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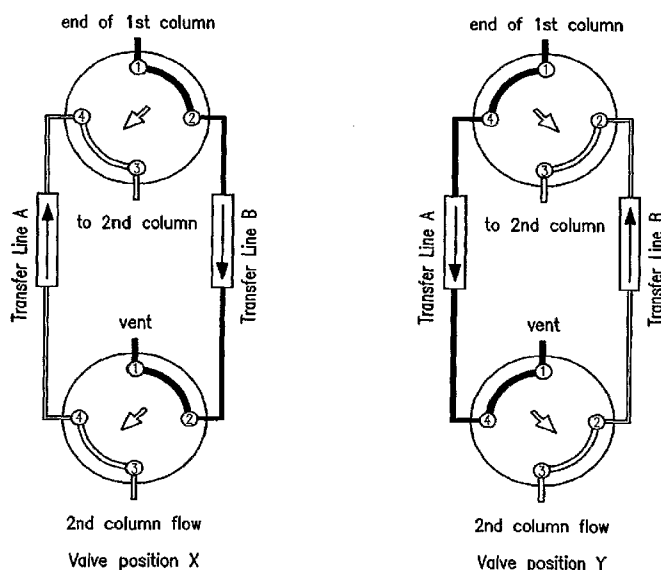
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(54) Title: A TWO VALVES SWITCHING MODULATOR FOR COMPREHENSIVE TWO-DIMENSIONAL GAS CHROMATOGRAPHY



(57) Abstract: The present invention is an improvement to two-dimensional comprehensive gas chromatography. The improvement is a two-valve switching modulator connecting two different type of separation columns. The advantages of current invention are (1) a simple system can be built by readily available parts; (2) no specific materials required (other than electricity) to operate the system, especially, do not need any type of coolant; (3) can be build on any GC as an externally added on unit; (4) The first and the second dimensional column flow are independently controlled, it is easier to design the experiment; and (5) it is cost effective, the cost of building this system is inexpensive than other type of modulation.

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A TWO VALVES SWITCHING MODULATOR FOR COMPREHENSIVE
TWO-DIMENSIONAL GAS CHROMATOGRAPHY

SUMMARY OF THE INVENTION

[0001] The present invention is an improvement to a comprehensive two-dimensional gas chromatography system. This improvement is a valve switching modulation system that has been designed and built for a comprehensive two-dimensional gas chromatography (GCxGC). This valve switching modulation system utilizes two four-port valves switch at the same time in each modulation period to achieve the modulation.

[0002] There are many advantages of the present invention. These include no need for any type of coolant. In addition, the first and the second dimensional column flow are independently controlled.

[0003] Comprehensive two-dimensional gas chromatography (GCxGC) is a powerful separation technique that provides the superior chromatographic type separation to a complex mixture. It is the most significant development in the gas chromatography technology area during recent years. The key to make a conventional GC into a comprehensive two-dimensional gas chromatography (GCxGC) is the modulation system. In the prior art, modulation is achieved by the trap and release mechanism called "thermal modulation". This method of modulation for GCxGC requires coolants (liquid nitrogen or liquid carbon dioxide) to operate. It is relatively inconvenient and it creates difficulty in the coolant handling situation, especially in the remote location or in the manufacture plant environment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] Figure 1 shows a schematic diagram of the valve modulation system of the present invention.

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[0005] Figure 2 shows a schematic diagram showing the flow of the fluid from the first column through the valve modulation system into the second column.

[0006] Figure 3 shows a comprehensive two-dimensional gas chromatogram of naphtha using the valve modulation system of the present invention.

[0007] Figure 4 shows a comprehensive two-dimensional gas chromatogram of diesel using the valve modulation system of the present invention.

[0008] Figure 5 shows a schematic diagram of an alternative arrangement of the comprehensive two-dimensional gas chromatography switching valve modulation system of the present invention.

[0009] Figure 6 shows a schematic diagram of valve modulation system including only one valve.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0010] Comprehensive two-dimensional gas chromatography (GCxGC) was introduced approximately ten years ago at the academic society. During the last ten years, scientists worldwide have demonstrated further that two-dimensional separation can be applied to complex mixtures. The major advantages of GCxGC technique are *improved resolution* (two-column separation) and enhanced sensitivity (modulation, in this case, is cyro-focusing). The flame-ionization detector (FID) results demonstrated advantage of superior separation that gives the class separation among paraffins and aromatics.

