. 2, 5). The pump pulled saturated air from the test chamber through the bottles, where the water in the air was

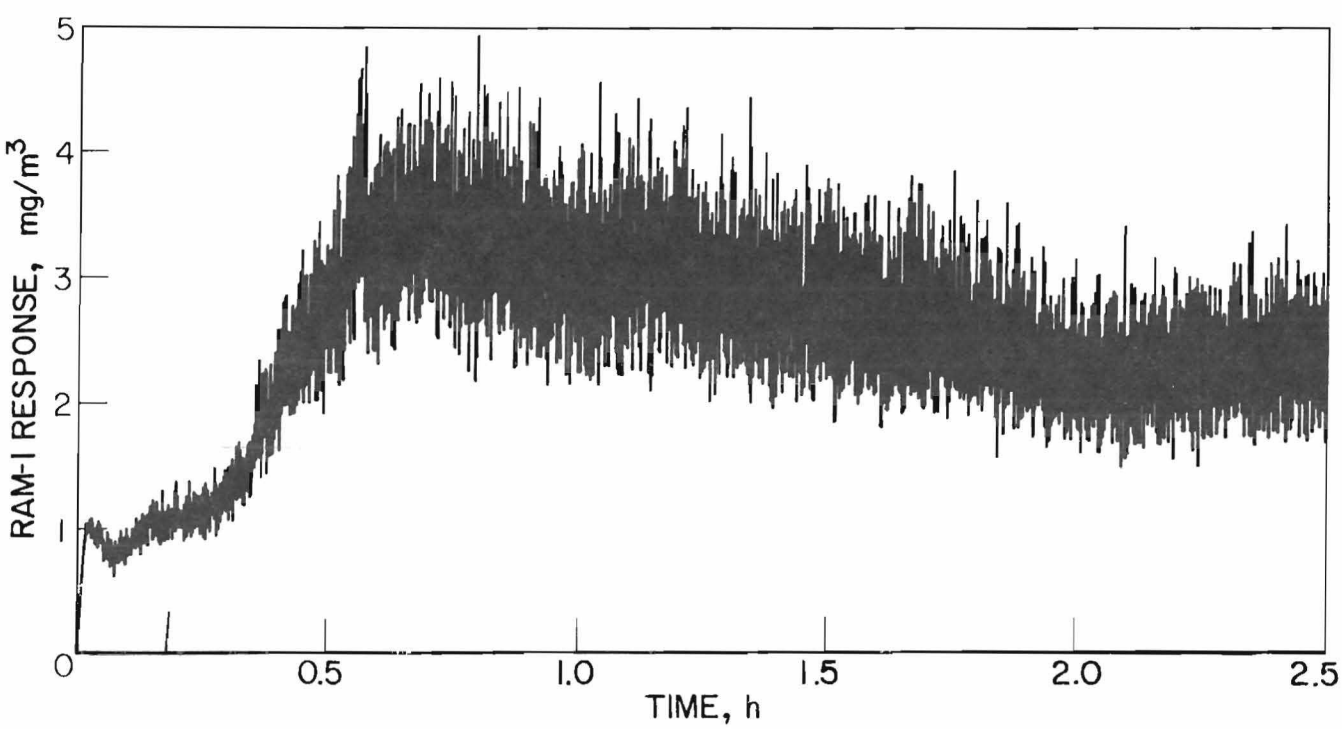

FIGURE 4. - RAM-1 response to water droplets with the humidifier outlet facing the test chamber wall opposite the RAM-1 inlet.

absorbed by the desiccant. The bottles were weighed before and after each test. The difference in the pretest and posttest weights equals the weight of water collected. A tube filled with color-indicating desiccant was connected to the outlet of each bottle. This made it possible to determine if any water was passing through the bottles and, thus, not being collected. None was. An orifice between the bottle and air pump was used to maintain a constant 2-L/min airflow for the duration of each test.

