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IN THERMIONIC GAS CHROMATOGRAPHIC DETECTORS

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PREPARATION AND CHARACTERIZATION OF GLASS BEADS FOR USE IN THERMIONIC GAS CHROMATOGRAPHIC DETECTORS

J. A. Lubkowitz¹, B. P. Semonian, Javier Galobardes and L. B. Rogers*

ABSTRACT

Glass beads containing rubidium or cesium can be prepared from either laboratory glass or synthetic glass mixtures. The sensitivity in the nitrogen-phosphorus mode was highest when the $\text{Na}_2\text{O}/\text{B}_2\text{O}_3$ ratio was larger than unity or when there was a high rubidium or cesium concentration. Beads containing no sodium showed the lowest noise and greatest stability. Linearities ranged from $3\text{--}11 \times 10^3$. Detectabilities of $40\text{--}70 \times 10^{-13}$ g/sec and $1.5\text{--}8 \times 10^{-13}$ g/sec were typical for azobenzene and malathion, respectively, in the N-P mode. In the phosphorous mode, the corresponding detectabilities were $20\text{--}8900 \times 10^{-13}$ g/sec and $1\text{--}120 \times 10^{-13}$ g/sec.

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INTRODUCTION

Alkali thermionic detectors have been used for many years in gas chromatography but they have been notoriously difficult to work with because careful control of all detector parameters was necessary to obtain reproducibility. The use of ceramic elements for halogen detection has been previously described (1). Recently, a new version of this detector has appeared (2,3) which utilizes a small glass bead containing rubidium (oxide or silicate). This bead is positioned within 0.5-1.5 mm of the flame tip and is maintained at a negative potential. The detector can be operated in a nitrogen-phosphorus (N-P) mode or in a phosphorus (P) mode by changing the flow rates of hydrogen and air as well as the potential applied to the flame tip. The bead is heated electrically and, thus, careful control of the volatility of alkali atoms in the glass can be achieved. Our recent studies of the response of this detector have shown that, if the bead current is carefully controlled, the detector is very reproducible (4).

During our studies aimed at characterizing the detector, these beads were found to have lifetimes of only about 3-4 months, so numerous beads were utilized. As a result, an effort was made to produce these beads in the laboratory. Unfortunately, a description of the glass composition and the procedure for preparation of the beads was not available. Hence, we examined the behavior of several different compositions. Furthermore, we wanted to see if the sensitivities and specificities could be modified by changing bead composition.

This paper describes a simple procedure for preparing the beads using materials having a cost of about one dollar per bead. The most important characteristics of the beads are also given.

EXPERIMENTAL

Chemicals

Amorphous silica (Illinois, Mineral Co., Cairo, Illinois), grade 200, was used in preparing beads 5-8. Beads 1-3 were prepared from finely ground Corning glass 7740 (Pyrex^R). Sodium carbonate (Baker Analyzed reagent) was added as a flux to beads 1 and 6-8. Boric acid (Baker Analyzed reagent) was also used as a flux in beads 6-8. Sodium borate decahydrate (Baker Analyzed reagent) was used in making bead 5 and thus the sodium-to-boron ratio was fixed. Rubidium nitrate (Fairmount Chemical Co., Newark, NJ) was used in beads 1-3 and 5-7. In the case of bead 8, cesium fluoride (Peninsular Chemical Research, Gainesville, FL) was used instead of rubidium nitrate. All beads were fused to a platinum wire (Fisher Scientific, Atlanta, GA) having a diameter of 0.020 cm whereas the commercial bead was mounted on 0.025 mm wire.

Malathion and azobenzene were used as model compounds for characterization of the beads. Malathion, S(1,2-dicarboxyethyl)-0,0-dimethyldithiophosphate (American Cyanamid Co., Princeton, NJ) having a purity of 99.3% was dissolved in *n*-hexane (Nanograde, Mallinkrodt, St. Louis, MO). The concentration of the solution was 5 ng/ μ l. Solutions of azobenzene (Eastman, Rochester, NY) in *n*-hexane were prepared containing 0.05, 0.5, 5, 50, 500 and 5000 ng/ μ l.

