

DESCRIPTION

TITLE: DEVICE FOR CONCENTRATING VAPOURS OF CHEMICAL MOLECULES CONTAINED IN THE AIR

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TECHNICAL FIELD OF THE INVENTION

The present invention relates to the field of the detection of vapours of chemical molecules contained in the air, for example in the field of security (explosive vapours), the environment or industry.

10 The invention relates more particularly to a device for concentrating these vapours in the air.

PRIOR ART

There are many techniques for detecting vapours of molecules in the air. Whatever the
15 technique used, however, it is important to sample the air volume correctly, i.e. to supply the detector itself with an air sample comprising the vapours in a concentration that matches the detection limit of the detector. For example, for the explosive vapours, the saturation vapour pressure is typically between 10^{-2} bar and 10^{-18} bar depending on the nature of the explosive vapour.

20 For a given detector, which is intrinsically more or less sensitive depending on the technique it employs, it is therefore possible to vary the detection limits by modifying the quantity sampled containing the vapours of the chemical molecules to be detected. The lower the concentration of vapour sampled, the greater the volume of air that needs to be collected to provide the detector with enough material to exceed its own detection limits (sensitivity).

25 In addition, each detector has an optimised design which generally locks its ability to analyse volumes (or air flow rates) within a given, generally restricted, range. The air sampling is also a means for collecting the vapours of the chemical molecules to be detected in the *right* place, by supplying the right volume of air to the detector used.

At a given temperature, each molecule is intrinsically capable of releasing its own maximum
30 vapour pressure, i.e. the saturation vapour pressure, into the air immediately surrounding it. However, in a real situation, the saturation vapour pressure is rarely reached and the actual pressure may even be much lower than the saturation vapour pressure (by one or more orders of magnitude). The causes may be linked to the presence of a physical barrier such as one or more packages between the compound (solid or liquid) generating the
35 vapours of chemical molecules to be detected and the air sampling location, an air sampling

before the saturation vapour pressure is reached in the volume to be sampled, for example in a very large volume of air, or the presence of a ventilation generating a vapour dilution effect, or a combination of several of these or other factors.

It is therefore clear that, whatever the detection technique used in the detector, it is important to concentrate the vapours of interest in a volume of air compatible with the performance of the detector. Moreover, doing so with high air flow rates may only lead to a significant reduction in sampling time (speed).

Several types of devices for concentrating vapours of chemical molecules already exist.

Some concentrators are well suited to very sensitive detectors with very low analysis volumes, as they process small volumes of sample per unit of time. For example, the article of Giordano, Braden C., Daniel C. Ratchford, Kevin J. Johnson, and Pehr E. Pehrsson. "Silicon Nanowire Arrays for the Preconcentration and Separation of Trace Explosives Vapors." *Journal of Chromatography A* 1597 (2019/07/19/ 2019): pp. 54-62. This article describes a device for concentrating vapours of chemical molecules adapted for a flow rate of 180 mL/min (3 L/h) based on silicon-based nanowires heated to 200°C. This type of concentrator is not suitable for addressing large volumes of air.

On the other hand, other concentration devices are well suited to the detectors with very large analysis volumes, common in the chemical reprocessing industry, for example. For example, the article by Linker, Kevin L. *Large-Volume Sampling and Preconcentration for Trace Explosives Detection*, Sandia National Laboratory, 2004 describes a series of very large-volume concentrators with flow rates of between 200 and 1160 m³/h. However, this type of device is not mobile and therefore may not be used *ad hoc* in any particular location. Devices for concentrating vapours of chemical molecules in the air that are both capable of processing large volumes and mobile (or portable) are rarer or little described. However, we may mention Gillanders, Ross N. and James M. E. Glackin, Janja Filipi, Nikola Kezic, Ifor D. W. Samuel, and Graham A. Turnbull. "Preconcentration Techniques for Trace Explosive Sensing." *Science of The Total Environment* 658 (2019/03/25/ 2019): 650-58. This article describes a device with a sampling flow rate of 60 L/min (1 L/h) for a high concentration. In fact, the concentration factor for 120 cm² of absorbent improves the final concentration by a factor of 3 for 10 minutes of sampling. This means is described as specific to the detector used (fluorescence) and the environment to be sampled (beehives).

SUMMARY OF THE INVENTION

One aim of the invention is to provide an improved device for concentrating vapours of chemical molecules in the air.