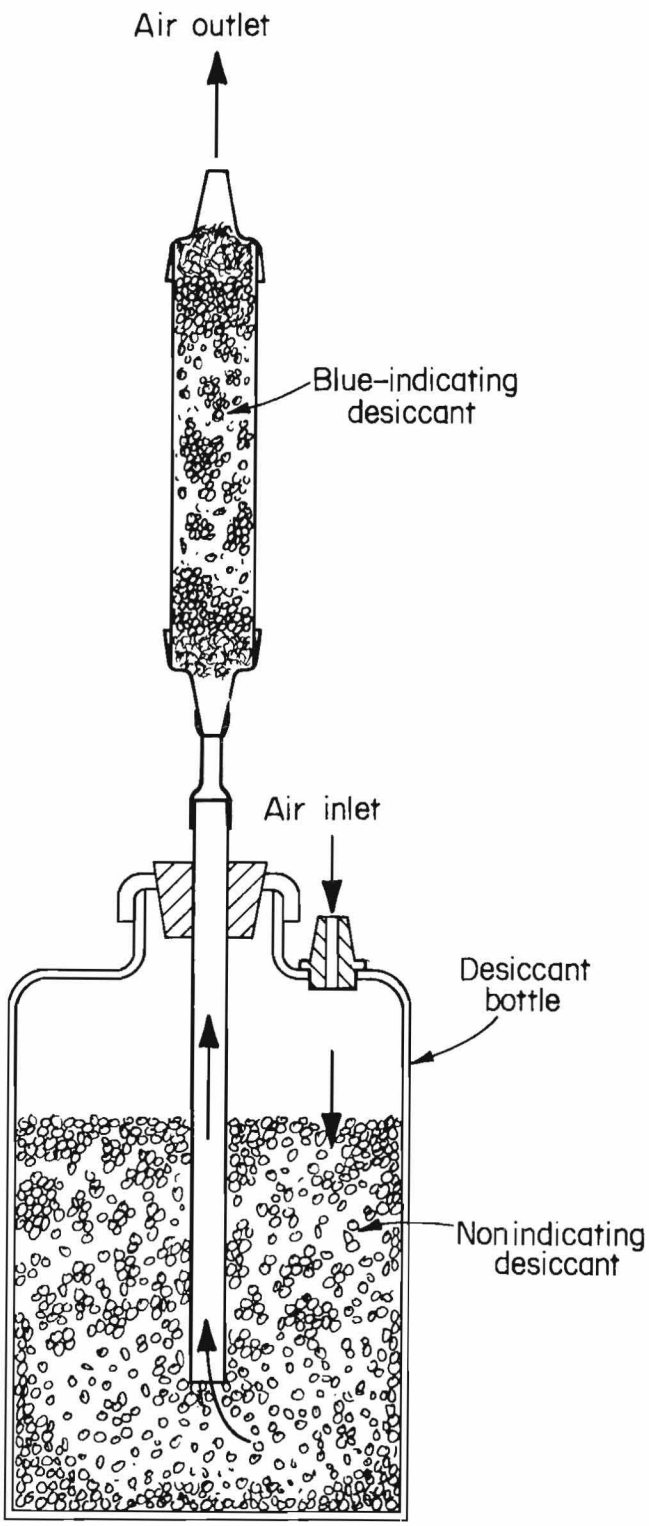

FIGURE 5. - Cross section of desiccant bottle.

Both the desiccant bottles and the RAM-1 drew air from the test chamber at the same rate and for the same amount of time. Therefore, the amount of water collected by the desiccant bottles would be equivalent to the amount of water sampled by the RAM-1.

WATER VOLUME MEASURED

As in previous RAM-1 tests, these tests were divided into two groups based on the orientation of the humidifier outlet, which faced either the inlets of the desiccant bottles (tests A-C) or the wall of the test chamber (tests D-E), as described previously. Table 1 gives the amount of water collected. The average amount of water collected was 12.2 g when the humidifier outlet faced the desiccant bottle inlets and 10.2 g when the humidifier outlet faced the wall of the test chamber. A comparison was made of these two means using a "t" test, which showed that with 5 deg of freedom and at the 95-pct confidence level both means were from the same population. Thus, the water volume sampled by the RAM-1 would not be significantly different for these two configurations.

TABLE 1. - Water collection in desiccant bottles, grams

Test	Bottle 1	Bottle 2
A.....	10.4	9.7
B.....	[1]12.8	12.8
C.....	[1]14.6	12.9
D.....	[1]9.9	[1]9.2
E.....	[1]11.0	[1]10.8

[1]10-mm nylon cyclone connected to desiccant bottle inlet.

