There is a need for low cost continuous gas monitors for use in gas detection applications. Ion mobility is a principle upon which a low cost sensor could be based. Most gas sensors employing ion mobility have been based on a time of flight principle and are expensive. In this study, a simple device employing ion mobility but not using a time of flight principle to separate ions was constructed and tested. In this new device, ions produced from various substances using photoionization, enter a channel through a narrow opening. In the channel, an electric field is used to force the ions to travel in a vertical direction; and an air flow is used to force the ions to travel in a horizontal direction. If the air flow and electric field meet certain criteria, the ions hit a narrow collector and produce a current. To modify the flow pattern, a number of flow rates and several types of flow modifiers were investigated. The device was found to be very sensitive to flow, and that current, at a given flow rate, was obtained over a large range of voltages instead of a narrow range as desired. There was some selectivity of response for the two substances tested (acetone and ethylbenzene), but the responses could not be separated completely. Some areas for further work, such as, detailed theoretical analysis of the performance of the device are suggested.

CONSTRUCTION AND TESTING OF A VAPOR SENSOR BASED ON ION MOBILITY AND GAS FLOW

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16. Abstract (Limit: 200 words) In order to answer the need for low cost gas monitors for use in gas detection applications, a prototype sensor was built on the principle of ion mobility, and the performance of this prototype was evaluated. Ion mobility employed the difference in drift velocity in an electric field of ions formed from different substances. Due to its sensitivity, ion mobility has been used for the monitoring of a number of kinds of pollutants in air for a number of years. The technique was simple as separation of different ions depended on the difference in their drift velocities in air at atmospheric pressure. The ions were measured from the substance of interest at a narrow collector after they had traveled in a vertical direction under the influence of an electric field and in a perpendicular direction using air flow. It was anticipated that ions of different mobilities could be separated in this manner. The sensor functioned as predicted in a qualitative sense. At a given flow rate, response from the device was obtained over a given range of voltages, determined by the flow rate used. The device was very sensitive to flow parameters. By changing the flow pattern, response varied from that of no response to high levels of response. The use of either positive pressure or suction affected the magnitude and type of response. Higher flow resulted in not only higher sensitivity but also in wider peaks which reduced separation. Lower flows resulted in lower sensitivity but also in narrower peaks. Complete separation of acetone (67641) and benzene (71432) could not be achieved with the present configuration of the device.

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INTRODUCTION

There is a need for low cost gas monitors for use in gas detection applications. The basic approach used to determine the feasibility of development of a sensor based on a given principle is to build a prototype sensor based on the principle and examine the performance of the sensor. This approach can be used to determine whether the sensor will perform according to expectations based on the operating principle and point the way for further development. Ion mobility employs the difference in drift velocity in an electric field of ions formed from different substances. Because of its sensitivity, ion mobility has been employed for the monitoring of a number of kinds of pollutants in air for a number of years.[1,2] The technique also is simple because separation of different ions depends only on the difference in their drift velocities in air at atmospheric pressure. Ion mobility has usually been employed in a time of flight mode where ions formed from different substances arrive at a collector at different times. Ions are formed from the substance of interest using either a radioactive source or photoionization. These ions are carried by an electric field to a grid which either stops or passes the ions, depending on the grid's potential relative to the overall electric field in the device. A short burst of ions are allowed to pass through the grid by applying a short electrical pulse to the grid at the proper potential. After the ions pass through the grid, they are allowed to drift

freely a given distance in a drift region under the influence of an electric field. The ions arrive at a collector where the current due to the ions is measured. Different ions arrive at the collector at different times depending on their drift velocity, or mobility defined as drift velocity per electric field strength. Several treatises have examined the physical principles of ion mobility at the molecular level.[3,4]

Because of the simplicity of the technique, a sensor employing ion mobility has very few parts that can fail. However its application to continuous air monitoring has been limited by the high cost of instrumentation employing this principle and lack of selectivity. The study described herein was undertaken to determine the feasibility of developing a simple, rugged, and low-cost instrument with the sensitivity to monitor a wide range of workplace gaseous pollutants. To determine feasibility a prototype sensor was constructed and its performance was examined. The operating principle chosen results in a sensor that could be constructed inexpensively since it would have few parts.

Ion mobility has been applied using a number of different means to ionize the sample of interest. The most common method uses a form of chemical ionization.[5] In this method reactant ions are formed from the air that contains the substance of interest by using beta particles from a radioactive source. Ion molecule reactions result in charge transfer from

the reactant ions to the substance of interest to form product ions. The product ions can then be separated and measured. This method is very sensitive; however, complex spectra are observed since product and reactant ions must be separated. Reactant ions will interact with a wide range of substances and therefore not provide much specificity. Also, as reactant ions are depleted at higher concentrations of sample and interferents, the method has a very short linear range.

Photoionization also has been used with ion mobility.[6,7] In this case, the substance of interest is ionized directly using a photoionization source. The sample spectra is much simpler since reactant and sample ions do not need to be separated. Also, the linear range is extended. With this method, it is possible to obtain a more selective response since a photoionization lamp of the proper wavelength ionizes the substance of interest and not an interferent, however, photoionization by itself provides limited selectivity since a given substance will either be ionizable or not.

The goal of this study was to determine the feasibility of developing a simple device for application to air monitoring. Instead of the time of flight method used in previous devices, the ions were measured from the substance of interest at a narrow collector after they had traveled in a vertical direction under the influence of an electric field and in a

perpendicular direction using air flow. It was anticipated that ions of different mobilities could be separated in this way. This operating principle has the advantage of being simple and could result in the development of a low cost monitor. Because of its simplicity and selective properties, photoionization was chosen as the means of ion production.