A glass column, 183 cm x 2 mm i.d., containing 3% OV-1 on 90-100 mesh Gas-Chrom Q (Applied Science Labs., State College, PA) was used. Nitrogen (Selox) was purified by passage through molecular sieve and silica gel. Air and hydrogen (Selox), purified by passage through molecular sieve and silica gel, were used as auxiliary gases for the flame ionization detector and the nitrogen-phosphorus detector.

Apparatus

A Perkin-Elmer nitrogen-phosphorus detector was used on their Model 3920 gas chromatograph. All of our beads were mounted in the Perkin-Elmer bead assembly. The

heating current was measured by placing a 0-10A ammeter (Weston, Newark, NJ) in series with the bead. A flame ionization detector mounted in parallel with the nitrogen-phosphorus detector received 48.5% of the injected sample. The output of the electrometer was fed to a Linear Instruments Co. dual-pen recorder (Irvine, CA).

Procedures

Bead Construction. The glass mixture was prepared by weighing the silica, the fluxes and either the rubidium nitrate or cesium fluoride. The weight of the total mixture was kept at about 2 g. The percentage composition of each bead prepared is given in Table I. Beads 1-3 were made by using ground Corning glass 7740 and subsequently adding sodium carbonate (bead 1) and rubidium nitrate (beads 1-3). Again, the total weight was kept at about 2 g. To calculate the final composition of the latter beads, the original composition of Corning 7740, as reported in the literature, was used (5). The weights of all components in the mixture are reported in Table I as the oxide, a common practice in reporting glass composition (5).

The weighed mixture was transferred to a 15-ml Coors porcelain crucible. Using a natural gas-oxygen rich mixture and a blow pipe torch (National 3A, Atlanta, GA), the powdered mixture was melted and stirred with a quartz rod. At this point, a thin strand of glass was pulled from the melt. The strand was later used to make the bead. The fused glass mixture could be left in the crucible and reheated at a later time to obtain additional strands. The mixture for making bead 6 was melted using an oxyacetylene "Rose-bud" heating tip (Meco-Wg-1) because its low sodium content resulted in a very high melting material.

A 1.5 cm section of the 0.020 mm diameter platinum wire was shaped in the form of an arch and secured in a vice. A 7 cm x 0.159 cm piece of stainless steel tubing was

inserted into the tip of the torch. The torch was lit and the natural gas-oxygen mixture was adjusted so that the flame was no longer than 0.5 cm. The tip of the strand of glass was brought to the flame and held there long enough to form a bead no larger than 1.5 mm in diameter. The platinum and bead were heated again and brought together to attach the bead to the wire. By reheating the bead and the strand of glass, they could be reunited to adjust the size of the bead. The bead was then reheated and the heat maintained long enough for the wire to reach the center of the bead. The bead always assumed a nearly spherical shape with a slightly shorter transverse axis. All beads had dimensions of 1.4 x 1.6 mm and weighed about 4 mg. However, bead 3 was made by adding additional glass to bead 2 until the bead was 1.8 x 2.0 mm. A magnifying glass provided with a mm scale was used to measure bead size. The entire step of attachment and centering of the bead on the wire required only about 5 minutes.

The wire-bead assembly was then spot-welded to the Perkin-Elmer bead assembly holder. After installation, the beads were conditioned by passing sufficient current to cause the bead to glow with a medium red color. The conditioning period for beads 1-7 lasted from 1-24 hours. During the conditioning period, the bead current (background current) reached values of about 200 pA. The sensitivity towards either malathion and azobenzene was quite low and the detector was almost useless. However, after the bead had been conditioned, the bead current usually reached about 1 pA and gave sensitivities typified by those in Table I. One exception to that behavior was bead 8 for which details will be discussed later.

Bead Current. All beads were tested in the range of 0.50-10.0 pA because we have previously shown (4) that a 10 pA bead current was the best compromise between sensitivity and bead lifetime. All beads, except bead 6, were capable of delivering currents greater than 100 pA. Bead 6, which had a high silica concentration, low boron and low rubidium concentration, showed a short range of bead current.