NOTE.--In tests A-C, humidifier outlet faced desiccant bottle inlets; in tests D-E, outlet faced wall opposite inlets.

The measured water volumes revealed a rough correlation between the amount of water collected for each test and the average RAM-1 response for the same test. The recorded output of the RAM-1 was used to calculate the average response for each test in milligrams per cubic meter. This average value was then graphed with respect to the average weight of water collected in the desiccant bottles for each test (fig. 6). Although there are only five data points available, there appears to be a relationship between the average response and the total water through the RAM-1.

The water volume measurement method was also used to determine whether an equivalent volume of water would be sampled by the RAM-1 when operated inside the test chamber and outside the chamber (sampling the saturated air inside the chamber).

The RAM-1 and two desiccant bottles were placed outside the test chamber (fig. 2*B*) and sampled the saturated air in the chamber through equal lengths of flexible tubing (3 ft long, 1/4 in. in diam) connected to 10-mm cyclones placed inside the test chamber. The purpose of these tests was to determine if a significant amount of water was condensing onto the tubing wall. The weights of the collected water with the desiccant bottles outside and inside the test chamber are shown in table 2.

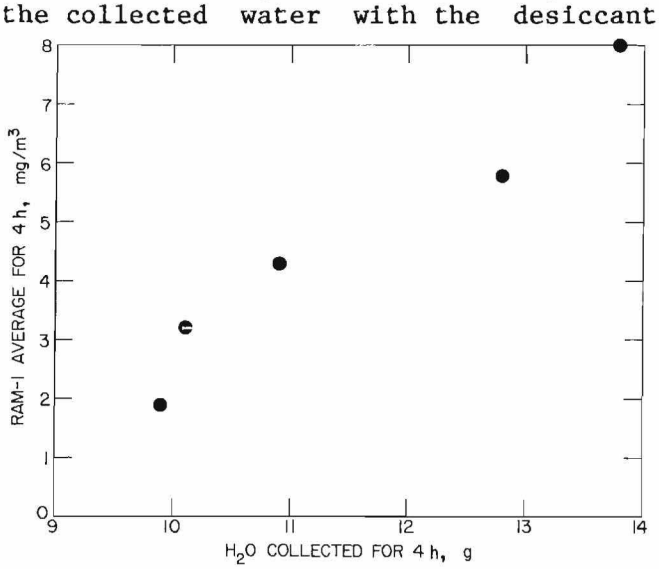

FIGURE 6. - Average RAM-1 response versus weight of water collected.

TABLE 2. - Water collected inside and outside the test chamber, grams

Test	Bottle inside	Bottle outside
A.....	10.4	NAp
	9.7	
B.....	12.8	NAp
	12.8	
C.....	NAp	14.6
		12.9
D.....	9.9	9.2
E.....	11.0	10.8
Av.....	11.9	11.1

NAp Not applicable.

The small difference of 0.8 g between the average weights of water collected inside and outside the chamber (11.9 and 11.1 g) indicates that the tubing did not substantially reduce the airborne water reaching the RAM-1 outside the chamber. Hence, experiments conducted with a RAM-1 outside the chamber, sampling the atmosphere inside the chamber, are valid.

RAM-1 OUTSIDE THE TEST CHAMBER

The RAM-1 was placed outside the test chamber and sampled saturated air inside the test chamber (fig. 2*B*) to eliminate any possible effects that water contamination might have on the RAM-1's output signal. This test configuration ensured that the output signal of the RAM-1 would be affected only by the response of the light-detection system to the water droplets as they passed through the optical chamber.

The RAM-1 response in this configuration was equivalent to its response when operated in the test chamber. There was an initial reading for approximately one-half hour of about 1 mg/m^3. The response then rapidly increased to about 3 mg/m^3 and stayed at that level for the remainder of the test.

It is concluded that the response of the RAM-1 in all of the tests was due solely to the detection of light

scattered by water droplets in the optical chamber.