[0011] The GCxGC system includes an injector, then the two columns followed by a detector. A modulation system is located between the columns. The injector feeds the carrier or mobile phase into the first column. In the present invention, the carrier gas is branched prior to the injector.

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[0012] The key to make a conventional GC to a comprehensive two-dimensional gas chromatography (GCxGC) is the modulation system. There are several ways to accomplish the modulation. One way is utilize the trap and release mechanism called thermal modulation. This type of modulation requires the liquid nitrogen or liquid carbon dioxide as the coolant to accomplish the trapping process. The present invention shows another way. This way utilizes the differential flow mechanism called switching valve modulation. This type of modulation requires a differential flow and a switching valve(s) system to achieve the modulation. This invention is one type of differential flow modulation. The detailed design is shown in the Figure 1.

[0013] This modulation system accomplishes modulation by two valve switching at the same time in a modulation period. The system includes transfer lines A and B that transfer carrier gas and eluent as shown in Figures 1 and 2. Both transfer lines need to have exactly the same inner diameter and the same length. The detailed modulation process is explained below:

(1) When valves in the position X in the one modulation period (as left side valves in Figure 1)

- (a) The eluent comes out from the first dimensional column deposits to transfer line B
- (b) The second dimensional column flow sweeps the eluent deposited on transfer line A from last modulation period to the second dimensional column

(2) In next modulation period, the valves switched to position Y (as right side valves in Figure 1)

- (a) The eluent come out from the first dimensional column deposits to transfer line A

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- (b) The second dimensional column flow sweeps the eluent deposited on transfer line B from last modulation period to the second dimensional column

[0014] This modulation system continuous switching between position X and Y through entire experiment to accomplish the comprehensive two-dimensional gas chromatography.

[0015] Figure 2 shows a diagram of the 2DGC-switching valves system of the present invention showing the flow of fluid from the first column through the valve modulation system to the second column.

(1) In the first modulation period, both valves in the position X, the carrier gas flow through injector, through the first dimensional column and moves eluent to transfer line B. The second column flow, which is a branch of carrier gas (branched before the injector) sweep through transfer line A and flow through the second dimensional column to the detector.

(2) In the second modulation period, both valves in the position Y, the carrier gas flow through injector, through the first dimensional column and moves eluent to transfer line A. The second column flow, which is a branch of carrier gas (branched before the injector) sweep through transfer line B and flow through the second dimensional column to the detector.

(3) In the $(2n+1)$ st modulation period, both valves in the position X, the carrier gas flow through injector, through the first dimensional column and move eluent to transfer line B. The second column flow, which is a branch of carrier gas (branched before the injector) sweep through transfer line A and flow through the second dimensional column to the detector.

(4) In the $(2n+2)$ st modulation period, both valves in the position Y, the carrier gas flow through injector, through the first dimensional column and move eluent to transfer line A. The second column flow, which is a branch of carrier gas (branched before the injector) sweep through transfer line B and flow through the second dimensional column to the detector.

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[0016] Depending on the flow direction in the transfer line, the switching valve modulation system can also have different connection than what illustrated in the Figure 1. Figure 5 shows a schematic diagram of an alternative arrangement of the comprehensive two-dimensional gas chromatography switching valve modulation system of the present invention.

[0017] This modulation system accomplishes modulation by two valve switching at the same time in a modulation period. The detailed modulation process is explained exactly as that for the modulator valve system in Figure 1.

[0018] However, this modulation system reverses the switching between the valves in position X and Y to accomplish the comprehensive two-dimensional gas chromatography. The difference between the Figure 5 design and the Figure 1 design is that in Figure 1 the valve connects the end of first column to the second column and in Figure 5, the valve connects the end of first column to the second column flow. In Figure 1 design, the connection to the end of the first column and the connection to the second column are in the same valve. However, in the Figure 5 design, the connection to the end of the first column and the connection to the second column are in the different valve.

