Effect of Altitude, Sample Port Inlet Loading, and Temperature on the Volumetric Flow Rate of the MSA Escort® Elf Constant-Flow-Rate Pump

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A previous evaluation of four constant-flow pumps used to perform respirable dust sampling showed that volumetric flow rate may increase as air density decreases. Recently, the Mine Safety Appliances Company, Inc. Escort Elf personal sampling pump, which incorporates a flow measurement device and a closed-loop feedback system designed to maintain constant volumetric flow over a wide range of environmental conditions, was approved for coal mine dust sampling. The objective of this article is to show the effect that changes in altitude, sample inlet loading, and temperature have on the volumetric flow rate of this pump. The laboratory method used involved measuring flow rate with a wet test meter under different simulated altitudes using a sealed test chamber and a vacuum pump. Increases in sample inlet loading were simulated by partially obstructing the pump inlet. An environmental chamber was used to test for the effects of temperature. All laboratory tests were performed over flow rates ranging from 1.0 to 3.0 L/min. Some field data were also obtained. The test results show that the pump maintains volumetric flow rate, within ±5 percent of set point, at altitudes up to 10,000 ft. Similar changes in volumetric flow rate were observed as sample inlet loading was increased to 20 and 30 inches of water and as temperature was varied from 4° to 40°C. Setting the flow rate of the pump was found to be particularly easy and convenient. It was concluded that the personal sampling pump which was recently approved for coal mine dust sampling maintains volumetric flow within ±5 percent over a wide range of altitudes, sample inlet loadings, and temperatures.
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The U.S. Mine Safety and Health Act of 1977[1] requires that the Mine Safety and Health Administration (MSHA) inspect surface mines at least twice a year, and underground mines at least four times a year to assure compliance with mandatory health and safety standards. These MSHA inspections often include collection of full-shift respirable dust samples to assure that respirable dust standards are being met. Furthermore, the U.S. Mine Safety and Health Act of 1977 requires operators of coal mines to periodically collect and submit respirable dust samples to MSHA to further assure compliance with dust standards.

The equipment used to collect the respirable dust samples includes a Dorr-Oliver 10-mm nylon cyclone preseparator, which is used to remove nonrespirable dust particles, a filter cassette to collect the respirable particles, and a portable battery-powered pump to provide air movement.[2] In order for the cyclone to operate properly, the correct volumetric flow must pass through it. For respirable dust sampling in coal mines, the pump must maintain a volumetric flow of 2.0 ± 0.1 L/min through the cyclone, with no more than two manual corrections to the flow rate setting of the pump during the sampling period. A more desirable feature would be the ability of the pump to maintain constant flow throughout the sampling period.

Conditions that could affect the flow rate of the pump during the sampling period include changes in pressure drop across the sampling device and changes in temperature. Calibrating the pump at one altitude and using it at another altitude can also affect flow rate. To study the magnitude of these effects, MSHA has periodically evaluated the flow rate of pumps, which can be used for in-mine respirable dust sampling, by subjecting them to changes in one or more of these conditions.[3,4]

A recently introduced portable sampling pump developed by the Mine Safety Appliances Company, Inc. (MSA) Cranberry Township, Pennsylvania, the Escort Elf personal sampling pump, uses a unique flow measurement device located within a closed-loop feedback system to maintain constant volumetric flow over a wide range of environmental conditions. This pump has recently been approved by MSHA for use in coal mine dust sampling. This article describes the pump and discusses its performance as sample inlet loading, temperature, and altitude are varied.

Sampling Pump Specifications

With the rechargeable battery pack, the MSA Escort Elf sampling pump measures 4 inches high, 3-⅞ inches wide, and 2 inches deep. It weighs 19 oz. The liquid crystal display (LCD) integrated into the pump housing provides 0.01 L/min flow resolution and flow rate adjustment in 0.1-L/min increments between 0.5 and 3.0 L/min. Volumetric flow is specified to remain within ±2.5 percent of set point over the 1.0 to 3.0 L/min range during any 8-hour shift, with automatic compensation for changes in battery voltage, altitude, temperature, and sample inlet loading.