Heating Current. The heating current was dependent, among other variables, upon the cross-sectional area of the wire. The wire used in this study was slightly smaller than that used in the commercially available bead. Thus, the heating currents were higher due to the increased heat-loss. The heating current was also a function of the bead composition since in the molten state, the bead conducted electricity. Thus, it was observed that a high boron content and the presence of cesium led to low bead currents at lower heating currents. The importance of achieving a low heating current lies in the fact that the power supply was current-limited so it would shut off at currents of about 4.6 A.

Gas Chromatography. Each bead was characterized in the N-P mode and in the P mode. In the N-P mode, hydrogen flow was kept constant at 2.60 ml/min while air was maintained at 83.5 ml/min. In the P-mode, hydrogen flow was 23.1 ml/min and air was kept at 240 ml/min. The heating current in the N-P mode was adjusted as shown in Table I so as to obtain a bead current in the range of 0.1-10 pA. However, since the beads did differ substantially in the P mode, a heating current was selected so as to obtain a sensitivity of about 0.1 C/g. A more detailed description of these two modes of operation has been recently prepared (6).

The detectors were maintained at 260°C, the column at 190°C, and the injector at 260°C. The carrier gas flow rate was 80 ml/min. The samples were injected using a Hamilton 75N-5 μ l syringe (Supelco Inc., Bellefonte, PA). The injection volume was kept constant at 3.2 μ l. The areas were obtained from the mean of two injections except when measuring the reproducibility of response when larger numbers of replicates were used.

Calculations. None of the column or operating parameters were changed during the study. The peak shapes for azobenzene and malathion were very symmetrical. Thus, the peak areas were obtained by the product of height and width at half height. The peak areas were expressed in terms of coulombs (C) and divided by the mass injected. Thus, the

sensitivity as defined by Hartmann (7) was used as one of the criteria for characterization. Ratios of sensitivities at bead currents of 3.0 and 7.8 pA were also calculated. This ratio indicated the specificity of the detector (7).

Noise measurements were made with the recorder and expressed in amperes. The detectabilities were calculated as twice the noise divided by the sensitivity (7).

Linearity ranges were determined by a semilogarithmic plot of sensitivity vs logarithm of the mass injected. The slope of this plot should be zero. The upper limit was the mass that yielded a response which deviated from linearity by an arbitrarily defined 5%; the lower limit was ^{the mass} where the signal was equal to twice the size of the noise. The linearity range was the ratio of the upper limit to the lower limit.

Stability of the detector with different beads was calculated by measuring the bead current for 12-14 h. The loss in bead current per hour was expressed as a percentage of the original bead current. All beads were subjected to a reproducibility test by injecting azobenzene and malathion over a 5-6 h period. During that time, the bead current was maintained constant by increasing the electrical heating.

RESULTS

Sensitivity Studies in the N-P Mode

The plots of sensitivity vs bead current for the commercial beads were linear for azobenzene in the range of 1-150 pA and for malathion in the range of 1-50 pA (4,6). However, the beads made in our laboratory showed linear plots of sensitivity vs bead current for azobenzene only in the range of 1-10 pA, and for malathion, in the region of 1-4 pA. Thus, when the sensitivities are compared in Table I at bead currents of 3.0 and 7.8 pA, one expects to find a higher sensitivity ratio of malathion to azobenzene at 3.0 pA than at 7.8 pA. This characteristic is not necessarily a disadvantage because it

permits one to control to a certain extent the specificity by means of the bead current. At present, we do not have an explanation for this difference except that it is related to the composition of the beads.

Bead 7 which contained the highest rubidium content, showed the closest behavior to the commercially available bead. This is reflected by the fact that ratio of sensitivities at the two currents differed by less than 7%.