[0019] The modulation system can also be built on two valves with more than four ports, however, because of extra loops and ports involved, it will not perform as simple and as good as four port valves.

[0020] The modulation system can also be built on one valve with at least twelve ports. Figure 6 shows a schematic diagram of valve modulation system including only one valve. The detailed modulation process is explained below:

(1) When valves in the position X in the one modulation period (as left side valves in Figure 6)

(a) The eluent come out from the first dimensional column flow through port 1 pass through port 12 and deposits to transfer line B and through port 8 and port 9 to vent

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- (b) The second dimensional column flow pass the port 3 to port 2 and sweeps the eluent deposited on transfer line A from last modulation period through port 6 to port 7 and to the second dimensional column

(2) In next modulation period, the valves switched to position Y (as right side valves in Figure 6)

- (a) The eluent come out from the first dimensional column flow through port 1 pass through port 2 and deposits to transfer line A and through port 6 and port 5 to vent
- (b) The second dimensional column flow pass the port 11 to port 12 and sweeps the eluent deposited on transfer line A from last modulation period through port 8 to port 7 and to the second dimensional column

[0021] The modulation system can also be built on one valve with more than twelve ports, however, because of extra loops and ports involved, it will not perform as simple and as good as one twelve port valve.

[0022] Because of two valves switching modulation system makes the second dimensional column flow independent from the first dimensional column flow; the separation in the second dimensional column can be better controlled. By varying the flow in the second dimensional column, the separation among different component can be increased or decreased depend on the purpose or desired of the separation. Therefore, the peak width and the separation in the second dimensional column can be independently adjusted.

[0023] One of the other ways to control the separation in the second dimensional column is the temperature. Because of two valves switching modulation system makes the second dimensional column flow and the second dimensional column completely independent from the first dimensional column and the first dimensional column flow, The second dimensional column flow and the second dimensional column can be put into a separate oven to have a

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separated temperature to increased or decreased separation that will be depend on the purpose or desired of the separation.

Examples

[0024] Two examples are given to demonstrate the valve switching comprehensive Two-dimensional gas chromatography.

Example 1

[0025] The naphtha fuels used in this study are typical refinery streams boiling between 65°C (150°F) to 215°C (420°F) with carbon number from approximately C₅ to C₁₂.

The Set-Up and Conditions

[0026] The GCxGC system consists of an Agilent 6890 gas chromatograph (Agilent Technology, Wilmington, DE) configured with injector, columns, and detectors. A split/splitless inlet system with an 100 tray autosampler is used. The two-dimensional capillary column system utilizes a weak-polar first column (007-1, 30 meter, 0.25mm I.D., 5.0 µm film), (Quadrex Inc. Corp, Woodbridge, CT, USA) and a polar (Sol-Gel Wax, 3 meter, 0.25mm I.D., 1.0µm film), (SGE Inc. Austin, TX) second column. A switching two valves modulation assembly based on this invention is installed between these two columns. The valve is electrical actuated (VICI Valco Instruments Co. Inc., Houston, TX, USA). The transfer line is a set of pre-cut 1/16 inch stainless steel tubing with 0.25mmID and 20cm length (Alltech Associate Inc. State College, PA, USA). The detector is a Flame ionization detector (FID) which comes with Agilent GC system.

[0027] A 1.0 µL sample was injected with 50:1 split at 300°C in constant head pressure mode at 15 psi with an oven temperature 36°C. The oven is programmed from 36°C with 2 minute hold and 3°C per minute increment to 240°C with 0 minute hold and with total run time 70 minutes. The second

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column is in constant head pressure at 8 psi. The modulation period is 10 seconds. The sampling rate for the detector was 100Hz.

[0028] After data acquisition, it was processed for qualitative analysis. The qualitative analysis converts data to a two-dimensional image that is processed by a commercial program "Transform" (Research Systems Inc. Boulder, CO). The two-dimensional image is further treated by "PhotoShop" program (Adobe System Inc. San Jose, CA) to generate publication-ready images. Figure 3 is the comprehensive two-dimensional gas chromatogram of the naphtha.