OTHER OBSERVATIONS FROM LABORATORY TESTS

During the tests both inside and outside the test chamber, the RAM-1 response would suddenly increase, roughly doubling the initial reading (figs. 3-4). This usually occurred within 2 h after the start of a test. This behavior was probably due to the cyclone's filling with water, which stopped or changed the separating effect of the cyclone, thus allowing water droplets of all sizes to enter the light-scattering system of the RAM-1. After many of the tests, the cyclone body had filled with water, but no water had collected in the grit pot. The Bureau hypothesized that the first water droplets to be separated out plug the very small entrance to the grit pot.

As previously mentioned, the electronic components of the RAM-1 are affected by condensation. For example, when the RAM-1 was operated in the saturated atmosphere, the LCD gave peculiar displays such as three decimal points. Water had condensed and migrated inside the LCD laminations causing such improper displays. The trapped water was removed by placing the LCD in a vacuum for about 1 h.

TESTS IN A FULL-SCALE MINE ENTRY

The RAM-1 response to water droplets in the previous tests caused concern as to how it would respond in underground mines near the working face where water sprays are used to control dust and methane. Therefore, two tests were conducted in the Bureau's full-scale model mine entry to examine what effect water sprays from a full-scale mining machine might have on the RAM-1. The full-scale model was first cleaned with a high-pressure spray washer to reduce the possible influence of residual coal dust from other tests. Since the purpose was to observe how well the RAM-1 would operate under the most severe spray conditions, two RAM-1's with 10-mm cyclones connected to their inlets were placed in the immediate return airway (fig. 7).

A Tyndallometer T. M. Digital, a German-made light-scattering dust monitor, was also included in these tests (4). The outputs of all three dust monitors were continuously recorded on chart recorders.

During these tests, the full-scale mine entry was operated with an exhaust ventilation system at 5,500 ft^3/min (2.59 m^3/s), producing an air velocity of 360 ft/min (1.83 m/s) in the return airway. The only change made for the two tests was the water spray's pressure and flow.

Table 3 shows that the response of the RAM-1 was very low and did not directly relate to the water spray pressure and flow.

TABLE 3. - Dust monitors' responses to water droplets for two 0.5-h tests

	Test 1	Test 2
Water sprays:		
Pressure.....psi..	100	400
Flow.....gal/min..	18	36
Dust monitor response, mg/m^3:		
RAM-1:		
Front.....	0.09	0.06
Back.....	0.14	0.08
T. M. Digital.....	5.5	25.2

At the end of test 2, the front RAM-1 continued to operate, to determine if there was a change in response owing to the cyclone filling with water as was indicated in the laboratory tests.

Almost at the beginning of the second half hour, the RAM-1 response increased in a manner similar to that recorded in the laboratory tests. The original cyclone was replaced with a clean, dry one to find out if this increase was due to water in the cyclone. Once the clean, dry cyclone was installed, the RAM-1 reading dropped from 0.25 to 0.13 mg/m^3.

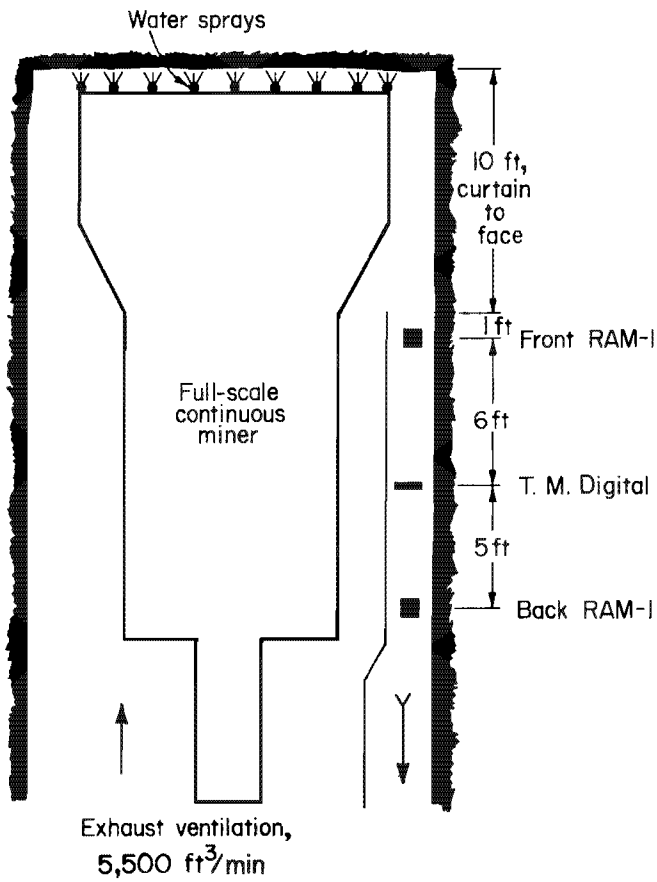

FIGURE 7. - Test setup in the full-scale mine entry model.