Bead 5, which had the highest percentages of boron oxide and sodium oxide, showed the greatest sensitivity for azobenzene. However, this bead was not extensively studied since it suffered drastically from losses in bead current over short periods of time. Sensitivity toward azobenzene did not show a trend with increasing boron oxide concentration alone. However, it is significant that the three most sensitive beads 1, 8 and 7 all had a ratio of Na_2O to B_2O_3 greater than unity. Hence, sodium in conjunction with boron appears to lead to high nitrogen sensitivity. Bead 7, which had a high concentration of rubidium, also had a high sensitivity toward azobenzene. Replacing rubidium by cesium also yielded a nitrogen sensitivity. However, the azobenzene sensitivity did not necessarily increase with rubidium concentration as can be seen from beads 1 and 2.

Bead 6, which had a high silica content but no sodium showed the lowest sensitivity for azobenzene. That result is not surprising considering that this bead was capable of generating only very low bead currents. This bead also had one of the lowest rubidium contents.

The sensitivities of the beads toward malathion followed the same order as that for azobenzene. An exception was the reversal in which bead 1, a Pyrex^R glass with added sodium, showed higher sensitivity than bead 8, which contained a high cesium content. The opposite was true for azobenzene. Thus, the sensitivity toward both azobenzene and malathion increased with the ratio of sodium to boron and with rubidium concentration and, possibly cesium concentration. In addition, a comparison of beads 2 and 3 showed that the larger bead had a somewhat greater sensitivity and improved detectability for both compounds.

The ratio of the sensitivities under conditions of equal noise is defined as the specificity (7). With the exception of the larger size Pyrex^R bead 3 and the cesium bead 8, the sensitivity ratio for malathion to azobenzene was always higher than that of the commercially available bead. This indicates that the beads were better phosphorus detectors than nitrogen detectors. Nevertheless, the sensitivities of our beads toward nitrogen were higher than that of the commercial bead except for bead 6 which contained no sodium. Hence, our beads were generally more specific toward phosphorus while, at the same time, more sensitive toward nitrogen than the commercial bead. However, the departures from linearity in the plots of sensitivity vs bead currents for malathion were greater for our stabilized beads. A marked exception was noted in the freshly prepared high cesium oxide bead which showed low malathion-azobenzene ratios, from 2.4-4.6 which means that the sensitivity toward azobenzene was eighty times greater than usual, especially when first used. However, after aging for three weeks, the behavior resembled that of the other beads.

For some beads, the sensitivity toward the solvent n-hexane was measured. The sensitivity for azobenzene and malathion was 10^6 and 10^7 larger than that for n-hexane. Thus, the beads had large specificities for nitrogen and phosphorus relative to hydrocarbons. The values were not significantly different, especially when one considers that they were not measured at the same bead current.

Sensitivity Studies in the P Mode

The use of the term, P mode, is deceptive in that azobenzene could usually be determined with reasonable sensitivity. The only exception was the high cesium bead, 8, which showed no sensitivity toward nitrogen in this mode. The sensitivities for azobenzene and malathion were less, except for the high rubidium bead, 7, than those obtained in the N-P mode, an observation consistent with what we have previously reported for the

commercial bead 4 (6). However, the orders of sensitivity toward azobenzene and malathion were not the same in this mode. As indicated above, the cesium bead, 8, showed a low sensitivity for malathion, and it was not possible to detect azobenzene in this mode. At the other extreme the high rubidium bead, 7, showed sensitivities toward both compounds which were nearly the same in both modes.

The larger bead 3 showed rather low sensitivities for both compounds. When the bead was removed and examined under magnification, it appeared that only half of the bead had been heated by the flame because a crater appeared in the bead directly above the flame. This confirms our previous study (6), indicating that the flame profile is important in this mode.

The data suggest that sensitivity toward nitrogen was related to the sodium content. The bead having no sodium showed low azobenzene sensitivity relative to that of malathion. Beads 2 and 6 that had the highest sensitivity ratio had the lowest amount of sodium oxide. Among the rubidium beads, those having the highest sensitivities towards both compounds had the highest rubidium concentration. Thus, in the P-mode just as in the N-P mode, high sodium and high rubidium led to high sensitivity for both compounds.

