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(71) Ansøger:
Tørbåd ApS, Ingerslevs Boulevard 22, 8000 Århus C, Danmark

(72) Opfinder:
Rasmus Toftegaard, Agervej 13, 8320 Mårslet, Danmark
Thomas Rønnow Olesen, Ingerslevs Boulevard 22, 4. tv., 8000 Århus C, Danmark
Jesper Lund Jørgensen, Jordbrovej 6, 1. tv., 8200 Århus N, Danmark

(74) Fuldmægtig:
Zacco Denmark A/S, Arne Jacobsens Allé 15, 2300 København S, Danmark

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(57) Sammendrag:
Herein is detailed a 3-rotor drying system (30,40,50) for producing technical air having a very low dew point comprising three rotary desiccant dryers (2,21,22), each rotary desiccant dryer (2,21,22) comprising a drying sector (2a,21a,22a) and a regeneration sector (2b,21b,22b), the rotary desiccant dryers (2a,21a) arranged in sequence and sharing a common regeneration-air flow path (9) for passing regeneration-air through the respective regeneration sectors (2a,21b,22b) of the rotary desiccant dryers (2,21,22) and a common intake-air flow path (6,7) for passing intake-air through the respective drying sectors (2a,21a,22a) of the rotary desiccant dryers (2,21,22) for dehumidifying the intake-air to product-air having a very low dew point.

Fortsættes...

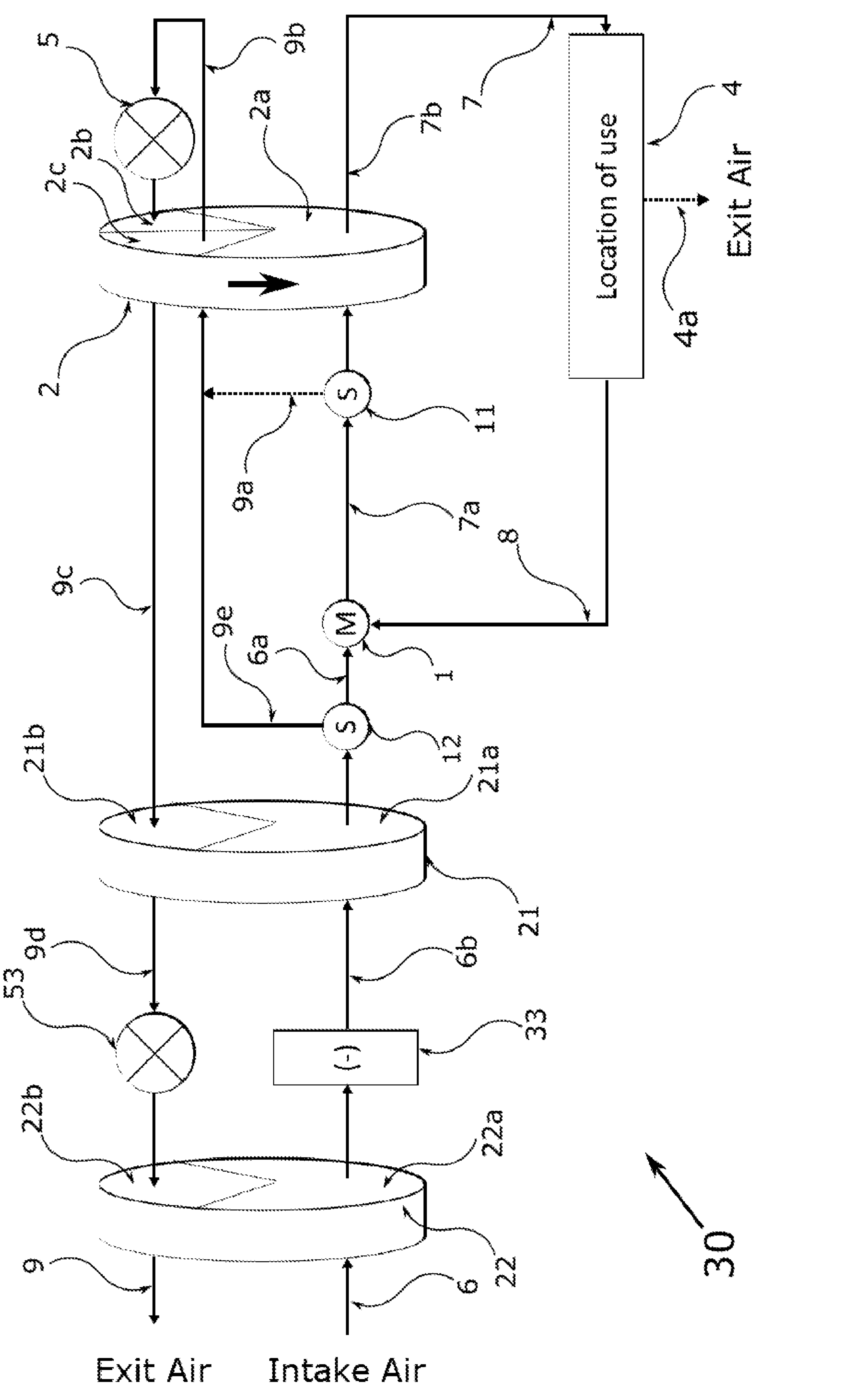
5
9b
2a
7b
7
4
2b
2c
Location of use
Exit Air
4a
2
11
9a
7a
8
9c
9e
6a
M
1
S
12
21b
21a
21
9d
53
6b
33
(-)
22b
22a
22
9
6
30
Exit Air
Intake Air