BACKGROUND

Ion mobility depends on the difference in drift velocity in an electric field of ions formed at atmospheric pressure from different substances. The equation relating drift velocity V_d to the electric field E is $V_d=KE$ where K is the mobility of the ion in cm/sec/(V/cm. K will vary depending on the ion being examined.

The basic operating principle of the proposed device is shown in Figure 1. Ions produced from the substance of interest enter channel (C) in a narrow beam. Ideally this beam would be infinitely narrow and in the present arrangement would be circular in shape. Two sides of the channel are plates (P_1 and P_2) to which a voltage is applied to produce an electric field (E). The other two sides of the channel are insulators. This channel also has air flowing in a direction perpendicular to the electric field at air velocity (V_a). Ions travel from P_1 to P_2 under the influence of E at a velocity (V_d) determined by their mobility (K). At

the same time, ions travel in a horizontal direction at V_a. A narrow collector (C_s) isolated from P_2 is located in P_2 at some distance downstream from the point where the ion beam enters the channel. C_s is at the same potential as P_2. In order for ions to hit the collector and produce a current, they must travel a vertical distance (Δy)(due to the electric field) in the same amount of time that they travel a horizontal distance (Δx) due to V_a.

Since time=distance/velocity,

we can equate $\Delta y/V_d=\Delta x/V_a$ but $V_d=KE$

$$\Delta y/KE=\Delta x/V_a$$

$$E = \frac{V_a \Delta y}{\Delta x K} \qquad (1)$$

This assumes that the ion beam and collector have no physical width and current from the ions would be measured at only one voltage. In reality, current would be measured over a range of voltages since there are several sources of broadening of ion beam. The ion beam entering the channel and the collector would have some width and the ion beam would widen as it traveled down the channel due to diffusion and turbulence in the channel.

The diffusion and turbulence processes would be complicated and it would be difficult to predict their effect quantitatively. To approximate the effect of beam and collector width, it will be assumed that the physical width of the beam is broadened an amount, Lc (Lc = the sum of the collector and beam widths). To approximate the effect of this width on beam broadening, we let

$$E_s = \frac{V_a \Delta y}{(\Delta x + Lc)K} \quad \text{and} \quad E_f = \frac{V_a \Delta y}{\Delta x K}$$

$$\text{therefore, } \Delta E = E_f - E_s = \frac{V_a \Delta y}{K}\left[\frac{1}{\Delta x} - \frac{1}{(\Delta x + Lc)}\right] = \frac{Va\ \Delta y}{K\ \Delta x}\left[\frac{Lc}{\Delta x + Lc}\right] \qquad (2)$$

where ΔE is the range of voltages where current is measured which is the width of the response

This formula can be used to predict the effects of various factors such as collector and beam width on the width of the response. It would not be useful, however, in predicting the effects of diffusion or turbulence on beam broadening. Further theoretical analysis would be needed to predict these effects quantitatively.

EXPERIMENTAL

A cross sectional view of the device used to test the operating principle of the ion mobility sensor is shown in Figure 2. The original dimensions of the device were chosen to allow easy construction and assembly and to allow ions sufficient residence time in the channel for separation. Each part of the device (either a plate or spacer) was constructed from a 7.62 cm x 7.62 cm piece of aluminum or teflon of varying thicknesses. Top views of the individual plates and spacers are shown in Figure 2a. The centers of the plates and spacers lined up if the edges of the plates and spacers were lined up. The plates or spacers were held in a metal frame that had had four bolts at the corners. This allowed the plates and spacers to be moved in relation to one another. The top was a 1.25 cm thick piece of teflon in which a center circular area was milled to hold the lamp holder. A hole was drilled in the center of the milled out area to let light from the lamp hit the sample. Two different lamps were used: a lamp from a Photovac TIP (PhotoVac, Inc., Thornhill, Ont.) and an HNU lamp from a model PI-52 detector (HNU Systems, Inc, Newton, MA). The Photovac TIP lamp was used with a standard TIP lamp holder, with the end removed to allow light from the lamp to hit the sample. The HNU lamp also was used with the standard lamp holder from the detector. Both lamps provided 10.2 eV radiation.

The sample was brought to the lamp window through a piece of 1.59 mm teflon tubing. A long narrow groove was milled into the underside of the top to allow the tubing to pass into the lamp window. The first plate (R), which was made of aluminum (Al), was used to extract ions produced at the lamp window using an electric field. R was 0.127 cm thick and had a 3.2 mm hole in its center. A voltage (V_1) was applied between plates T and R to produce this field. Plate R was separated from plate T by a 3.2 mm thick teflon spacer (S) with a 0.95 cm hole in the center. Plate T was also Al, 0.127 cm thick and had a 0.05 cm hole at its center to allow ions into the channel C. Two sides of the channel were formed by plates T and W. Plate W was Al and 0.635 cm thick. The other two sides of the channel were milled into the channel spacer (CS). CS was a 1 cm thick piece of teflon with the 1 cm wide channel milled into its center. The inlet and outlet of the channel were 0.95 cm round holes. The channel, therefore, had a 1 cm^2 cross section in the center. A voltage V_2 was applied to plates T and W to produce a field across the channel. Gas flow in the channel could be achieved by providing a positive pressure to the inlet of the channel or by providing suction to the outlet of the channel. The flow of air to the channel was measured using a Laminar Flow Element LFE (Mariam, Inc., Cleveland, OH) and manometer. The LFE produces a pressure drop that depends on the flow and the manometer was used to measure this pressure drop.