The sensitivity towards n-hexane, although low, was about 150-50,000 times greater in this mode. Thus, one should chromatograph under conditions where solvent tailing will not interfere with the component in question.

Detectability Studies in the N-P Mode

The beads usually fell in the same order with respect to detectability as they did for the sensitivity. The only exceptions were the reversals of beads 1 and 3 with respect to azobenzene. Bead 1, the Pyrex^R with sodium added, had lower detectability. There was no obvious explanation for the lower noise of the larger size Pyrex^R bead 3. It is worthwhile noting that, when comparing bead 4 with 6, and bead 1 with 3, the sensitivities for beads 6

and 3 were lower but their detectabilities were either higher (bead 3) or comparable (bead 6). This is a direct result of the lower noise of beads 3 and 6. Hence, larger bead size and low sodium content led to lower noise values.

Detectability Studies in the P Mode

Similar trends in sensitivities and detectabilities were observed in this mode. However, a reversal was obtained with beads 4 and 1 in their responses toward azobenzene. Although bead 1 had a higher sensitivity, bead 4 showed a higher detectability. Since the composition of the commercial bead, 4, is not known, one cannot make any correlations with composition.

Linearity

Although our method for determining the linear range was more rigorous than the conventional method, the four beads for which linearity ranges were calculated had values comparable to those reported for older versions of thermionic detectors (8,9). The highest linear range was found for bead 7 which had the highest rubidium concentration. However, the linearity values must be used with caution because they will undoubtedly depend on the nitrogen or phosphorus compound used.

Loss of Bead Current

This is one of the most important aspects of the thermionic detector. We have previously shown how the very small changes in bead current drastically altered the reproducibility of the detector (4). If the bead current vs heating current shifted too rapidly toward higher heating currents, continuous readjustments by the operator were required in order to achieve the best reproducibility of response. We obtained relative standard deviations of 3-6% in a six-hour period by maintaining the bead current constant.

Bead 6, the sodium-free bead, showed the highest stability while bead 5, which had high boron and sodium contents, showed the least stability.

DISCUSSION

A high rubidium oxide concentration (10-20%), a high sodium oxide content (4-10%) and a low boron oxide content (2-3%) yielded beads having good sensitivities and detectabilities. However, a reasonably good bead could be made without sodium in contrast to what has been stated (3). While bead 6 showed very good stability and low noise, it did have lower sensitivities. It would be desirable to study beads having no sodium but a higher rubidium concentration. Those beads should have much higher sensitivities and detectabilities, the latter because of their low noise.

The presence of Al_2O_3 and K_2O were not deleterious to bead performance. In fact, bead 7 was an exceptional bead which showed larger sensitivities than the commercially available bead in both modes for azobenzene and malathion. Furthermore, its N-P and P modes did not show significant differences in behavior.

Cesium bromide and chloride have been previously used as an alkali source in thermionic detectors (8). Our bead 8 showed good sensitivity and detectability in the N-P mode but very low sensitivities in the P mode. It would be worthwhile to investigate compositions that might stabilize the bead current at 600-800 pA because, at those high bead currents, the bead showed the best nitrogen sensitivity relative to phosphorus, a commendable property. The need for detection of phosphorus is less acute because it can also be performed using the flame photometric detector (9).

The beads were easily made in the laboratory, and they showed good sensitivities and detectabilities for nitrogen and phosphorus compounds. In addition, a new bead could easily be fused to the wire of the commercially available bead holder. The easiest beads to prepare were beads 1 and 2 because it was only necessary to add either rubidium nitrate or a mixture of the rubidium nitrate and sodium carbonate to powdered glass.

Finally, a word of caution is necessary. Our conclusions were reached using different heating currents but with otherwise identical operating conditions. From earlier studies (6), we know that operating conditions can drastically change both the sensitivity and the selectivity of a bead. Hence, one should recognize the limitations of our conclusions until detailed studies have been made under optimal conditions for each bead.