[0029] Figure 3 shows the detailed composition of this naphtha can be displayed in this two-dimensional chromatogram. Every compound class is clearly separated in the second dimension. The two valves switching modulation has accomplished this low-temperature two-dimensional separation.

Example 2

[0030] The diesel fuels used in this study are typical refinery streams boiling between 150°C (300°F) to 430°C (800°F) with carbon number from approximately C₉ to C₂₈.

[0031] The GCxGC system consists of an Agilent 6890 gas chromatograph (Agilent Technology, Wilmington, DE) configured with inlet, columns, and detectors. A split/splitless inlet system with an 100 tray autosampler is used. The two-dimensional capillary column system utilizes a weak-polar first column (SPB-1, 15 meter, 0.53mm I.D., 1.0 µm film), (SUPELCO Inc. Bellefonte, PA, USA) and a polar (Wax-10, 0.5 meter, 0.53mm I.D., 1.0µm film), (SUPELCO Inc. Bellefonte, PA, USA) second column. A switching two valves modulation assembly based on this invention is installed between these two columns. The valve is electrical actuated (VICI Valco Instruments Co. Inc., Houston, TX, USA). The transfer line is a set of pre-cut 1/16 inch stainless steel tubing with 0.50mmID and 20cm length

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(Alltech Associate Inc. State College, PA, USA). The detector is a Flame ionization detector (FID) which comes with Agilent GC system.

[0032] A 1.0 μ L sample was injected with 20:1 split at 300°C in constant head pressure mode at 3 psi with an oven temperature 60°C. The oven is programmed from 60°C and 2°C per minute increment to 240°C with 0 minute hold and with total run time 90 minutes. The second column is in programmed head pressure from 2.0 psi and 0.01psi increment to 2.9 psi. The modulation period is 10 seconds. The sampling rate for the detector was 100Hz.

[0033] After data acquisition, it was processed for qualitative analysis. The qualitative analysis converts data to a two-dimensional image that is processed by a commercial program "Transform" (Research Systems Inc. Boulder, CO). The two-dimensional image is further treated by "PhotoShop" program (Adobe System Inc. San Jose, CA) to generate publication-ready images. Figure 4 is the comprehensive two-dimensional gas chromatogram of the diesel.

[0034] Figure 4 shows the detailed composition of this diesel can be displayed in this two-dimensional chromatogram. Every compound class is clearly separated in the second dimension. The two valves switching modulation has accomplished this high temperature two-dimensional separation.

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CLAIMS:

1. In a two-dimensional comprehensive Gas Chromatography system (GCxGC), the improvement which comprises a two valve switching modulator.
2. The GCxGC of claim 1 wherein the two valve switching modulator maintains a carrier gas through both chromatographs.
3. The GCxGC of claim 2 wherein said carrier gas is helium, or hydrogen or nitrogen or other inert (non-reactive gas).
4. The GCxGC of claim 3 wherein said modulator includes two valves and two transfer lines.
5. The GCxGC of claim 4 wherein said carrier gas is switched between said transfer lines.
6. The GCxGC of claim 5 wherein said modulator that connects the first dimensional column, the second dimensional column, the second dimensional column flow, and the vent can have more than one type of valve.
7. The GCxGC of claim 6 wherein said the second dimensional column flow can be independently controlled.
8. The GCxGC of claim 7 wherein said the second dimensional column temperature can be independently controlled.
9. The GCxGC of claim 8 wherein said modulator switching system can be accomplished by only one valve.