If the electric field and flow conditions were appropriate, ions could hit one of two collectors, C_1 or C_s. These were mounted in 0.75 cm long grooves that were milled out in plate W. C_1 was directly across from the point where the ions entered the channel while C_s was 1 cm down stream from the point where the ion beam entered the channel. C_1, an 18 gauge (0.1 cm) gold wire, and Cs, a 30 gauge (0.025 cm) platinum wire, were isolated from the plate W by insulators. Electrical connections were located at the bottom of Plate W. The current at C_1 or C_s was measured with an electrometer from an HNU PI-52 detector.

Flow Pattern Modifiers (FPMs) were added to the channel to change the flow pattern since response changed with flow conditions. The FPMs examined are shown in Figure 3. These FPMs were made of teflon and were press fit into the channel so that the outlet from the FPM was directly in front of the point where the ion beam entered the channel and all the flow passed through the FPM. FPMs 1, 2, and 4 were single holes to confine the flow to the center of the channel. FPM 3 contained 36 pieces of 1.6 mm teflon tubing to spread the flow over the entire channel to produce a more even pattern.

Voltages (V_1 and V_2) were produced by providing low voltage to high voltage DC-DC converters-Del model PMS-1-11 (Del Electronics, Mount Vernon, NY). Using these converters a low voltage at the input will produce a high

voltage at the output. Zero to nine hundred Volts could be produced with each of these converters; two converters wired in series were used to produce higher voltages.

Two mixtures of a solvent in air (300 ppm acetone in air and 190 ppm ethyl benzene in air) were ionized to see if any separation of ions produced from different substances could be achieved. These solvents were chosen on the basis of availability and difference in molecular weight. It is presently not known how much the ions produced from the two solvents differ in mobility. The concentrations of the solvent of interest was prepared by injecting a volume of the liquid into a calibrated volume of air in an aluminized polyester bag. The exact concentration is not important for these studies. The mixture of either acetone or ethyl benzene in air was supplied to the photoionization lamp at 10 ml/min through the sample tubing using a syringe pump.

The response of the sensor was measured at a given air flow rate by flowing the solvent of interest (ethylbenzene or acetone) in air to the photoionization lamp using the syringe pump. With no flow in the channel current could be measured at C_1. Then a given gas flow was established in the channel and the current at C_s was measured as a function of voltage (V_2). This was done by manually varying the voltage (V_2) and measuring the response.

RESULTS AND DISCUSSION

Ion Production

As mentioned earlier, ion production was studied by measuring the current at C_1 with no air flow in the channel. A number of configurations were tried. Several of the configurations used a plate between R and T in an attempt to better focus ions onto the outlet hole in T. However, none of the configurations yielded higher current at C_1 than the more simple two plate configuration shown in Figure 2. The effect of V_1 (the voltage between R and T) was studied briefly. Ion production increased up to about 600 volts but did not increase for voltages greater than 900 volts. Therefore, a V_1 of 900 volts was used for subsequent experiments.

Ion Separation

Figure 4 shows the typical response of the sensor as a function of voltage at two different flow rates. As described in the experimental section, the response was the current observed at C_s at a given flow rate and at a given applied voltage. Response was measured using either acetone or ethylbenzene as a source of ions. Under some conditions, acetone and ethylbenzene yielded different although not completely separated responses as a function of voltage. The responses were normalized by dividing

response at each voltage by the highest response observed to get all peaks on the same scale. The manual method of taking the data might have resulted in slight distortion of some of the response curves. To study the effects of flow and flow pattern, measurements were obtained from each response vs voltage curve developed under different conditions. These are shown for one of the peaks in Figure 4. The Emax is the voltage where the maximum response was observed for each response curve under each condition. The ΔE is the 50% peak width which is the width in voltage from the 50% response points on the rising and falling parts of the curve, and the maximum response is the current observed at the peak maximum. The ratio of $\Delta E/Emax$ was calculated to compare the relative peak width under different flow conditions.

A number of conflicting effects were investigated. The main variable was flow rate. Faster flows in the channel would minimize the effects of ion beam spreading due to diffusion, since this spreading is dependent on the beam residence time in the channel. However, turbulence in the channel increased at higher flow rates. Maximum response also increased at higher flow rates. Positive pressure or suction flow as well as addition of FPMs affected the character and quantity of response from the device.

Without a flow modifier, no response was observed with positive pressure flow (Table I). A response was observed with suction produced flow but the response was spread out over a wide range of voltages with the dE greater than the Emax. Also, no difference was observed in the Emax from ethylbenzene and acetone with the suction flow.

Table II shows the response with FPM 3 in place. FPM 3 had 36 pieces of 1.6 mm teflon tubing arranged in a symmetrical pattern as shown in Figure 3. This was done in order to obtain even flow across the channel. With suction flow, the ΔE to Emax ratio was greater than with positive pressure flow. Suction flow, however, resulted in greater maximum response at the same flow rate than positive pressure flow. Higher flow rates resulted in higher maximum response for both suction and positive pressure flow. Under some conditions, there was a small difference in Emax for acetone and ethylbenzene with positive pressure flow, but little difference with suction flow.

Several FPM's (FPM 1, 2, 4) that had a single central hole to confine the flow to the center of channel were then tried. The results with these FPM's are given in Tables III-VII. In general, the ΔE to Emax ratio was better than that for FPM 3.