Although the RAM-1 response was relatively low throughout the tests, the reading dropped to almost half with the dry cyclone. It seems, therefore, that the increase in the response of the RAM-1 with time in highly water-saturated atmospheres is caused by the total volume of water collected by the cyclone preseparator and is not a function of the total volume of water passing through the RAM-1 per se. The phenomenon is not associated with the RAM-1 detection principle but with the cyclone.

After the second test, the front RAM-1 (the one closest to the spray) was disassembled and examined. Water had condensed on the inner components, the purge air filters were soaked, the main flowmeter was half filled with water, and the pump and pulsation dampener contained 0.14 oz of water. (In previous laboratory tests, water was found inside the RAM-1 case; however, the motor and pulsation dampener were not dismantled.) It is very unlikely that the RAM-1 will ever be subjected to an environment this severe even in a coal mine, since dust is seldom monitored in the immediate return airway. Even if the RAM-1 is operated in the return airway of a real coal mine, the water droplet concentration will be lower because a large quantity of water will impact on the coal being mined and never reach the return airway. The results indicate that the RAM-1 will perform satisfactorily in underground mines provided it is not placed in a high concentration of water spray for long periods.

The Tyndallometer was much more sensitive to water droplets than were the RAM-1's because it had no preseparator. Table 3 shows that the average response of the T. M. Digital to these conditions is significant.

CONCLUSIONS AND RECOMMENDATIONS

This limited series of tests in both the laboratory and the full-scale mine model indicates that, although water can affect the RAM-1's performance, the effect in most underground sampling situations will be minimal.

The full-scale mine tests also revealed that the Tyndallometer T. M. Digital is very sensitive to airborne water aerosols.

It was also found that the performance of the 10-mm nylon cyclone preseparator is affected by the accumulation of water. This conclusion with regard to the cyclone may have implications of wide concern. The evidence suggests that the cyclone loses its ability to separate (for whatever reason) water droplets from the air after it has accumulated water. However, this still leaves unresolved the question of the cyclone's performance as

a size selector in this condition with respect to solid aerosols.

When sampling with the RAM-1, place it in locations that are free from water sprays.

The effect of water droplets on the separation efficiency of the 10-mm nylon cyclone should be more thoroughly examined. In addition, the combined effects of water and dust particles on the 10-mm cyclone should be investigated.

A series of in-mine studies should be conducted to determine the incidence of water collected in cyclones.

REFERENCES

1. Lilienfeld, P. Improved Light Scattering Dust Monitor (contract H0377092, GCA Corp.). BuMines OFR 90-79, 1979, 44 pp.; NTIS PB 299 938/AS.

2. Schnakenberg, G. H., Jr., and J. E. Chilton. Direct Reading Systems. Dosimetry for Chemical and Physical Agents. Ann. Am. Conf. Gov. Ind. Hyg., v. 1, 1981, pp. 273-289.

3. Williams, K. L., R. J. Timko. Performance Evaluation of a Real-Time Aerosol Monitor. BuMines IC 8968, 1983, 20 pp.

4. Breur, H. Das Feinstaub-Streulichtphotometers T. M. Digital (The Fine-Dust Light Scattering Photometer T. M. Digital). Staub-Reinhalt. Luft, v. 36, Jan. 1976, p. 6.

5. May, K. R. The Measurement of Airborne Droplets by the Magnesium Oxide Method. J. Sci. Instrum., v. 27, May 1950, pp. 128-130.