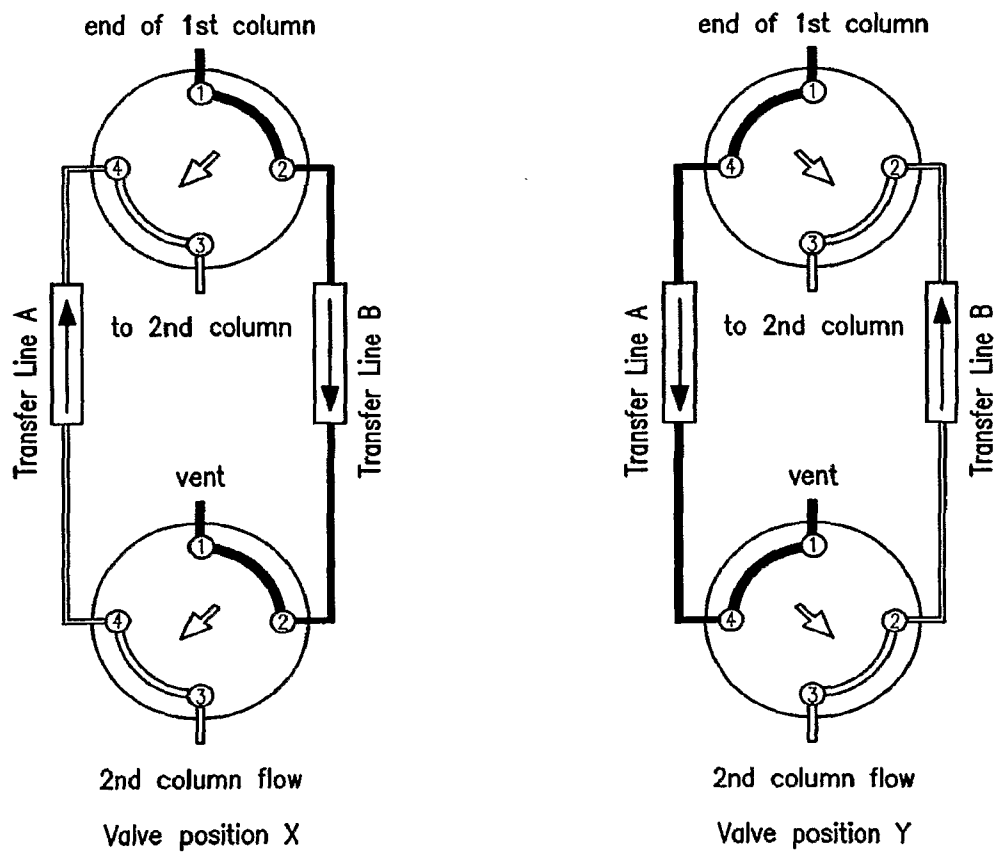


FIG. 1

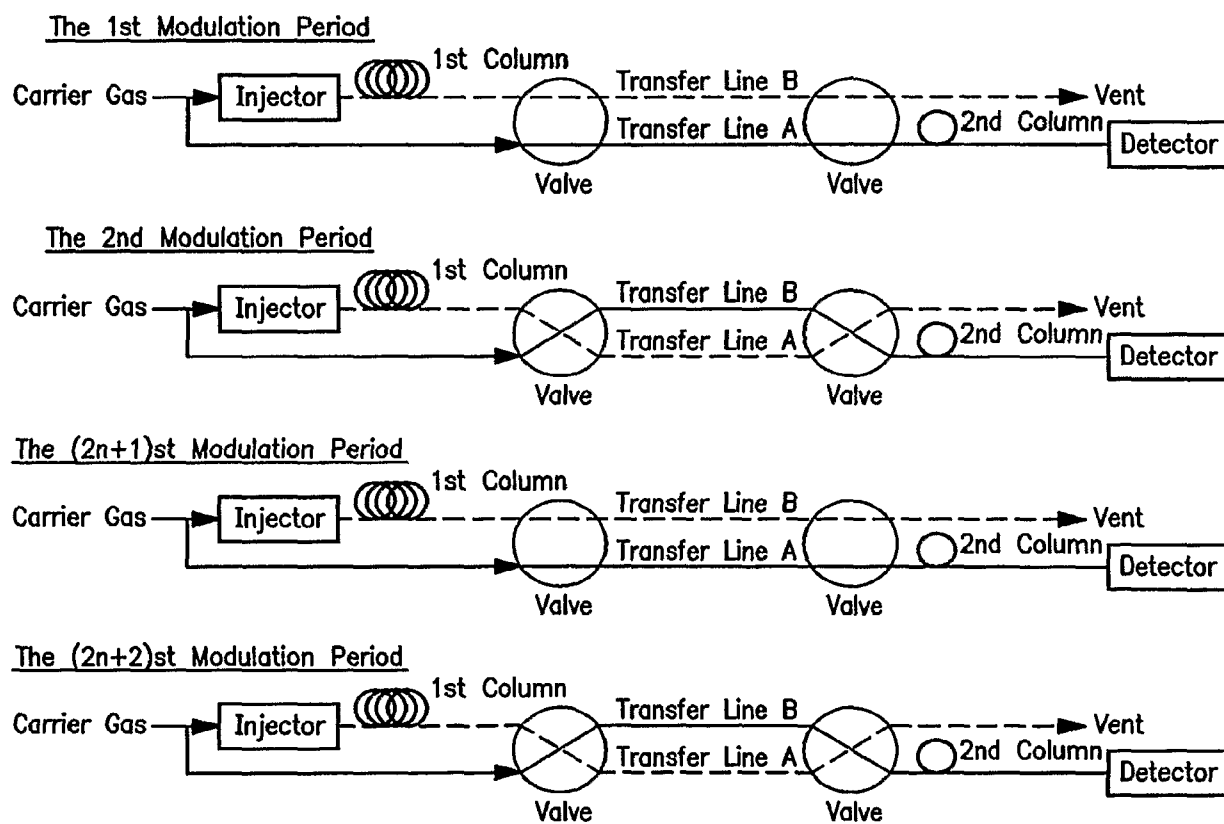