Figure 3

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TITLE OF INVENTION

Drying System for product-air having a very low dew point

TECHNICAL FIELD

Within the field of drying systems, there is a detailed herein a drying system for producing technical air having a very low dew point (i.e. very dry technical air) at reduced energy costs. Such systems are e.g. very suitable for producing conditioned air for very moisture sensitive applications such as clean rooms for lithium battery production or for the production of gasses with very low moisture contents.

BACKGROUND

Within the field of drying systems, there is a detailed herein a drying system for producing technical air having a very low dew point (i.e. very dry technical air) at reduced energy costs. Such systems are e.g. very suitable for producing conditioned air for very moisture sensitive applications such as clean rooms for lithium battery production or for the production of gasses with very low moisture contents.

In the art, it is known to manufacture drying systems for the production of resulting air having a very low dew point, such as dew points below -30°C or lower. In the art, drying systems are known, which are suitable for producing resulting air having very low dew points. However, in general these systems are not capable of producing technical air, i.e. air in large volumes and at high flowrates for technical purposes, or if useable at all, at reasonable energy or operating costs. Within the present disclosure therefore, technical air encompasses air for purposes such as central air conditioning of buildings, clean rooms or other production facilities, for spray drying towers, fluid bed dryers etc., which for adequate function all rely on high volumes and flowrates of air with well-specified properties. Accordingly, the present invention relates to drying systems for the production of technical air having very low dew points (i.e. very dry technical air), and is discussed in that context herein.

In the art of producing dry technical air, it is well known to make use of drying systems comprising rotary desiccant dryer, also called drying wheels or rotary dryers. An advantage of these systems is their capacity for rapidly dehumidifying large volumes of intake air, e.g. in excess of 1000 m3/h, for technical purposes. In such drying systems air to be dried passes through a desiccant layer embedded in a rotary wheel, thereby becoming dryer and warmer, whereafter the moist sector of the rotary dryer is passed by rotation to a sector of air-drying and desiccant regeneration and back to an absorption position. Depending on the entry air, such rotary dryers are capable of producing technical air in large volumes and at high flowrates with a broad range of below 0°C dew points.

Also in the art of producing technical air having very low dew points such as below -30°C, rotary desiccant dryers have found widespread use, even for providing technical air having dew points below -40°C or -50°C.

A considerable problem, however, when operating drying systems comprising rotary desiccant dryers for providing technical air at -30°C or below is the energy cost for operating the drying systems. E.g. within the field of lithium battery production, it is estimated that the primary cost in energy is from operation of various dry rooms that are vital to the quality of the battery cells (Ellingsen et al. J. Industrial Ecology, Vol 18, No 1, pp 113-124).