Table III shows the results with FPM 2, which had a 6.35 mm central hole. For a given flow rate, the Emax value occurs at a higher value than with the more even flow. Again, there was some slight difference in the Emax from ethylbenzene and acetone with positive pressure flow.

Two more FPM's were tried with smaller central holes (Tables IV and V). FPM No. 1 had a 4.8 mm hole and FPM No. 4 had a 2.9 mm hole. As mentioned previously as the hole diameter became smaller, the Emax value became slightly greater than with a more even flow. ΔE values would become larger but the ratio of peak width to Emax remained about the same. Suction flow yielded higher sensitivity and wider peaks, with no observable difference between the substances studied. There were slight differences in the Emax from acetone and ethylbenzene with positive pressure flow; these were the most prominent for FPM No. 1.

Further studies were therefore conducted using FPM No. 1. A lower flow was used to test how this affected the separation. The results at lower flow are presented in Table VI. Lower flow resulted in narrower peaks, but the ratio of ΔE to Emax was not appreciably better. Lower flow also resulted in lower maximum response than higher flows.

In an attempt to get a compromise between narrow peaks observed at lower flow and better peak separation observed at higher flow, an experiment also

was done with the distance between the point where the ion beam entered the channel and the collector Cs reduced by one half. This was done by moving plate W 0.5 cm out of alignment with the other plates and spacers which remained lined up along the edges. As predicted by Equation 1, the Emax value became greater at a given flow (as shown in Tables VI and VII). The shift in Emax value was greater than that predicted by the equation, but the exact distance Cs was moved could not be measured. Thus, the distance may have been changed more than desired. The ΔE also increased as predicted by Equation 2. If we assume that Lc is initially small compared to Δx, ΔE will be small. If Δx is made smaller such that Lc is larger compared to Δx, then ΔE will become larger. The ratio $\Delta E/Emax$ became smaller with this decreased distance.

CONCLUSION

The simple ion mobility based sensor functioned as predicted in a qualitative sense. At a given flow rate, response from the device was obtained over a given range of voltages, determined by the flow rate used. The device was found to be very sensitive to flow parameters. By changing the flow pattern, response varied from that of no response to high levels of response. Also, the use of either positive pressure or suction affected the magnitude and type of response. Suction flow resulted in higher sensitivity at a given flow rate, but did not result in a difference in

Emax for the two substances studied. There were conflicting effects. Higher flow resulted in not only higher sensitivity but also, in wider peaks, which reduced separation. Lower flows resulted in lower sensitivity, but also in narrower peaks. However, the ratio of peak width to peak maximum was not improved. Movement of the point of entry of the ion beam closer to the collector improved this ratio.

Complete separation of acetone and benzene could not be achieved with the present configuration of the device. If Figure 4 is examined, it can be seen that trying to measure the response from either substance at the maximum value for its response results in significant interference from the other substance. Better selectivity can be obtained by measuring the response at another voltage away from the maximum response. For instance at 6 LPM, the response for ethylbenzene can be measured at 700 Volts with 60% response from ethyl benzene and 10% response from acetone, and the response for acetone can be measured at 450 Volts with 70% response from acetone and 10% response from ethylbenzene. This provides some advantage in terms of selectivity,however, sensitivity is reduced.

There are a number of poorly understood aspects of the device's operation. Emax values are at potentials about twice as large as expected. For instance, a flow rate of 30 LPM results in a velocity in the channel of 500

cm/sec. If ions have a mobility of about 2 (cm/sec)/(V/cm) and travel a distance of 1 cm, equation 1 predicts an Emax of roughly 250 V rather than the 500 V typically observed.

RECOMMENDATIONS

A more detailed theoretical analysis of the device is needed to allow a prediction of whether or not changing various factors would improve its operation. The flow pattern in the device is poorly understood. Confining the flow to the center of the channel results in better separation of the two substances. Different ways of modifying the flow pattern need to be studied in order to achieve better separation of ions. The effect of distance flow rate and flow pattern need to be be optimized. A better understanding of the ion production mechanism would result in increased sensitivity for the device. If a larger number of the ions produced could be focused into the channel, increased response would result. The device's operation should be compared to the more conventional time of flight mobility sensor operation under the same conditions. The conventional mobility sensor is better understood and, thus, could provide a reference point on which to base further development.

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Table I

Response With No Flow Pattern Modifier (FPM)

Flow (LPM)	Substance	Emax (V)	ΔE (V)	Ratio (ΔE/E)	Max Response (pA)
No Response with Positive Pressure Flow					
			Suction Flow		
37	Acetone	300	350	1.17	7.4
37	Ethylbenzene	300	350	1.17	6.6
21	Acetone	150	200	1.33	4.6
21	Ethylbenzene	150	200	1.33	3.7
9	Acetone	100	150	1.50	3.0
9	Ethylbenzene	100	150	1.50	2.2

Table II

Response With Even Flow Pattern
Flow Pattern Modifier No. 3 (36 pieces tubing)

Flow (LPM)	Substance	Emax (V)	ΔE (V)	Ratio (ΔE/E)	Max Response (pA)
		Positive Pressure Flow			
60	Acetone	900	600	0.67	6.1
60	Ethylbenzene	1000	750	0.75	4.2
30	Acetone	500	350	0.70	3.4
30	Ethylbenzene	500	400	0.80	2.2
18	Acetone	300	250	0.83	1.3
18	Ethylbenzene	400	200	0.50	1.0
		Suction Flow			
37	Acetone	350	500	1.43	5.0
37	Ethylbenzene	400	500	1.25	4.2
18	Acetone	200	300	1.50	3.4
18	Ethylbenzene	200	300	1.50	4.0