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REFERENCES

1. C. W. Rice, German Patent 907223 (1947).
2. B. Kolb and J. Bischoff, *J. Chromatogr. Sci.*, 12, 625 (1974).
3. B. Kolb and J. Bischoff, U. S. Patent 3852037 (1974).
4. J. A. Lubkowitz, J. L. Glajch, B. P. Semonian and L. B. Rogers, *J. Chromatogr.*, 133, 37 (1977).
5. E. L. Wheeler, "Scientific Glass Blowing," Interscience Publishers, New York, 1966, p. 12.
6. B. P. Semonian, J. A. Lubkowitz and L. B. Rogers, submitted to *J. Chromatogr.*
7. C. H. Hartmann, *Anal. Chem.*, 43, 113A (1971).
8. D. J. Davy, "Gas Chromatographic Detectors," John Wiley and Sons, New York, 1974, p. 131.
9. J. Sevcik, "Detectors in Gas Chromatography," Elsevier Scientific Publishing Co., Amsterdam, 1976, p. 115.

TABLE I. CHARACTERISTICS OF GLASS BEADS

PROPERTY	Operating Mode	BEAD NO.							
		1	2	3	4	5	6	7	8
COMPOSITION									
%SiO ₂		61.1	69.1	69.1	- ^d	60.0	94.1	68.2	69.5
%B ₂ O ₃		9.79	11.1	11.1	-	24.5	1.14	2.80	1.95
%Na ₂ O		14.4	3.30	3.30	-	10.9	-	7.90	8.65
%K ₂ O		0.30	0.33	0.33	-	-	-	-	-
%Al ₂ O ₃		1.70	1.90	1.90	-	-	-	-	-
%Rb ₂ O		12.7	14.4	14.4	-	4.53	4.73	21.1	-
%Cs ₂ O		-	-	-	-	-	-	-	20.0
CURRENT RANGE									
Heating, A	N-P	3.98-4.13	3.90-4.30	4.10-4.40	2.70-3.50	2.80-3.50	3.99-4.30	3.90-4.11	3.40-3.90
Bead, pA	N-P	0.40-9.0	0.50-7.00	0.50-7.00	0.50-10.0	0.50-7.00	0.10-1.00	0.20-10.0	2.5 -10.0
SENSITIVITY									
Azobenzene, C/g x 10 ⁻²	N-P	2.41	1.91	2.30	1.06	5.40	0.184	4.50	2.85
Malathion, C/g x 10 ⁻¹	N-P	4.91	1.89	1.96	0.960	-	0.330	6.55	2.45
Ratio ^a	N-P	20.4	9.92	8.52	9.06	-	17.9	14.6	8.60
Ratio ^b	N-P	24.5	15.9	13.4	9.06	-	26.6	15.6	17.7
n-Hexane, C/g x 10 ⁻⁸	N-P	2.1	1.3	-	2.8	1.3	0.66	4.3	3.8
Azobenzene, C/g x 10 ⁻³	P	3.35	0.933	0.179	3.10	-	0.0672	42.5	-
Malathion, C/g x 10 ⁻¹	P	1.14	1.48	0.132	2.01	-	0.120	6.91	0.102
Ratio ^c	P	34.0	159	0.737	64.8	-	179	16.3	-
n-Hexane, C/g x 10 ⁻⁶	P	9.3	-	-	21	-	-	12	19
DETECTABILITY, g/sec x 10 ⁻¹³									
Azobenzene	N-P	75	86	52	110	-	330	22	49
Malathion	N-P	3.7	8.7	6.1	12	-	18	1.5	5.7
Azobenzene	P	180	880	-	130	-	8900	19	-
Malathion	P	5.3	5.5	-	2.0	-	50	1.1	118
LINEARITY, x 10 ³									
	N-P	4.1	-	-	3.0	-	-	11.0	3.2
LOSS OF BEAD CURRENT, %/hr.									
	N-P	6.2	5.3	5.8	5.1	~12	3.0	4.0	5.2

^aSensitivity Ratio: Malathion/Azobenzene at 7.8 pA. ^bSensitivity Ratio: Malathion to Azobenzene at 3.0 pA. ^cSensitivity Ratio: Malathion to Azobenzene.
^dA hyphen indicates that a particular measurement was not made.