APPENDIX.--MEASUREMENT OF WATER DROPLETS

Droplets produced by the humidifier were sized using techniques devised by May (5),[1] whereby magnesium strips were burned using a propane torch. The resulting magnesium oxide smoke was used to coat glass microscope slides, which were then passed through the droplet stream about 1 ft from the humidifier exit port. Droplets striking the slides make somewhat permanent impressions in the magnesium oxide coating, which can be measured microscopically. According to May, the diameter of the impression times 0.86 is the true droplet diameter for water droplets between 20 and 200 μm. Figure A-1 shows a microscopic photograph of a typical magnesium oxide slide with droplet impressions. Droplets produced by the humidifier and measurable by this technique appeared to be about 35 μm on the average, with a standard deviation of about 13 μm. Note, however, that droplets smaller than about 10 μm will not be measured by this technique.

[1]Underlined numbers in parentheses refer to items in the list of references preceding this appendix.

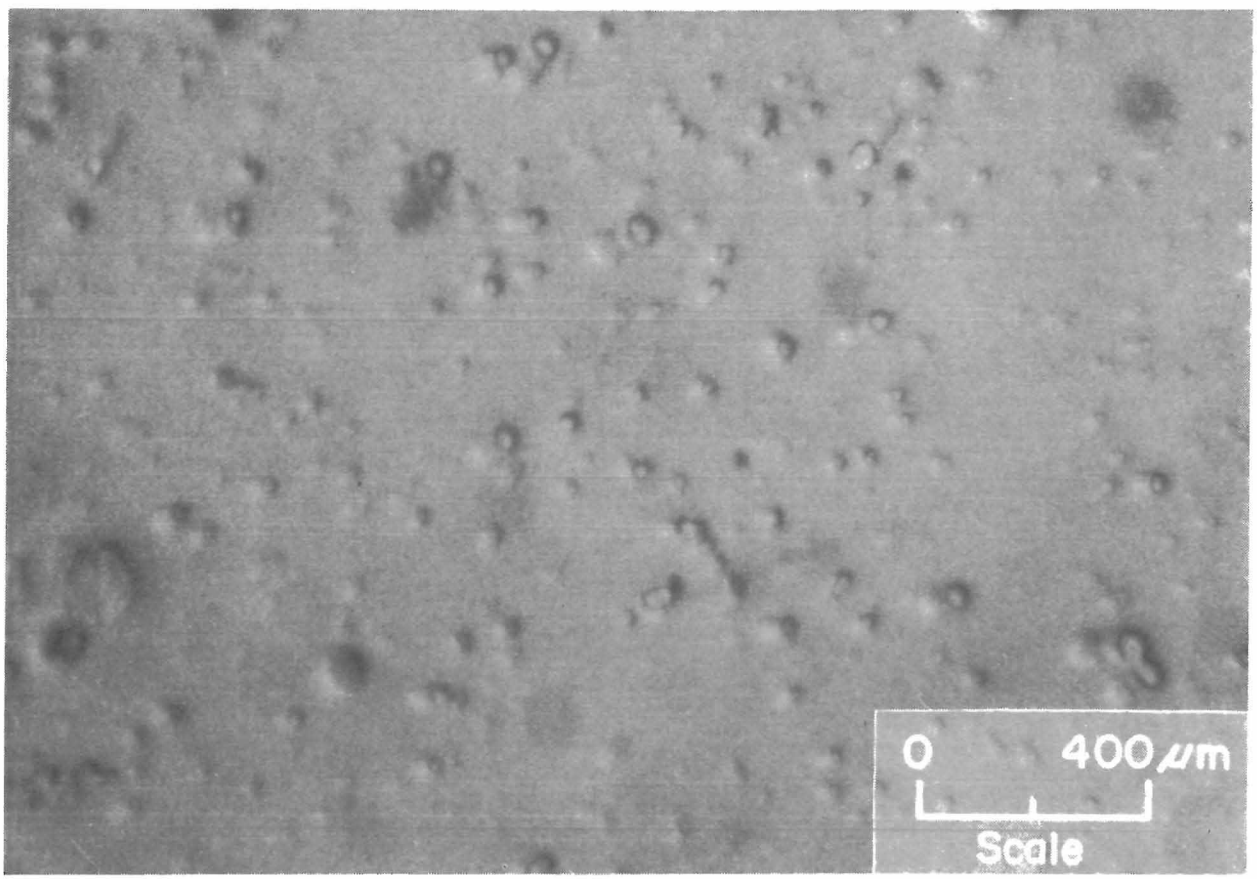

FIGURE A-1. - Droplet impressions on magnesium oxide (X 50).

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