In particular, one aim of the invention is to provide a device for concentrating vapours of chemical molecules capable of processing large volumes of air at high flow rates.

It is also a particular aim of the invention to offer such a device that is portable by a human operator.

5 To this end, the invention proposes a device for concentrating vapours of chemical molecules contained in the air, said device comprising:

- a receptacle comprising a central air inlet orifice;
- a cylindrical cage housed in the receptacle, said cage comprising: a first ring defining a central orifice communicating with the central air inlet orifice of the receptacle, a second ring, a plurality of rods extending parallel between the first ring and the second ring, said rods being distributed around the circumference of said rings, and a heating wire equipped with a sheath either made of the same electrically insulating material, resistant to the temperature level likely to be produced in the heating wire and capable of absorbing said vapours, or made of at least two layers made of distinct materials but all resistant to the temperature level likely to be produced in the heating wire, the radially inner layer also being made of an electrically insulating material and the radially external layer also being made of a material capable of absorbing said vapours, said heating wire being either wound around all the rods or woven with the rods;
- a cover for the receptacle, said cover comprising one or more outlet orifices radially external with respect to said cage and extending around the peripheral contour of said cage.

The invention may comprise at least one of the following characteristics, taken alone or in combination:

- said rods are odd in number;
- said rods are distributed at regular intervals around the circumference of said rings;
- the cage comprises at least one thermocouple;
- the device according to the invention also comprises an additional cylindrical cage housed in the receptacle, said additional cage comprising a first ring defining a central orifice, a second ring defining a central orifice, and a plurality of rods extending parallel between the first ring and the second ring, said rods being distributed around the circumference of said rings, the central orifices of said rings of the additional cage having a diameter corresponding to the external diameter of the rings of said cage, a heating wire equipped with a sheath either made of the same electrically insulating material resistant to the temperature level likely to be produced in the heating wire and capable of absorbing said vapours or made of at least two layers made of different

- materials but all resistant to the temperature level likely to be produced in the heating wire, the radially inner layer also being made of an electrically insulating material and the radially external layer also being made of a material capable of absorbing said vapours, said heating wire being either wound around all the rods or woven with the rods of the additional cage, the or each air outlet orifice of the cover being radially external with respect to the additional cage;
- said plurality of rods of the additional cage is odd in number;
 - said rods of the additional cage are distributed at regular intervals around the circumference of said rings;
- the sheath of the heating wire of the additional cage is made of a material identical to the sheath of the heating wire of said cage;
- the additional cage comprises at least one thermocouple;
 - the device according to the invention comprises another cylindrical additional cage housed in the receptacle, said another additional cage comprising a first ring defining a central orifice, a second ring defining a central orifice, and a plurality of rods extending parallel between the first ring and the second ring, said rods being distributed around the circumference of said rings, the central orifices of said rings of said one additional cage having a diameter corresponding to the external diameter of the rings of the additional cage, a heating wire equipped with a sheath either made of the same electrically insulating material, resistant to the temperature level likely to be produced in the heating wire and capable of absorbing said vapours or made of at least two layers made of different materials but all resistant to the temperature level likely to be produced in the heating wire, the radially inner layer also being made of an electrically insulating material and the radially external layer also being made of a material capable of absorbing said vapours, said heating wire being either wound around all the rods or woven with the rods of said one other additional cage, the or each air outlet orifice of the cover being radially external with respect to said one other additional cage;
- said rods of said one other additional cage are odd in number;
 - said rods of said one additional cage are distributed at regular intervals around the circumference of said rings;
 - the sheath of the heating wire of said one other additional cage is made of a material identical, on the one hand, to that of the sheath of the heating wire of the additional cage and, on the other hand, to that of the sheath of the heating wire of the cage;
 - the cumulative surface area of all the cross-sections of the outlet orifices is strictly greater than the surface area of the cross-section of the central air inlet orifice;

- a means for opening/closing the or each air outlet orifice of the cover.