Table III

Response With Central Flow
Flow Pattern Modifier FPM No. 2 (6.35 mm hole)

Flow (LPM)	Substance	Emax (V)	ΔE (V)	Ratio (ΔE/E)	Max Response (pA)
			Positive Pressure Flow		
54	Acetone	1100	600	0.55	13.4
54	Ethylbenzene	1200	800	0.67	8.0
30	Acetone	600	300	0.50	7.4
30	Ethylbenzene	750	450	0.60	4.3
21	Acetone	400	250	0.63	4.0
21	Ethylbenzene	500	400	0.80	2.6
			Suction Flow		
37	Acetone	400	450	1.13	13.6
37	Ethylbenzene	400	500	1.25	10.4
18	Acetone	200	250	1.25	11.2
18	Ethylbenzene	200	250	1.25	9.1

Table IV

Response With Central Flow
Flow Pattern Modifier FPM No. 1 (4.8 mm hole)

Flow (LPM)	Substance	Emax (V)	ΔE (V)	Ratio (ΔE/E)	Max Response (pA)
		Positive Pressure Flow			
54	Acetone	1300	800	0.62	18.6
54	Ethylbenzene	1700	1200	0.70	11.5
30	Acetone	800	500	0.63	9.3
30	Ethylbenzene	1050	700	0.67	7.2
21	Acetone	600	300	0.50	7.2
21	Ethylbenzene	650	400	0.62	5.0
		Suction Flow			
34	Acetone	600	550	0.92	20.8
34	Ethylbenzene	650	600	0.92	8.8
18	Acetone	300	350	1.17	17.6
18	Ethylbenzene	400	350	0.88	10.4

Table V

Response With Central Flow
Flow Pattern Modifier FPM No. 4 (2.9 mm hole)

Flow (LPM)	Substance	Emax (V)	ΔE (V)	Ratio (ΔE/E)	Max Response (pA)
		Positive Pressure Flow			
45	Acetone	1600	900	0.56	26.9
45	Ethylbenzene	1700	900	0.53	18.6
30	Acetone	900	600	0.67	15.7
30	Ethylbenzene	1050	900	0.86	10.4
21	Acetone	600	350	0.58	9.8
21	Ethylbenzene	600	500	0.83	5.4

Table VI

Response With Flow Pattern Modifier FPM No. 1
Low Flow

Flow (LPM)	Substance	Emax (V)	ΔE (V)	Ratio (ΔE/E)	Max Response (pA)
		Positive Pressure Flow			
12	Acetone	310	200	0.65	2.3
12	Ethylbenzene	350	225	0.64	1.8
6	Acetone	150	75	0.50	0.80
6	Ethylbenzene	175	85	0.49	0.80
3	Acetone	90	50	0.56	0.45
3	Ethylbenzene	100	60	0.60	0.40

Table VII

Response With Flow Pattern Modifier FPM No. 1
.5 cm distance from channel inlet to collector

Flow (LPM)	Substance	Emax (V)	ΔE (V)	Ratio (ΔE/E)	Max Response (pA)
		Positive Pressure Flow			
12	Acetone	900	400	0.44	5.8
12	Ethylbenzene	1100	600	0.55	4.8
6	Acetone	500	200	0.40	3.2
6	Ethylbenzene	600	250	0.42	2.7
3	Acetone	350	100	0.29	1.3
3	Ethylbenzene	350	100	0.29	0.8
		Suction Flow			
12	Acetone	1000	425	0.43	42.9
12	Ethylbenzene	1000	600	0.60	33.3
6	Acetone	475	250	0.53	24.6
6	Ethylbenzene	475	225	0.67	19.2
3	Acetone	300	200	0.67	15.0
3	Ethylbenzene	350	150	0.43	12.8

FIGURE CAPTIONS

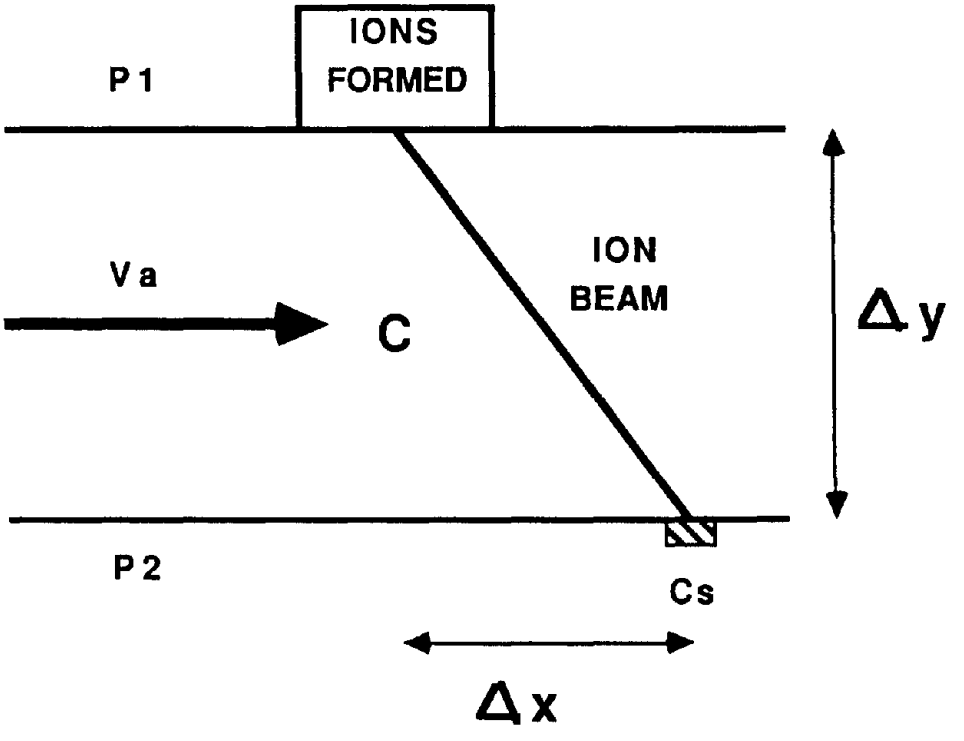
Figure 1: Basic Operating Principle of Sensor