The Escort Elf sampling pump is specified to operate from 0° to 45°C. With flow rates up to 2.0 L/min, the pump will operate with sample inlet loads up to 30 inches of water. With loads of up to 20 inches of water, the pump will operate at flow rates up to 2.5 L/min, while it will operate at flow rates above 2.5 L/min with sample inlet loads up to 10 inches of water. Operating time varies with flow rate and sample inlet loading, but for most operating conditions is well above 8 hours. Calibration of the Escort Elf pump after every 200 hours of operation is recommended.

Elapsed time readout is provided by the LCD display in 1-minute increments up to 999 minutes. A flow-fault light-emitting diode (LED) is lit when flow blockage is detected. Pump shutdown occurs within 90 seconds if the flow blockage is not cleared. A second LED provides warning of low battery voltage. The stainless-steel-impregnated plastic case provides mechanical abuse resistance, corrosion resistance, and protection against electrostatic and electromagnetic interference. Four gaskets seal the case, making it resistant to water spray and dust while running. The Escort Elf pump is MSHA certified as intrinsically safe for underground use, National Institute for Occupational Safety and Health (NIOSH) certified for coal mine dust sampling, and Underwriters Laboratory certified as intrinsically safe for use in Division 1—Class I, Groups A, B, C, and D; Class II, Groups E, F, and G; and Class III hazardous locations.

Experimental Procedures

Ten pumps were used for the laboratory evaluation. Five of them had been in the possession of, and used by, MSHA for about a year. The other five were newly manufactured by MSA. The two groups of pumps are the same size, look similar, have identical flow control hardware and software, and have the same MSA part number; however, the older pumps require use of a screwdriver to adjust flow rate, whereas the new pumps incorporate a keyboard with up and down arrows to allow for easier flow rate adjustment. The older pumps also have a yellow LED whereas the new pumps have a green LED to indicate flow blockage.

The effect of changing altitude, sample inlet loading, and ambient temperature on the flow rate of the Escort Elf pump was measured in the laboratory by using an oil-filled, 1-liter-per-revolution, wet test meter and an electronic timer capable of 0.01-minute precision. The wet test meter was located in the same environment as the pump to assure that it was measuring the same gas volume as the pump was aspirating; however, this arrangement made it difficult to see the sight glass of the wet test meter.

Changes in altitude were simulated using a modified LABCONCO vacuum desiccation cabinet with interior dimensions of 1 ft high, 1 ft wide, and 1 ft deep. Modifications to the cabinet included the addition of valves and plumbing to allow control of interior chamber pressure with the aid of a vacuum pump. Within the chamber, the wet test meter was connected with tubing to a filter cassette connected to the Escort Elf sampling pump. A Taylor Instrument Co. (Rochester, New York) Model #U.S.G. G-568 surveyor's altimeter was also placed within the chamber and was used to monitor simulated altitudes to 9100 ft. Above this altitude, use of a WeatherMeasure Corp. (Sacramento, California) Model #5292 altimeter was required.

Before the start of all laboratory work the pumps were calibrated to 2.0 L/min under ambient laboratory conditions with a bubble meter. The accuracy of the calibration was then checked with the wet test meter and found to be within 1.6 percent. The pump flow rates were set so the displays read 1.0, 1.5, 2.0, 2.5, or 3.0 L/min. This allowed data to be obtained with the pump displays set at the 2.0 L/min flow rate used for respirable dust sampling in U.S. coal mines[5] and in 0.5 L/min increments on either side of this flow rate.

Before altitude testing, the pumps were set so the displays read 1.0 L/min at 1035 ft, the altitude of the laboratory. The flow rate of each pump was then measured at 1035 ft, and then at simulated altitudes of 2000, 4000, 6000, 8000, and 9100 ft. After all the pumps had been checked with displays reading 1.0 L/min, testing was repeated with displays reading 1.5, 2.0, 2.5, and 3.0 L/min. One old pump and one new pump were then checked at each flow rate at 10,000 ft.

All ten pumps were used to study the effect of sample inlet loading on flow rate. The same flow measurement equipment was used, except an adjustable clamp was added after the wet test meter, to provide a higher pressure drop than was obtainable with a fresh filter cassette. A large water-filled U-tube manometer was also added at the pump inlet to allow measurement of sample inlet loading. Pressure drops ranged from that produced by the filter cassette (between 1.0 and 3.5 inches of water) to 30 inches of water and flow rates were varied from 1.0 to 3.0 L/min.