BRIEF DESCRIPTION OF THE FIGURES

Further characteristics and advantages of the invention will become apparent from the following detailed description, for the understanding of which reference is made to the attached drawings, for which:

[Fig. 1] is an exploded perspective view of a device for concentrating vapours of chemical molecules in accordance with the invention;

[Fig. 2] is a perspective view of various cages used in the device shown in [Fig. 1];

[Fig. 3] is a view of the cages shown in [Fig. 2] once assembled and housed in a receptacle of the device shown in [Fig. 1];

[Fig. 4] is a cross-sectional view of a heating wire equipped with an electrically conductive core surrounded by a sheath capable of absorbing vapours of chemical compounds, according to 3 figures to represent the 3 wires envisaged with each of the different cages shown in [Fig. 2];

[Fig. 5] is a diagram showing, in operation, the passage taken by an air flow within the device shown in [Fig. 1];

[Fig. 6] is a diagram showing a type of engagement between the ring of a cage and the bottom of the receptacle of the device according to the invention to ensure a seal;

[Fig. 7] is a diagram showing a type of engagement between the ring of a cage and the cover of the device according to the invention to ensure a seal;

[Fig. 8] is a side view of a variant embodiment of the device according to the invention wherein the heating wire is wound around the rods of the cage.

DETAILED DESCRIPTION OF THE INVENTION

The invention is described in the attached figures.

The invention provides a device DC for concentrating vapours of chemical molecules contained in the air. The device DC comprises a receptacle RCP comprising a central air inlet orifice OEA, a cylindrical cage CG housed in the receptacle RCP and a cover CVC equipped with an air outlet.

Advantageously, the receptacle RCP is cylindrical. The central air inlet orifice OEA is advantageously circular.

The cage CG comprises a first ring PC1 defining a central orifice OC1 communicating with the central air inlet orifice OEA of the receptacle RCP. The cage CG also comprises a second ring PC2. The cage CG also comprises a plurality of rods TG extending parallel

between the first ring PC1 and the second ring PC2, said rods TG being distributed around the circumference of the rings PC1, PC2. Finally, the cage CG comprises a heating wire FC equipped with a sheath G capable of absorbing said vapours, said heating wire FC being woven with the rods TG. Advantageously, the number of rods TG is odd. This makes it easier to weave the heating wire FC. Advantageously, the rods TG are also distributed at regular intervals around the circumference of the rings PC1, PC2. This ensures a homogeneous weaving of the heating wire FC on the rods and, consequently, a certain symmetry which, in use, is conducive to obtaining an isotropic behaviour of the circulation of the air and therefore of the concentration of the vapours to be detected.

The air outlet is, for example, formed by a plurality of orifices OSA1, OSA2, OSA3 in the cover CVC, radially external with respect to the cage CG, and distributed around the peripheral contour CPH of the cage CG. The air inlet orifice OEA being central and the orifices OSA1, OSA2, OSA3 being peripheral, the air flow within the receptacle RCP has both axial and radial movement. This arrangement facilitates the passage of air through the structure formed by the heating wire FC woven with the rods TG. Advantageously, the cumulative surface area of all the cross-sections of the outlet orifices OSA is strictly greater than the surface area of the cross-section of the central air inlet orifice OEA (single). In use, this reduces the pressure drops. For example, it may be provided that the cumulative surface area of all the cross-sections of the outlet orifices OSA is at least 10%, for example between 10% and 30%, greater than the cross-sectional surface area of the central air inlet orifice OEA.

The heating wire FC consists of an electrically conductive wire FCE, for example metallic but which may be made of another electrically conductive material, covered with a sheath G made of at least one material capable of absorbing the vapours of chemical molecules to be concentrated (and which it is *ultimately* intended to detect). The conductor wire FCE may be a single-strand wire, as shown in Figure 4, or a multi-strand wire. The electrical conductor wire FCE, for example shown in Figure 4, begins and ends with connection terminals CBE for external connection to an electrical power source. As may be understood, the sheath G is electrically insulating and capable of withstanding the temperatures (typically in a range from 140°C to 300°C) likely to be imposed by the conductor wire of the heating wire (Joule effect) when an electric current passes through it.

In practice, a sheath made of the same material with the above-mentioned properties may be envisaged. PDMS (polydimethylsiloxane) is a material that may be used for the sheath G. Its raw chemical formula is $-(\text{Si}(\text{CH}_3)_2-\text{O})_n$. This material concentrates the vapours such as 4-NT (4-nitrotoluene), TNT (trinitrotoluene) or DMNB (dimethyldinitrobutane).