Figures 1, 2A and 2B detail drying systems (10,20) comprising rotary desiccant dryers of the prior art for producing technical air having very low dew points, such as discussed in e.g. WO 2011/161693 to BryAir. The drying systems detailed in Figure 1 are based on a one-rotor system, whereas the drying systems detailed in Figures 2A and B are based on two rotary desiccant dryers in sequence. A particular issue of the prior art drying systems for producing technical air having very low dew points is that these rely on pre-cooling and simultaneous drying of the entry air for the desiccant wheel, which is both costly in energy as well as problematic from a hygienic position as condensation water is created, which must be removed before microbial or bacterial contamination can become a risk. In particular, where sterility is an issue, condensation water presents an unwelcome challenge.

For overcoming the problems of the prior art, the present inventors have devised a drying system for producing technical air having very low dew point comprising at least 3 sequentially arranged rotary desiccant dryers, the drying system of the invention having improved energy efficiency while avoiding the production of liquid water and the associated biological contamination risk.

SUMMARY OF THE INVENTION

According to the invention, there is herein disclosed a 3-rotor drying system (30) for producing technical air having a very low dew point comprising three rotary desiccant dryers (2,21,22), each rotary desiccant dryer (2,21,22) comprising a drying sector (2a,21a,22a) and a regeneration sector (2b,21b,22b), the rotary desiccant dryers (2,21,22) arranged in sequence and sharing a common regeneration-air flow path (9) for passing regeneration-air through the respective regeneration sectors (2a,21b,22b) of the rotary desiccant dryers (2,21,22) and a common intake-air flow path (6,7) for passing intake-air through the respective drying sectors (2a,21a,22a) of the rotary desiccant dryers (2,21,22) for dehumidifying the intake-air to product-air having a very low dew point;

- wherein a mixing point (1) for return-air is arranged on the common intake-air flow path (6,7) between a first (2) and a second (21) rotary desiccant dryer, thereby defining
  - a product-air flow path (7) for providing dehumidified product-air having a very low dew point to a location of use (4) downstream from the mixing point (1) for return-air, and where on the product-air flow path (7) the drying sector (2a) of the first rotary desiccant dryer (2) is arranged, and
  - an intake-air flow path (6) upstream from the mixing point (1) for return-air for providing intake-air to the mixing point (1), and where on the intake-air flow path (6) the drying sector (21a) of the second rotary desiccant dryer (21) is arranged;
- wherein a splitting point (12) for intake-air is arranged between the mixing point (1) for return-air and the second rotary desiccant dryer (21) on a first section (6a) of

the intake-air flow path (6), from which splitting point (12) intake-air is diverged as regeneration-air along the regeneration flow path (9);

- wherein a purge sector (2c) and the regeneration sector (2b) of the first rotary desiccant dryer (2) are arranged on the regeneration flow path (9) such that the regeneration-air via an air flow path (9e) first traverses the purge sector (2c) and subsequently the regeneration sector (2b) via a heater (5) arranged on the regeneration flow path (9) between (9b) the purge sector (2c) and the regeneration sector (2b);
- wherein the regeneration sector (21b) of the second (21) rotary desiccant dryer is arranged subsequent to the regeneration sector (2) of the first dryer (2) on the regeneration flow path (9), and
- where upstream on the intake-air (6) flow path and downstream on the regeneration flow path (9) from the second rotary desiccant dryer (21) is arranged an initial rotary desiccant dryer (22), where on the regeneration flow path (9) between (9d) the second (21) and the initial (22) rotary desiccant dryer is arranged an inter-heater (53) for inter-heating regeneration-air prior to traversing the regeneration sector (22b) of the initial rotary desiccant dryer (22);
- the 3-rotor drying system (30) further comprising a return-air flow path (8) for providing return-air from a location of use (4) to the mixing point (1) for return air and one or more air moving means.