Figure 2: Cross Sectional View of Sensor

Figure 2a: Top View of Individual Plates and Spacers

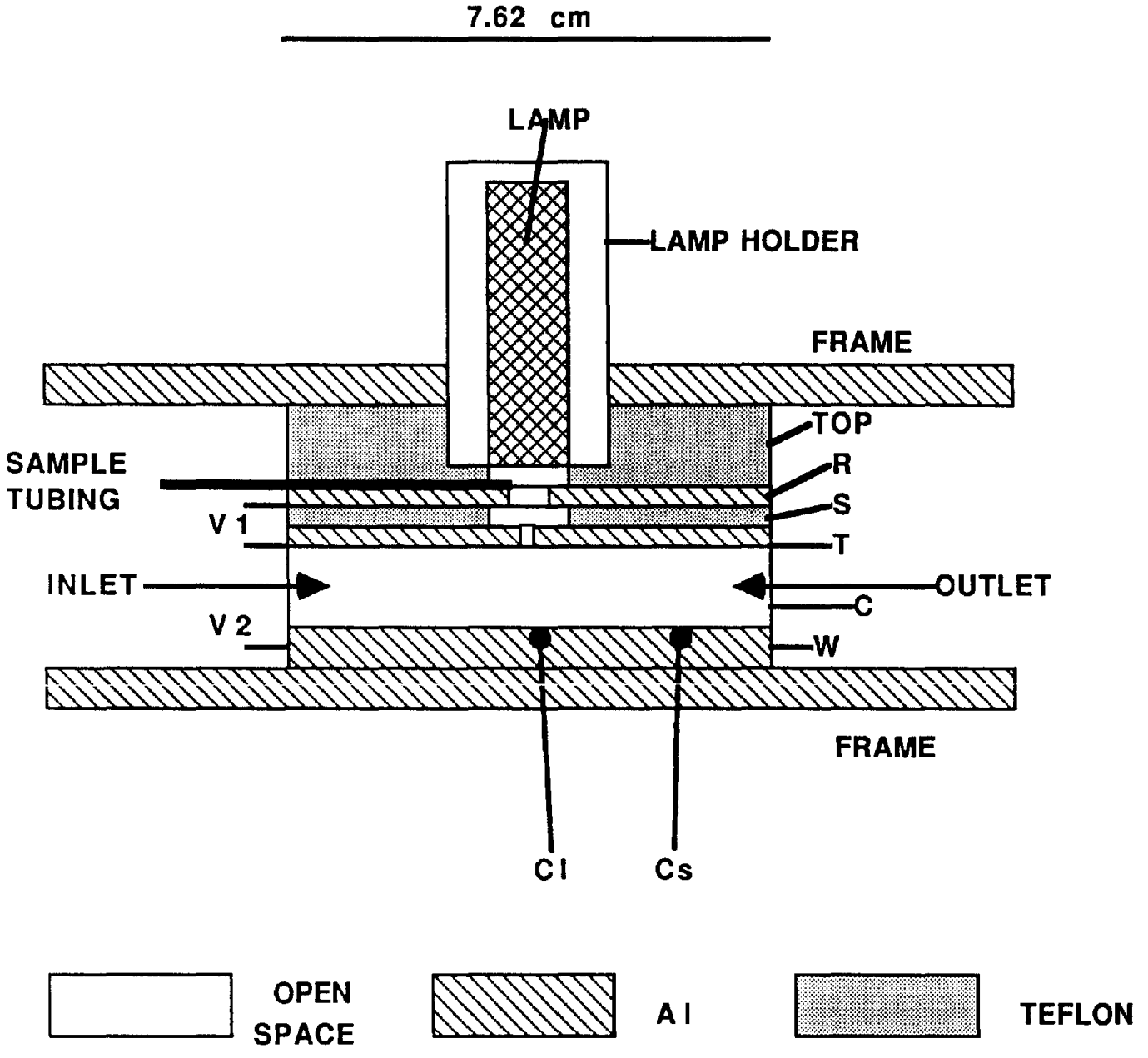
Figure 3: Flow Pattern Modifiers