- Alternatively, a sheath G with a structure made up of at least two successive layers may also be envisaged, with a radially inner electrically insulating layer capable of withstanding the temperatures likely to be imposed on it but not necessarily capable of absorbing the vapours of chemical molecules (this may, for example, be PDMS), and a radially external layer also capable of withstanding the temperatures likely to be imposed on it but also capable of absorbing the vapours of chemical molecules of interest, without necessarily being electrically insulating (this may be a PDMS-based material comprising one or more additives, for example of the molecular sieve type such as Carboxen®). It performs the same functions, but with two layers with complementary properties.
- The heating wire FC may release the trapped molecules by passing an electric current through the conductor wire located at the core (Joule effect). This causes the rapid release of vapours trapped in the sheath G. The decreasing temperature gradient from the core to the outside of the heating wire thus created in the absorbent material encourages the release of the vapours to the outside by strongly limiting the residual vapours in the material.
- Limiting residual vapours in the material means that the concentration device DC may be reused quickly, considerably reducing the magnitude of the memory effect responsible for a persistent residue of chemical molecules in the material.
- Advantageously, the concentration device DC comprises a means for opening/closing the orifices of the cover. This opening/closing means may take the form of a disc DSQ rotatably mounted on the cover CVC, the disc DSQ comprising openings OV1, OV2, OV3 which may (or may not) be brought into correspondence with the orifices of the cover CVC. The orifices OA1, OA2, OA3 may thus be left open (for example, during the absorption of the vapours of chemical molecule in the sheath provided for this purpose in the air flow rate circulating in the concentration device) or closed (for example, to ensure a more rapid rise in temperature of the volume of air present in the receptacle).
- In one variant, in this case illustrated in Figure 5, the cover CVC comprises a single air outlet orifice OSA radially external with respect to said cage CG and extending around the peripheral contour CPH of the cover, preferably around the entire peripheral contour. Such a cover CVC may be associated with a means for opening/closing the orifice OSA of the cover in the form of a cap (not shown) with dimensions adapted to those of the cover. Figure 5 also shows the air flow FA within the concentration device DC. This air flow is the same when there are several outlet orifices on the cover, as shown in Figure 1.
- The cage CG may comprise at least one thermocouple TC. This thermocouple TC is advantageously placed on the outside of the sheath G to measure the temperature at the level of the sheath G. The temperature may be monitored by one or more processors

connected to the electrical supply of the heating wire FC to ensure a precise control of the temperature at the level of the sheath G and more generally in the concentration device DC. In order to increase the performance or expand the capacity of the concentration device DC, the exchange surface between the sheath and the air within the (given) volume of the receptacle RCP may be increased.

To this end, the concentration device may provide an additional cylindrical cage CG1 housed in the receptacle and arranged around said cage CG. Generally speaking, the additional cage CG1 is similar to the cage CG, but simply has a larger diameter. More specifically, the additional cage CG1 comprises a first ring PC11 defining a central orifice OC11. The additional cage CG1 also comprises a second ring PC12 defining a central orifice OC12. The additional cage also comprises a plurality of rods TG10 extending parallel between the first ring PC11 and the second ring PC12, said rods being distributed around the circumference of said rings PC11, PC12. In addition, the central orifices OC11, OC12 of the rings PC11, PC12 of the additional cage CG1 have an internal diameter corresponding to the external diameter of the rings PC1, PC2 of said cage CG. Finally, the additional cage CG1 comprises a heating wire FC10 equipped with a sheath G10 made of a material capable of absorbing said vapours, said heating wire FC10 being woven with the rods TG10 of the additional cage CG1. Again, the or each air outlet orifice OSA, OSA1, OSA2, OSA3 of the cover CVC is radially external to the additional cage CG1. This ensures, for example during a step aimed at concentrating vapours of chemical compound within the concentration device DC, that the air entering through the air inlet orifice OEA of the receptacle RCP circulates inside the cage CG, but also radially so as to be able to reach the heating wire FC10 of said additional cage CG1 before leaving the receptacle RCP and the concentration device DC.

The additional cage CG1 may also comprise at least one thermocouple TC, advantageously placed on the outside of the sheath G10 of the heating wire FC10 to measure the temperature at the level of the sheath G10.

In order to facilitate the positioning of the cage CG inside the additional cage CG1, the concentration device DC advantageously comprises complementary cooperation means L1, T1 placed respectively on the first ring PC11 of the additional cage CG1 and on the first ring PC1 of said cage CG at a given point on their respective circumferences. Typically, and as shown in the attached figures, a tongue L1 may be provided on the external periphery of the first ring PC1 of the cage CG and a correspondingly shaped opening T1 on the inner periphery of the first ring PC11 of the additional cage CG1.