The effect of temperature was evaluated using a Standard Environmental Systems Inc. (Totowa, New Jersey) Model #RB/5S environmental chamber equipped with glove ports. The interior of the chamber was 21.75 inches high, 21 inches wide, and 20.5 inches deep. Two new pumps and two old pumps were tested at 4°, 13°, 22°, 31°, and 40°C at 1.0, 2.0, and 3.0 L/min. Before the beginning of the temperature testing all four pumps were turned on and placed in the environmental chamber. The environmental chamber was then turned on and after reaching the desired temperature the pumps were attached, in turn, to the wet test meter to measure flow rate. Measurements were repeated to ensure that the pumps had reached thermal equilibrium.

Some field data were also collected with 18 other Escort Elf pumps that had been in field use for 1 year. This was done by measuring the flow rate of each pump ten times with a bubble meter in a laboratory at an elevation of 1035 ft and then transporting the pumps, and the bubble meter, to a mine office at an elevation of 6310 ft. Subsequently, 8 days after taking the

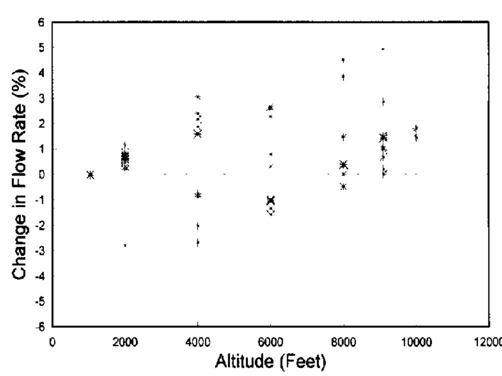

FIGURE 1. Change in flow rate versus altitude at a 1.0 L/min set point.

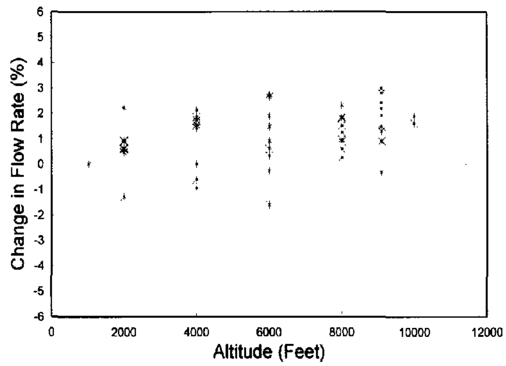

FIGURE 2. Change in flow rate versus altitude at a 1.5 L/min set point.

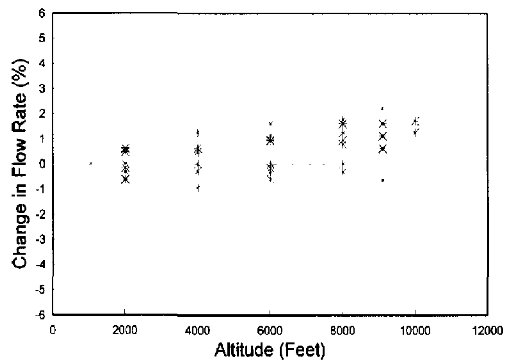

FIGURE 4. Change in flow rate versus altitude at a 2.5 L/min set point.

original measurements, ten additional measurements were taken on each pump in the mine office.

Results and Discussion

The data shown in Figures 1 through 5 were collected at nominal flow rates of 1.0, 1.5, 2.0, 2.5, and 3.0 L/min, respectively, and show the percent change in flow rate of all ten Escort Elf pumps as altitude increases from 1035 ft to 9100 ft. Also shown in Figures 1 through 5 are the data obtained on one new pump and one old pump at an altitude of 10,000 ft. The flow rate obtained at the laboratory altitude of 1035 ft was used as the reference point in each figure. This leaves the percent change in flow rate of 52, often overlapping, data points to consider in each figure.