Figure 4: Response as a Function of Voltage at Two Flow Rates



OPERATING PRINCIPLE

FIGURE 1



CROSS SECTIONAL VIEW

FIGURE 2

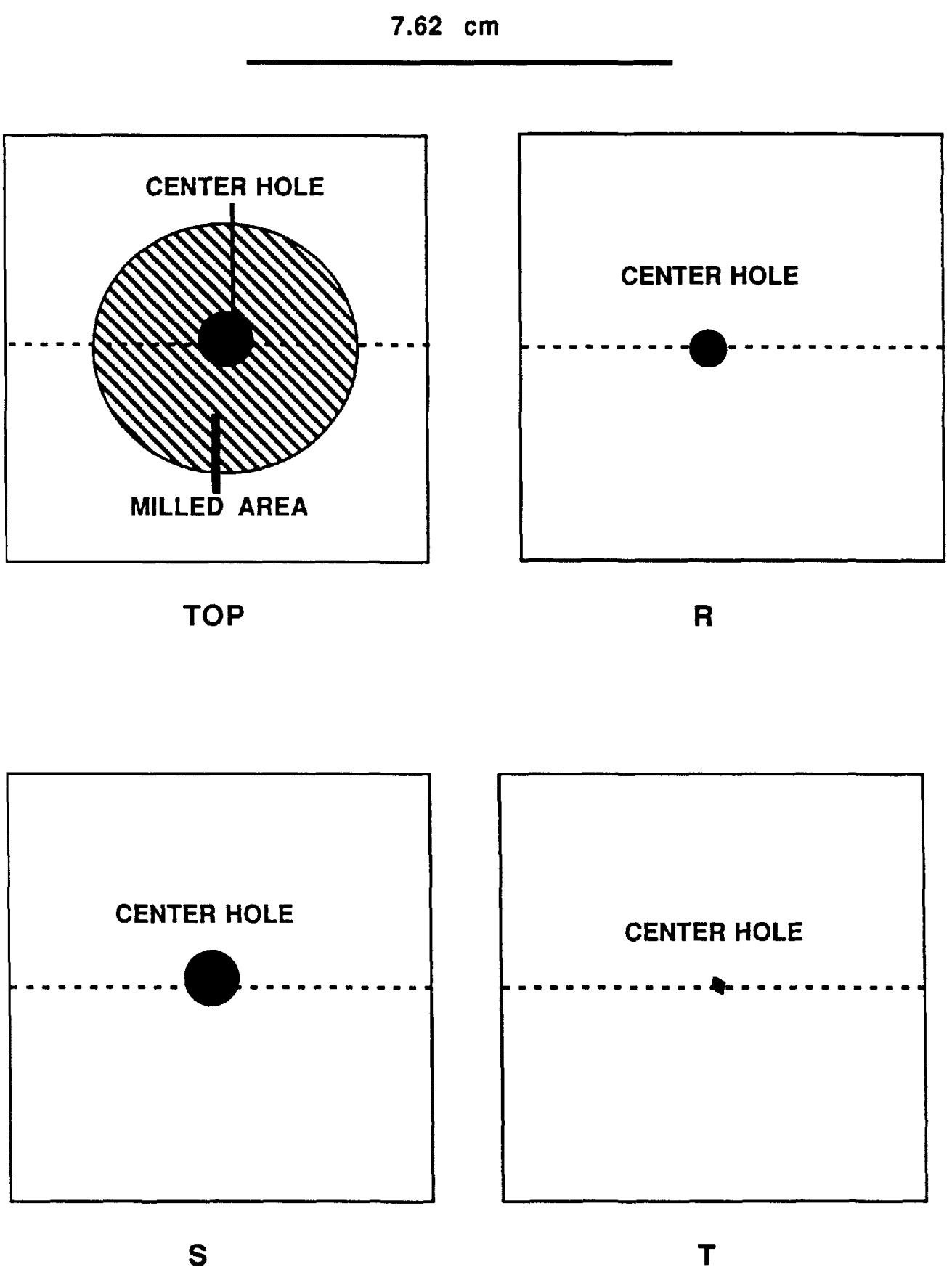
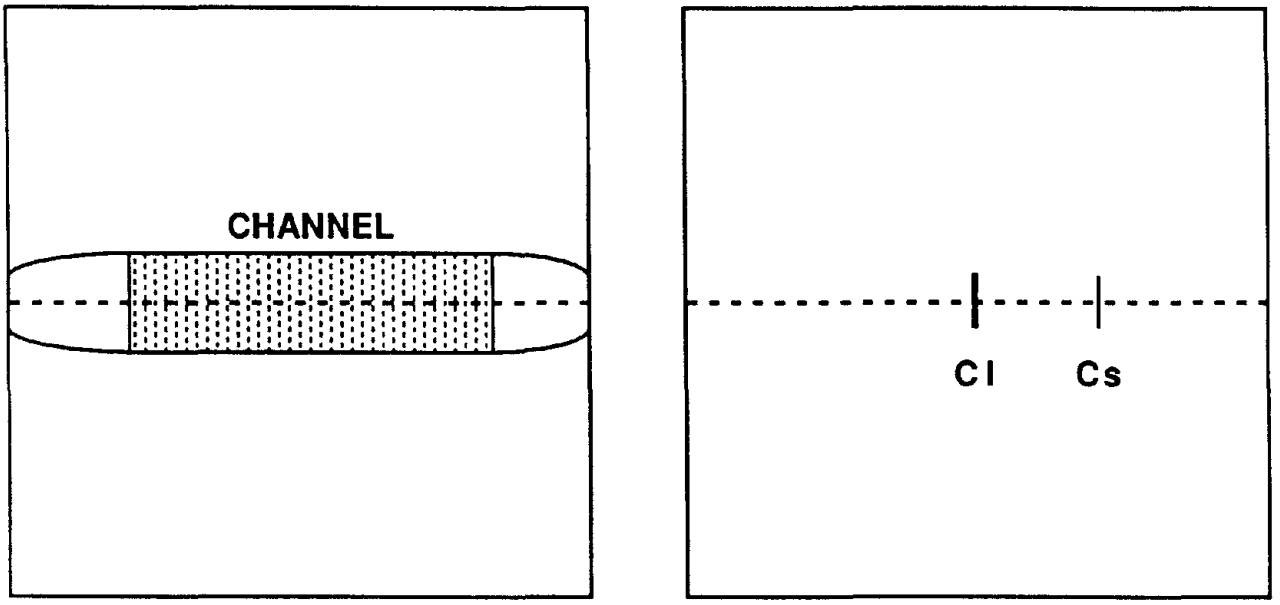