- The heating wire FC10 of the additional cage CG1 may be made of a material identical to the heating wire FC of said cage, particularly for the sheath. This is particularly useful when the aim is to increase the vapour concentration of a given chemical compound in the air and/or to increase the treatment speed for a given concentration. Furthermore, a heating
- 5 wire FC, FC10 of identical diameter for the two cages CG, CG1 implies a larger exchange surface between the sheath and the ambient air for the heating wire FC10 of the additional cage CG1, because this additional cage CG1 has a larger diameter. This increased exchange surface adds a second level of trapping for vapours not trapped by the sheath G of the heating wire FC in the cage CG.
- 10 It should be noted that, depending on the availability of materials, the external diameter of the heating wire FC10 may vary, as may its internal constitution, particularly its sheath, the important thing being that this does not significantly change the final characteristics, such as the electrical insulation, the trapping capacity or the weight.
- However, as an alternative, it is possible to have a sheath G10 of the heating wire FC10 of
- 15 the additional cage CG1 made from a different material to the sheath G of the heating wire FC of the cage CG1. In this case, it is possible to absorb vapours of different chemical compounds present in the air and therefore ultimately to concentrate different vapour molecules. For example, PDMS may be used for the sheath G of the heating wire FC of the cage CG1 and PDMS incorporating carbon for the sheath G1 of the heating wire FC10 of
- 20 the cage CG10. Carbon may be a material in the form of a molecular sieve (produced by the pyrolysis of polymers). With a molecular sieve, it is possible to vary the size of the pores and therefore target different types of chemical molecule vapours to be trapped. Typically, these vapours range in size from C2 to C5 n-alkanes. The Carboxen® product range is an example of this type of product.
- 25 The concentration device DC may also provide another additional cylindrical cage CG2 housed in the receptacle RCP. This additional cage CG2 comprises a first ring PC21 defining a central orifice OC21. This other additional cage CG20 also comprises a second ring PC22 defining a central orifice OC22 and a plurality of rods TG20 extending parallel between the first ring PC21 and the second ring PC22, said rods being distributed around
- 30 the circumference of said rings PC21, PC22. Furthermore, the central orifices OC21, OC22 of the rings PC21, PC22 of said one additional cage CG2 have an internal diameter corresponding to the external diameter of the rings PC11, PC12 of the additional cage CG1. Lastly, this other additional cage CG2 comprises a heating wire FC20 equipped with a sheath G20 made of a material capable of absorbing said vapours, said heating wire FC20
- 35 being woven with the rods TG20 of said other additional cage CG2. Here too, the or each

air outlet orifice OSA, OSA1, OSA2, OSA3 of the cover CVC is radially external with respect to said one other additional cage CG2. This ensures, for example during a step aimed at concentrating chemical compound vapours within the concentration device DC, that the air entering through the air inlet orifice OEA of the receptacle RCP circulates inside the cage CG, but also radially so as to be able to reach the heating wire FC20 of said at least one other additional cage CG20 before leaving the receptacle RCP and the concentration device DC.

Said one additional cage CG2 may also comprise at least one thermocouple TC20, advantageously placed on the outside of the sheath G20 of the heating wire FC20 to measure the temperature at the level of the sheath G20.

In order to facilitate the positioning of the additional cage CG1 inside said other additional cage CG2, the concentration device DC advantageously comprises complementary cooperation means L2, T2. More precisely, the complementary cooperation means L2, T2 are respectively placed on the first ring PC21 of said one additional cage CG2 and on the first ring PC11 of said additional cage CG1 at a given location on their respective circumferences. Typically, and as shown in the attached figures, a tongue L2 may be provided on the external periphery of the first ring PC11 of the additional cage CG1 and a correspondingly shaped opening T2 on the inner periphery of the first ring PC21 of said other additional cage CG2.

It may be envisaged that the sheath G20 of the heating wire FC20 of said other additional cage CG2 is made of a material identical, on the one hand, to that of the sheath G10 of the heating wire FC10 of the additional cage CG1 and, on the other hand, to that of the sheath G of the heating wire FC of the cage CG. In this case, it increases the exchange surface of the material absorbing the vapours of chemical compounds present in the air, in this case at the level of the radially outermost cage CG2, which locally sees a lower concentration of these vapours due to the absorption effected at the level of the two innermost cages CG, CG1.