Figures 1 through 5 confirm that the flow rates of all the pumps remain within ±5 percent of their nominal set points at all simulated altitudes. In fact, except at 1.0 L/min, the flow rate of all pumps remain within ±3 percent of the nominal set point. At 2.0 L/min, all pumps remain within +2.5 and −1 percent of the nominal set point. Also, at each of the flow rates studied there appears to be a tendency for flow rate to increase as altitude increases. Figure 6 summarizes the data shown in Figures 1 through 5 and shows that 97 percent of the data points obtained lie within +3.5 and −1.5 percent of the nominal flow rate set point as the equipment is taken from an altitude of 1035 ft to 10,000 ft.

The data obtained in Figures 7 through 9 were collected at nominal flow rates of 1.0, 2.0, and 3.0 L/min, respectively, and show the percent change in flow rate obtained with all ten Escort Elf pumps as sample inlet loading increases. The minimum sample inlet loadings obtained at flow rates of 1.0, 2.0, and 3.0 L/min for the same filter cassette were 1.0, 2.0, and 3.5 inches of water, respectively, and the flow rate obtained under each of these conditions was used as the reference point. This leaves the percent change in flow rate of 30 data points at 1.0 and 2.0 L/min, and 20 data points at 3.0 L/min to consider. The lower number of data points at 3.0 L/min is due to the smaller load range available at that flow rate.

Figures 7 through 9 confirm that the flow rates of all pumps remain within about ±5 percent of their nominal set points at all simulated sample inlet loadings. At 2.0 L/min, the flow rate of all pumps remains within +1 and −4 percent of the

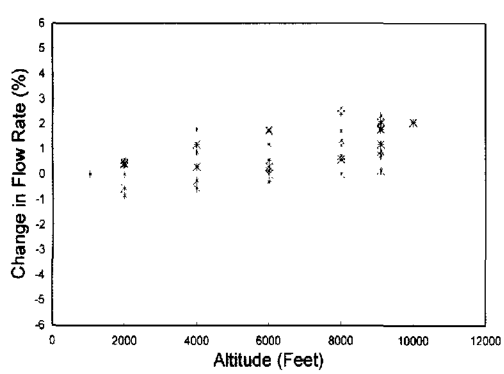

FIGURE 3. Change in flow rate versus altitude at a 2.0 L/min set point.

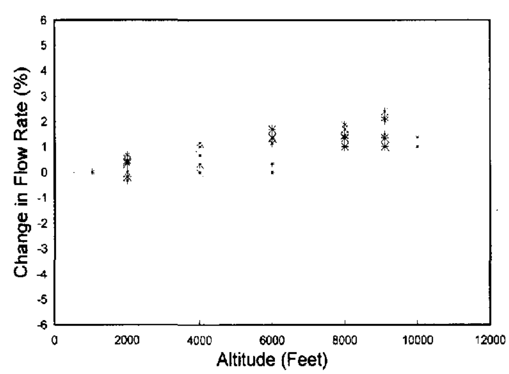

FIGURE 5. Change in flow rate versus altitude at a 3.0 L/min set point.

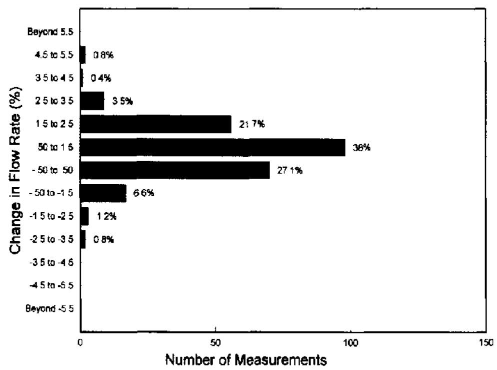

FIGURE 6. Summary of all data obtained as a function of altitude.

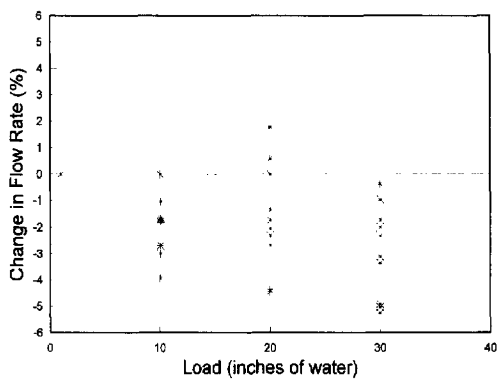

FIGURE 7. Change in flow rate versus sample inlet loading at a 1.0 L/min set point.