By the provision of the drying systems (30,40,50) of the invention, technical air a having very low dew point can be provided.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1: Prior art 1-rotor drying systems (10a,10b) for producing technical air having very low dew points.

Figure 2A: Prior art 2-rotor drying system (20a) for producing technical air having very low dew point.

Figure 2B: Prior art 2-rotor drying system (20b) for producing technical air having very low dew point.

Figure 3: Exemplary 3-rotor drying systems (30) of the invention.

Figure 4: Exemplary 3-rotor drying systems (40a,40b) of the invention.

Figure 5: Exemplary 3-rotor drying systems (50a,50b) of the invention.

Figure 6: Simulation of efficiency of a 3-rotor drying system (30) of the invention.

DETAILED DESCRIPTION

In Figures 1A and 1B are detailed two respective 1-rotor drying systems (10a,10b) of the prior art for producing technical air having a very low dew point and supplying the produced air to a location of use (4). Throughout the present disclosure the drying systems of the prior art (10,20) and of the present invention (30,40,50), and hence also the two drying systems (10a,10b) of Figure 1, are preferably detailed in the context of air conditioning for a room (4) for exemplification of the operating principle behind the systems of the prior art and of the invention. However, it is to be understood, that while the location or space of use (4) of product-air from the drying systems (10,20,30,40,50) generally will be discussed in terms of air-conditioning of rooms, such illustration is solely for the purpose of exemplification and that the drying systems of the invention are suitable for use in numerous other contexts apart from air conditioning, where technical air having very low dew point is desired.

In general, product-air is provided to a location of use (4) via a product-air flow path (7) and may be removed as return-air from the same location of use (4) along a return-air flow path (8) or, optionally, along additional flow path(s) (4a) for exit-air. The location of use (4) thereby does not form part of the drying systems of the present invention (30,40,50).

However, the present invention (30,40,50) and the drying systems of the prior art (10,20) are illustrated in the context of air conditioning of rooms and production facilities in order to illustrate and discuss their advantages and disadvantages with respect to their use in a production line for producing lithium batteries.

The supply of technical air having very low dew point for use in maintaining a very dry, air-conditioned building space, such as a clean room or a production space for the production of lithium batteries, is a particularly important aspect of lithium batteries production with a high propensity for failure, due to lithium’s extreme hygroscopic nature and rapid, potentially explosive, combustion when in contact with water. Production specifications on the technical air for use within the production buildings range between dew points of -20°C down to -60°C under present standards. Even at these standards, it is estimated that the total production line efficiency is only at about 50%-60% of theoretical maximum, not at least due to difficulties in controlling the humidity of the air in the production buildings and clean rooms.

In order to maintain production of technical air having a very low dew point during use of the produced technical air, the drying systems of the prior art (10a,10b,20a,20b) as well as the drying systems (30,40,50) of the present invention rely on recirculation of most of the dried air between a dehumidifier and the location of use (4), such that during operation only enough ambient air has to enter the drying systems as intake-air in order to compensate for loss of product-air during operation. In the prior art systems (10,20) and in the systems of the invention (30,40,50) intake-air is also leaving as exit-air after having served as regeneration-air for rotary desiccant dryer(s) (2) comprised as dehumidifiers in the drying systems (10,20,30,40,50). Usually, product-air is controllably lost during operation, e.g. by maintaining building space overpressure for preventing entry of contaminants by diffusion. In Figure 1, this is indicated by the hatched flow path (4a) for exit-air exiting the air-conditioned room (4).

The 1-rotor drying systems (10a,10b) of the prior art are constructed around a mixing point (1) for return-air to which intake-air is provided along an intake-air flow path (6), mixed at the mixing point (1) with return-air provided along a return flow path (8) and distributed as mixed-air for product-air dehumidification and desiccant regeneration along flow paths for respectively product-air (7) and regeneration-air (9). The product-air flow path (7), the location of use (4), the return-air flow path (8) and the mixing point (1) under normal operation of the drying systems (10a,10b) of the prior art form a semi-closed loop for air circulation, within which a substantially constant volume flow of air circulates during operation of the drying systems (10).