Of course, it is also possible to envisage the material forming the sheath G20 being different not only from the material forming the sheath G of the heating wire FC, but also from the material forming the sheath G10 of the heating wire FC10 of the additional cage CG1. The concentration device DC may be used to concentrate vapours from three different chemical families at the same time.

Alternatively, one of the sheaths G, G10, G20 may be made of a different material to the other two sheaths. In this case, vapours from two different chemical compounds may be

concentrated while, for example, increasing the concentration rate of vapours from another family of chemical compounds.

Furthermore, throughout the preceding description, we have presented embodiments wherein the heating wire FC, FC10, FC20 is woven with the rods of the associated cage CG, CG1, CG2. Alternatively, the heating wire FC, FC10, FC20 may be wound around said rods. When several cages are envisaged, the heating wire may be wound around the rods for a single cage, only certain cages or all the cages. Figure 8 shows an alternative embodiment for the cage CG.

In addition, when several cages are envisaged, these may be made secured to each other at the level of their respective rings. The cages are then presented in the form of a block, which facilitates the installation of the cages since only one set-up is required. This block may also be attached to the bottom of the receptacle and the cover may be secured to the block, the cover advantageously including a handle to make it easier to remove the block from its receptacle.

The seal between the bottom of the receptacle RCP and the rings of each cage CG, CG1, CG2 (Figure 6) on the one hand, and the seal between the cover CVC and these same rings (Figure 7) on the other hand, is advantageously achieved by machining a double wave in the mass, which allows the two parts to be assembled to provide a seal sufficient for the device to function properly. In Figure 6, this double wave is formed by a bead BPC1 made in the lower ring PC1 of the cage CG1 (in this case) which is inserted in a sealed manner in a corresponding recess CFRCP made in the bottom FRCP of the receptacle RCP. In Figure 7, this double wave is formed by a bead BPC2 made in the upper ring PC2 of the cage CG1 (in this case) which is inserted into a recess CCVC made in the cover CVC. This design eliminates the need of gaskets for this sealing. The beads BPC1 and FRCP may be seen in Figures 2 and 3 respectively.

The free volume of the receptacle, i.e. its total volume minus the volume of the cage housed in it or, as the case may be, of all the cages housed in it, must be as small as possible while remaining close to the volume required by the detector used downstream of the concentration device to carry out the analysis. For example, consider a detector of explosives with an analysis flow rate of 0.1 litres per minute for an analysis time of one minute and a detection limit of 1 ppbv (10^{-9} v/v). It may then be combined with a concentration device DC according to the invention sampling 100 litres of air containing 0.01 ppbv of explosive vapours which will be trapped and then released in a smaller volume of the 0.1 litre receptacle. In this case, the resulting concentration will be 1000, or three orders of magnitude. This gain will allow the detector, after the operation of the

concentration device DC according to the invention, to have a concentration of 10 ppbv, i.e. 10 times above the detection limit of the detector, whereas it would have been impossible to achieve this detection without the concentration device, the concentration being in fact one hundred times lower than the native detection limit of the detector. In reality, the concentration level is lower because of the trapping efficiencies specific to each "chemical molecule - cage equipped with its heating wire and its sheath" pair or the properties of the vapours of the chemical molecules studied.

It should be noted that several detection technologies are compatible with the concentration device DC according to the invention. These include, but are not limited to, mass spectrometry, Raman spectrometry or infrared spectrometry, gas chromatography associated with sensitive detectors (electron capture detector, mass spectrometry, etc.) and portable vapour detectors. In particular, in the case of gas chromatography, it is quite possible to use standard means such as SPME (Solid Phase Micro Extraction) to extract the vapours directly from the hot concentration device at the end of the heating cycle of the concentration device.

Presentation of experimental tests

Tests were carried out with air containing DMNB vapour, which is an official marker for commercial explosive compositions. Prior to the tests, DMNB vapours were diluted to a value of around 0.7 ppbv, i.e. a concentration almost 2,000 times lower than the saturation vapour pressure of this molecule at ambient temperature. These diluted vapours were drawn through the concentration device described in this patent application, with the air outlet orifices open, at a flow rate of 150 L/min (9,000 L/h) for 10 minutes at 20°C, representing a sampled gas volume of 1.5 m³ (at 0.7 ppbv DMNB). Three concentric cages were used, each comprising a heating wire with a PDMS sheath. The total and cumulative length of heating wire is 17 m and each heating wire has an external diameter of 2.1 mm. After 10 minutes of sampling diluted DMNB vapour from the device, the air outlet orifices are closed.