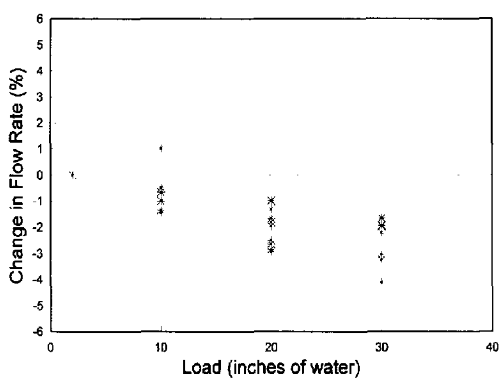

FIGURE 8. Change in flow rate versus sample inlet loading at a 2.0 L/min set point.

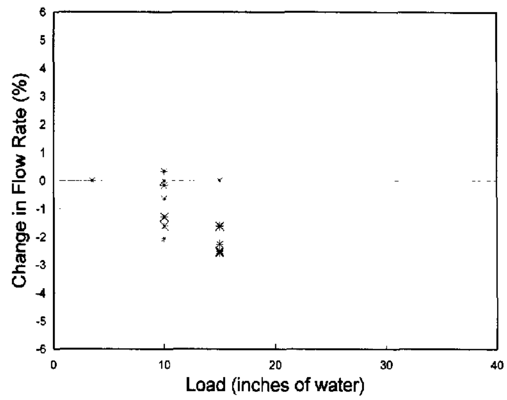

FIGURE 9. Change in flow rate versus sample inlet loading at a 3.0 L/min set point.

nominal set point. There also appears to be a tendency for flow rate to decrease as sample inlet loading increases. Figure 10 summarizes the data shown in Figures 7 through 9 and shows that 90 percent of the data points obtained lie within +1.5 and −3.5 percent of the nominal flow rate set point.

The data obtained in Figures 11 through 13 were also collected at the nominal flow rates of 1.0, 2.0, and 3.0 L/min, respectively, and show the percent change in flow rate obtained with two new and two old Escort Elf pumps as temperature changes. The flow rate obtained at the initial temperature of 22°C was used as the reference point in each figure. This leaves the percent change in flow rate of 16 data points in each figure to consider.

Figures 11 through 13 confirm that the flow rates of all the pumps remain within about ±5 percent of the nominal set point as temperature is varied between −4° and +40°C. At 2.0 L/min, the change in flow rate of the pumps remains about ±5 percent. As the temperature deviation from 22°C increased, the only clear trend in the data is toward increasing

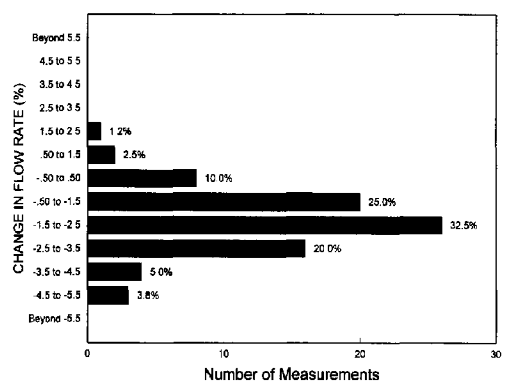

FIGURE 10. Summary of all data obtained as a function of sample inlet loading.

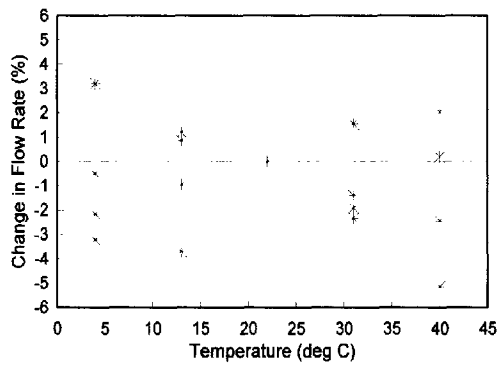

FIGURE 11. Change in flow rate versus temperature at a 1.0 L/min set point.