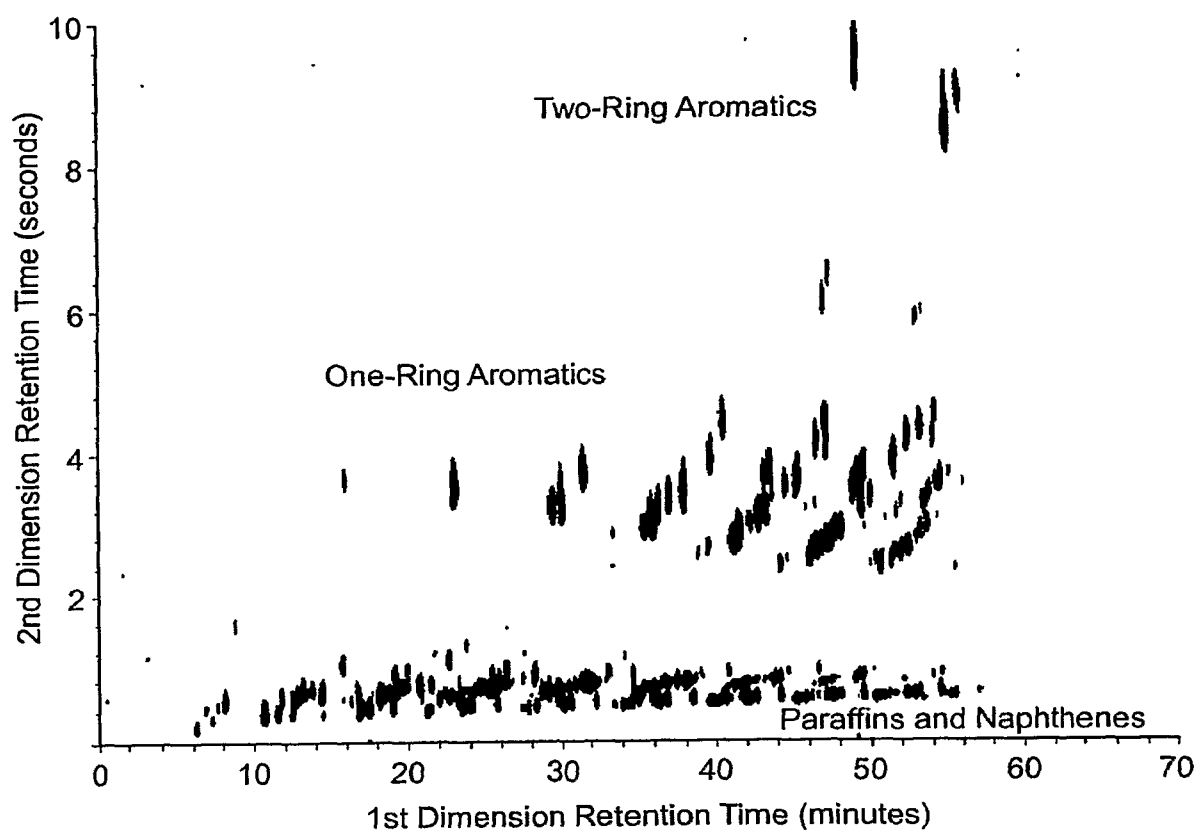
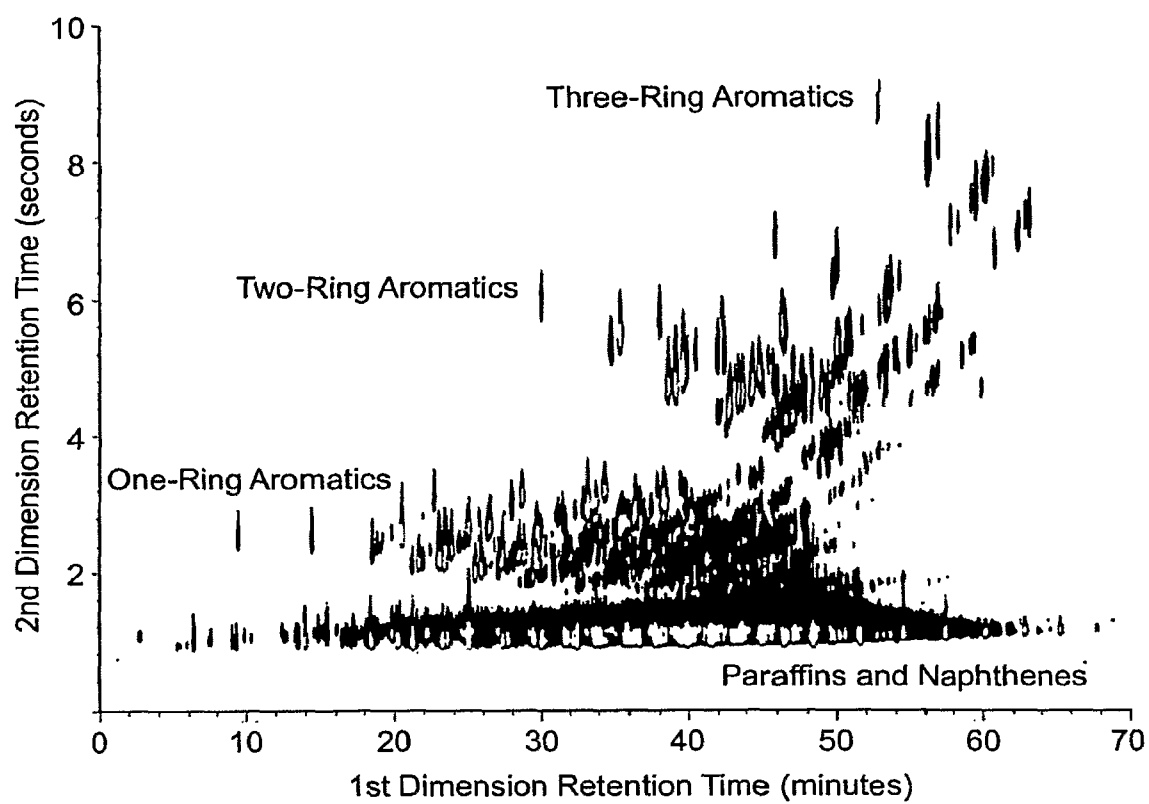