The device is then placed in an oven at 200°C and the heating wire is heated to the same temperature by passing a current through it.

When the temperature of 200°C is reached everywhere, in these tests after 4 minutes, a reference SPME fibre (57300-U, SUPELCO), previously activated in accordance with the recommendations of the manufacturer, is positioned for 3 minutes in the OEA orifice. During

the 3 minutes, the SPME passively captures the concentrated vapours released into the 368 cm³ free volume of the device according to the invention.

The SPME was then analysed using an AGILENT gas chromatograph equipped with an electron capture detector. The average of the area values obtained for the tests performed
5 is 2,299,388 AU (arbitrary units), which represents a signal-to-noise ratio of over 200.

The tests were carried out systematically after a blank run under the same conditions but without DMNB, in order to check that there was no memory effect of the device between each test. The value of the blanks is approximately 10,000 AU (arbitrary units) each time. This value is deduced from the results presented.

10 End of presentation of experimental tests.

There are three main steps in the use of the concentration device according to the invention. In a first step, the device DC is connected, with the air outlet orifices open, at ambient temperature to a device for drawing in the vapours to be collected. Typically, such a drawing
15 device provides an air flow rate of around 150 litres per minute for a period chosen by the user ranging from a few seconds to several hours, depending on concentration requirements.

In a second step, the device DC is placed, with the air outlet orifices closed, in an oven where the temperature may be raised, for example to around 200°C, in order to maintain its external walls at this temperature and at the same time supply the current required to heat
20 the heated wire to this same temperature. This allows the molecules previously collected in the sheath of the heating wire to be released into the free volume of the device DC. Heating takes just a few minutes. This is when the analyser or the concentrated vapour collector (e.g. SPME) is positioned above the device DC to analyse the concentrated vapours after drawing or collection.

25 In a final step, the invention is either maintained at a hot temperature with a flow rate of clean air to evacuate the last vapours or cooled naturally or by a flow rate of clean ambient air (for example with a flow rate of approximately 150 L/min), with the air outlet orifices open.

CLAIMS

1. A device (DC) for concentrating vapours of chemical molecules contained in the air, said device comprising:
 - 5 - a receptacle (RCP) comprising a central air inlet orifice (OEA);
 - a cylindrical cage (CG) housed in the receptacle, said cage (CG) comprising:
 - a first ring (PC1) defining a central orifice (OC1) communicating with the central air inlet orifice (OEA) of the receptacle (RCP),
 - a second ring (PC2),
 - 10 - a plurality of rods (TG) extending parallel between the first ring (PC1) and the second ring (PC2), said rods being distributed around the circumference of said rings (PC1, PC2), and
 - a heating wire (FC) equipped with a sheath (G) either made of the same electrically insulating material, resistant to the temperature level likely to be produced in the heating wire and capable of absorbing said vapours or made of at least two layers made of different materials but all resistant to the temperature level likely to be produced in the heating wire, the radially inner layer also being made of an electrically insulating material and the radially external layer also being made of a material capable of absorbing said vapours, said heating wire (FC) being either
 15 wound around all the rods (TG) or woven with the rods (TG);
 - 20 - a cover (CVC) for the receptacle (RCP), said cover comprising one or more outlet orifices (OSA, OSA1, OSA2, OSA3) radially external with respect to said cage and extending around the peripheral contour (CPH) of said cage.
- 25 2. The device (DC) for concentrating the vapours of chemical molecules contained in the air, as claimed in claim 1, wherein said rods (TG) are odd in number.
3. The device (DC) for concentrating the vapours of chemical molecules contained in the air according to one of the preceding claims, wherein said rods (TG) are distributed at
 30 regular intervals around the circumference of said rings (PC1, PC2).
4. The device (DC) for concentrating the vapours of chemical molecules contained in the air according to the preceding claim, wherein the cage (CG) comprises at least one thermocouple (TC).