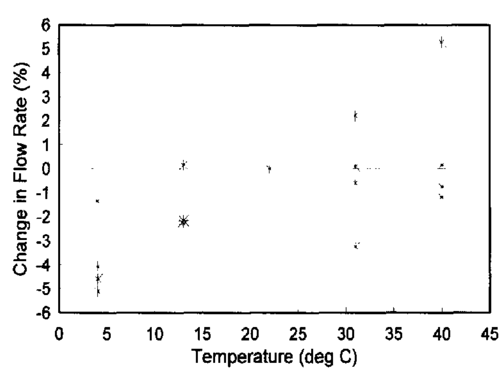

FIGURE 12. Change in flow rate versus temperature at a 2.0 L/min set point.

change in flow rate. Figure 14 summarizes the data shown in Figures 11 through 13 and shows that 90 percent of the data points obtained lie within +2.5 and −4.5 percent of the nominal flow rate set point.

Of the 18 Escort Elf sampling pumps used for field measurements, 8 had previously been set to 1.7 L/min and the remaining 10 had been set to 2.0 L/min. The increase in altitude between the laboratory and the mine office was greater than 5200 feet. The temperature in the laboratory ranged from 22° to 27°C and the temperature in the mine office ranged from 22° to 24°C when the data were collected. No sample inlet loading records were kept at either location. When the flow rates obtained in the mine office were compared to the flow rates obtained in the laboratory changes of −0.1, −1.1, +0.3, +1.2, −0.9, +3.3, +0.9, and +0.8 percent in flow rate were observed for the pumps set to 1.7 L/min. Changes of +0.9, −0.6, +0.1, −1.0, +0.2, −1.5, −0.3, −0.7, +0.2, and +0.1 percent in flow rate were observed for the pumps set for 2.0 L/min.

No significant performance differences were noted between the new pumps and the old pumps during testing; however, the field data seem to show somewhat less change in flow rate at similar altitudes than the laboratory data. This is consistent with the view that the laboratory data may be confounded by a small determinant error, thought to be related to oil level changes in the wet test meter, which may occur as altitude and/or temperature vary. This could explain the observed deviation from the manufacturer's stated ±2.5 percent accuracy.

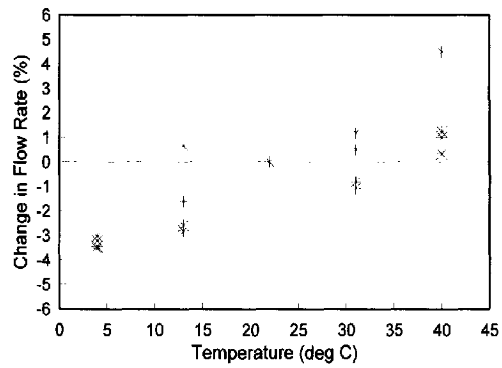

FIGURE 13. Change in flow rate versus temperature at a 3.0 L/min set point.

Conclusions

At flow rates of 1.0–3.0 L/min, the MSA Escort Elf pump demonstrated a change in flow rate of ≤5 percent of set point when subjected to a change in altitude of up to 8965 ft, a change in sample inlet loading of up to 29 inches of water, and a change in temperature of up to 18°C. This shows that the Escort Elf pump can be calibrated at one altitude and used at another altitude without causing sampling errors of more than about ±5 percent. It also shows that the changes in filter cassette loading and temperature, normally experienced during an 8-hour sampling period, will not cause sampling errors of more than about ±5 percent.

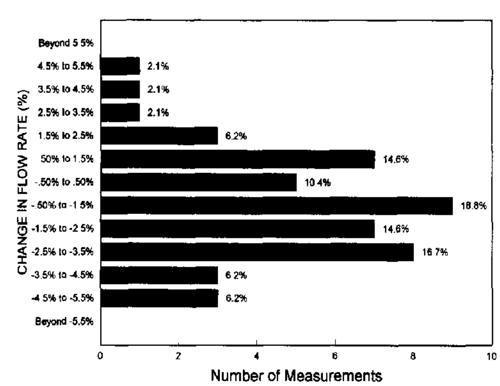

FIGURE 14. Summary of all data obtained as a function of temperature.

Acknowledgments

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