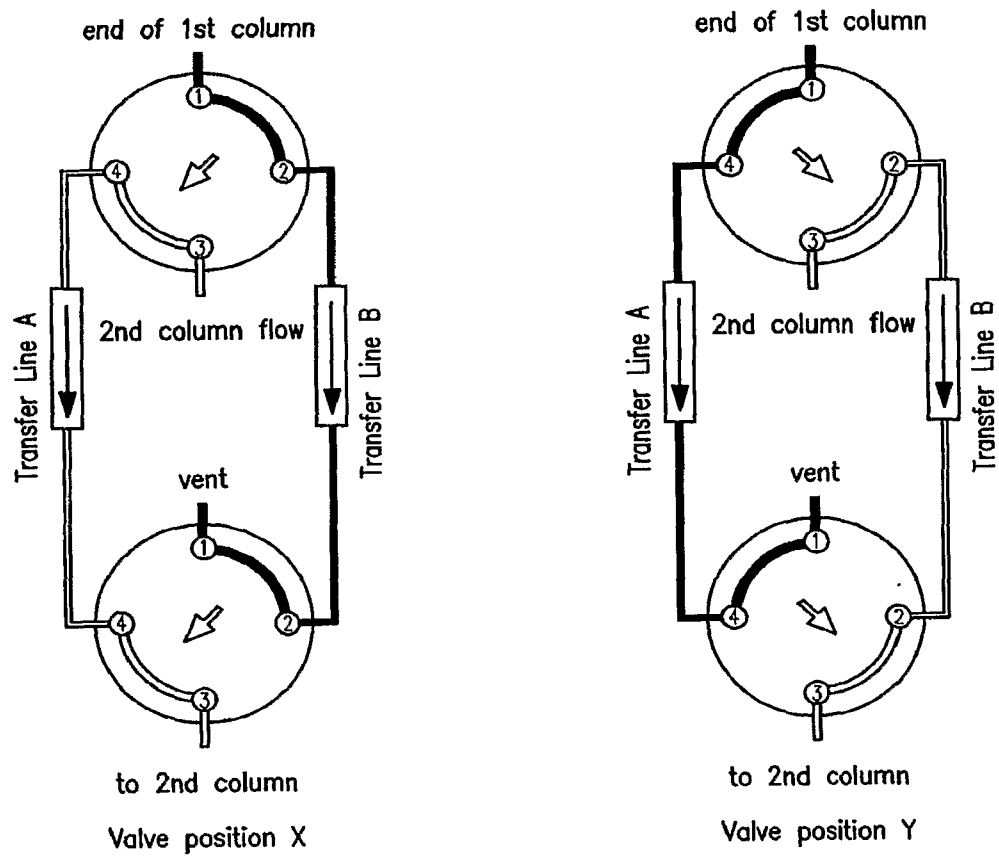