FIGURE 2
(Continued)



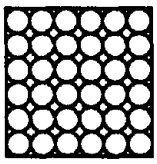
INDIVIDUAL PLATES AND SPACERS

FIGURE 2a

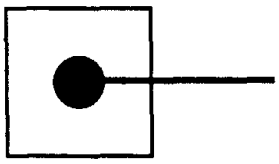
FLOW PATTERN MODIFIERS

1 cm

END VIEW



FLOW MODIFIER No. 3



FLOW MODIFIERS No. 1, 2, 4

FLOW MODIFER No	HOLE SIZE
1	4.8 mm
2	6.35 mm
4	2.9 mm

1.6 mm

SIDE VIEW-ALL FLOW MODIFIERS

2.54 cm

FIGURE 3

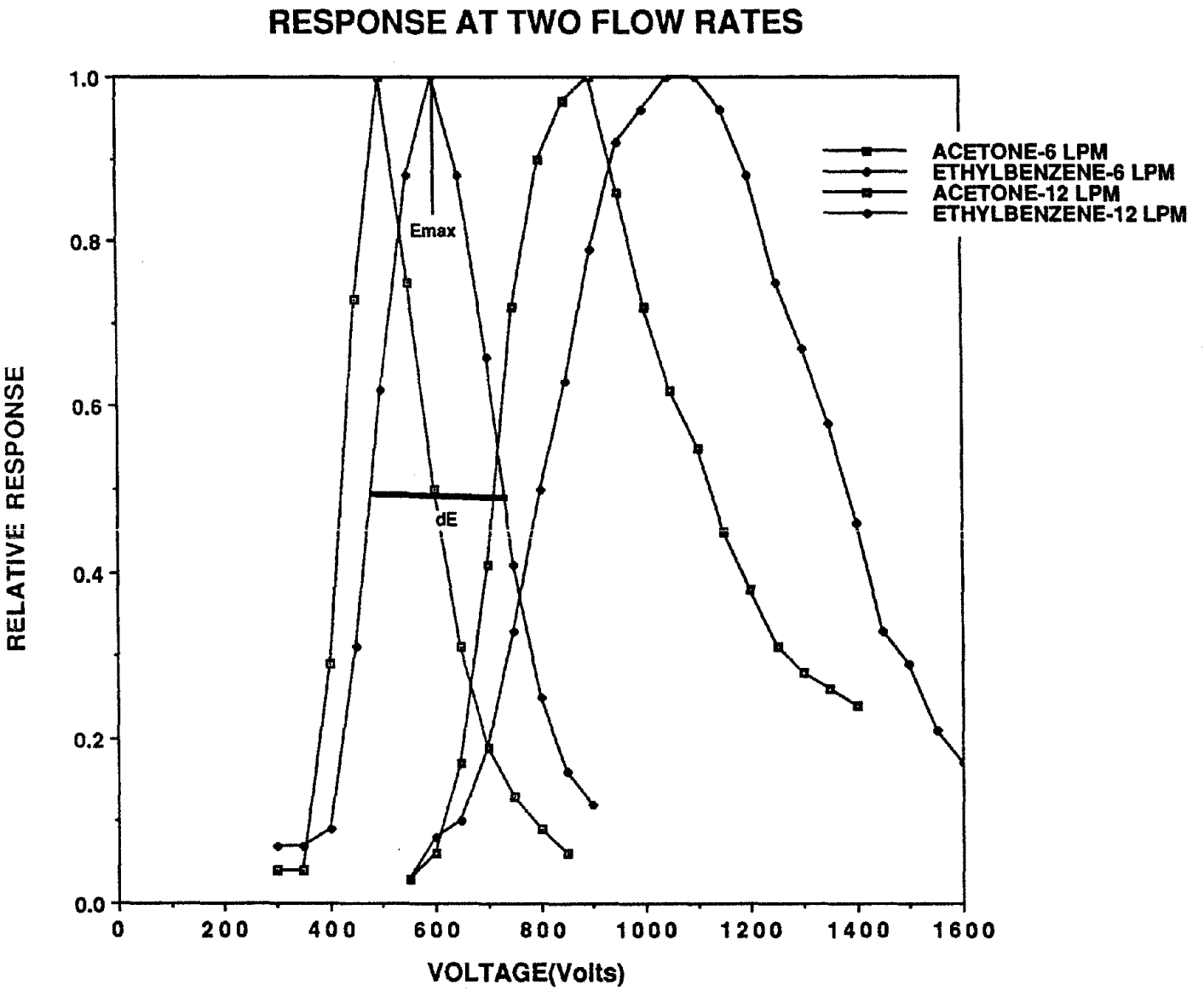

RESPONSE AT TWO FLOW RATES
RELATIVE RESPONSE
1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000
1200
1400
1600
VOLTAGE(Volts)
Emax
dE
ACETONE-6 LPM
ETHYLBENZENE-6 LPM
ACETONE-12 LPM
ETHYLBENZENE-12 LPM

FIGURE 4