5. The device (DC) for concentrating the vapours of chemical molecules contained in the air according to one of the preceding claims, comprising an additional cylindrical cage (CG1) housed in the receptacle, said additional cage comprising:
- a first ring (PC11) defining a central orifice (OC11),
 - 5 a second ring (PC12) defining a central orifice (OC12), and
 - a plurality of rods (TG10) extending parallel between the first ring (PC11) and the second ring (PC12), said rods being distributed around the circumference of said rings (PC11, PC12),
 - the central orifices (OC11, OC12) of said rings (PC11, PC12) of the additional cage (CG1)
 - 10 having a diameter corresponding to the external diameter of the rings (PC1, PC2) of said cage (CG),
 - a heating wire (FC10) equipped with a sheath (G10) either made of the same electrically insulating material, resistant to the temperature level likely to be produced in the heating wire and capable of absorbing said vapours or made of at least two layers made of different
 - 15 materials but all resistant to the temperature level likely to be produced in the heating wire, the radially inner layer also being made of an electrically insulating material and the radially external layer also being made of a material capable of absorbing said vapours, said heating wire (FC10) being either wound around all the rods (TG10) or woven with the rods (TG10) of the additional cage (CG1),
 - 20 the or each air outlet orifice (OSA, OSA1, OSA2, OSA3) of the cover (CVC) being radially external with respect to the additional cage (CG1).
6. The device (DC) for concentrating the vapours of chemical molecules contained in the air according to claim 5, wherein said plurality of rods (TG10) of the additional cage (CG1)
- 25 is an odd number.
7. The device (DC) for concentrating the vapours of chemical molecules contained in the air according to one of claims 5 or 6, wherein said rods (TG10) of the additional cage (CG1) are distributed at regular intervals around the circumference of said rings (PC11, PC12).
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8. The device (DC) for concentrating vapours of chemical molecules contained in the air according to one of claims 5 to 7, wherein the sheath (G10) of the heating wire (FC10) of the additional cage (CG1) is made of a material identical to the sheath (G) of the heating wire (FC) of said cage (CG).
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9. The device (DC) for concentrating vapours of chemical molecules contained in the air according to one of claims 5 to 8, wherein the additional cage (CG1) comprises at least one thermocouple (TC10).

- 5 10. The device (DC) for concentrating vapours of chemical molecules contained in the air according to one of claims 5 to 9, comprising another additional cylindrical cage (CG2) housed in the receptacle, said another additional cage comprising:
- a first ring (PC21) defining a central orifice (OC21),
- a second ring (PC22) defining a central orifice (OC22), and
- 10 a plurality of rods (TG20) extending parallel between the first ring (PC21) and the second ring (PC22), said rods being distributed around the circumference of said rings, the central orifices (OC21, OC22) of said rings (PC21, PC22) of said one additional cage (CG2) having a diameter corresponding to the external diameter of the rings (PC11, PC12) of the additional cage (CG1),
- 15 a heating wire (FC20) equipped with a sheath (G20) either made of the same electrically insulating material, resistant to the temperature level likely to be produced in the heating wire and capable of absorbing said vapours or made of at least two layers made of different materials but all resistant to the temperature level likely to be produced in the heating wire, the radially inner layer also being made of an electrically insulating material and the radially
- 20 external layer also being made of a material capable of absorbing said vapours, said heating wire (FC20) being either wound around all the rods (TG20) or woven with the rods (TG20) of said one other additional cage (CG2),
- the or each air outlet orifice (OSA, OSA1, OSA2, OSA3) of the cover (CVC) being radially external with respect to said one additional cage (CG2).

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11. The device (DC) for concentrating the vapours of chemical molecules contained in the air according to claim 10, wherein said rods (TG20) of said one additional cage (CG2) are odd in number.

- 30 12. The device (DC) for concentrating the vapours of chemical molecules contained in the air according to one of claims 10 or 11, wherein said rods (TG20) of said one additional cage (CG2) are distributed at regular intervals around the circumference of said rings (PC21, PC22).

13. The device (DC) for concentrating the vapours of chemical molecules contained in the air according to one of claims 10 to 12, wherein the sheath (G20) of the heating wire (FC20) of said one additional cage (CG2) is made of a material identical, on the one hand, to that of the sheath (G10) of the heating wire (FC10) of the additional cage (CG1) and, on the other hand, to that of the sheath (G) of the heating wire (FC) of the cage (CG).

14. The device (DC) for concentrating vapours of chemical molecules contained in the air according to one of the preceding claims, wherein the cumulative surface area of all the cross-sections of the outlet orifices (OSA) is strictly greater than the surface area of the cross-section of the central air inlet orifice (OEA).

15. The device (DC) for concentrating vapours of chemical molecules contained in the air according to one of the preceding claims, further comprising a means (DSQ) for opening/closing the (OSA) or each (OSA1, OSA2, OSA3) air outlet orifice of the cover.