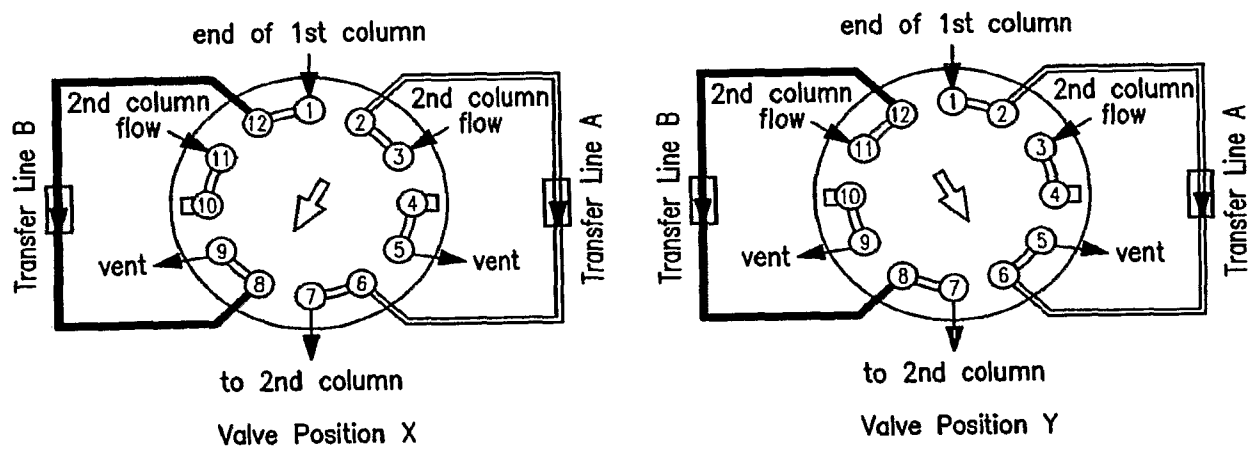


FIG. 2

**FIG. 3**

**FIG. 4**

**FIG. 5**

**FIG. 6**