In order to produce product-air having a very low dew point, i.e. under -30°C, using a 1-rotor drying system (10a,10b) of the prior art, intake-air is first subjected to cooling and condensation of water comprised in the intake-air in a cooling and condensation unit (3) arranged on the intake-air flow path (6) prior to reaching the mixing point (1).

The cooling and condensation unit (3) comprised in the prior art drying systems (10) must be of sufficient cooling and condensation capacity for obtaining intake-air at the mixing point (1) that is sufficiently dry such that when the dry intake-air is mixed with the return-air at the mixing point (1), the mixed-air diverged along the product-air flow path (7) is dry enough for a drying sector (2a) of a rotary desiccant dryer (2) arranged in the product-air flow path (7) between the mixing point (1) and the location of use (4) to remove remaining water in the mixed-air to an extent sufficient for obtaining a given target dew point in the product-air. Experience has shown that for providing a suitable cooling and condensation unit (3) compromises with respect to high operating costs, frequent service and maintenance (and associated production halts), and removal of condensation water from the cooling and condensation unit (3) have to be accepted.

At the mixing point (1) of the prior art dryers (10), the mixed-air, as mentioned, is split into two airflows, one for obtaining product-air by passage along the product-air flow path (7), and one for regeneration-air for passage along the regeneration-air flow path (9). In both flow paths (7,9) there is arranged a shared rotary desiccant wheel (2) comprising a drying sector (2a), a regeneration sector (2b) and a purge sector (2c), wherein the drying sector (2a) is arranged on the product-air flow path (7) such that mixed-air can traverse the desiccant wheel (2) across the drying sector (2a), thereby becoming product-air having a very low dew point, and the regeneration sector (2b) and the purge sector (2c) are arranged on the regeneration-air flow path (9) such that mixed-air can traverse the desiccant wheel (2) firstly at the purge sector (2c) and subsequently at the regeneration sector (2b). Between the purge sector (2c) and the regeneration sector (2b) mixed-air undergoes heating to become regeneration-air in a heater (5) arranged on the regeneration-air flow path (9) between (9b) the purge sector (2c) and the regeneration sector (2b). Thereby the regeneration-air can regenerate the desiccant wheel (2) upon passage of the regeneration sector (2b), whereupon in the 1-rotor dryers (10) of the prior art, the spent regeneration-air is discarded as exit-air. In all figures, where bold arrows are shown on desiccant wheels (2), these indicate an optimal direction of rotation during operation of the drying systems (10a,10b) of the prior art, and hence a preferred direction of rotation. In Figures 1A and 1B, the optimal direction of rotation is from drying sector (2a) to regeneration sector (2b) to purge sector (2c).

In the 1-rotor drying systems (10), and after the regeneration-air has traversed the regeneration sector (2b) of the desiccant wheel (2), the regeneration air, which has now become cooled and moist compared to after passage of the heater (5), is discarded as exit-air. A particular problem of the 1-rotor systems (10a,10b) of the prior art, is that while the exit-air has become cooled compared to after heating at the heater (5), the spent regeneration-air is still hot compared to either ambient air or the intake-air for the drying system (10). Typically, temperatures for the regeneration-air after passage of the heater (5) must be within the range of 140°C-170°C for obtaining sufficient regeneration of the desiccant wheel (2) in the 1-rotor drying systems (10a,10b), if the product-air obtained after passage of the drying sector (2a) is to meet the required specifications of having a very low dew point. As this leaves the product-air very hot after passage of the drying sector (2a), this has led to the development the two variants (10a,10b) of the 1-rotor drying system (10) for conditioning the product-air prior to use at the location of use (4).

In the first variant 1-rotor drying system (10a), a cooler (31) is arranged on the product-air flow path (7) after passage (7b) of the drying sector (2a); respectively in the second variant 1-rotor drying system (10b), a cooler (32) is arranged between (7a) the mixing point (1) and the drying sector (2a) on the product-air flow path (7) and an inter-heater (51) is arranged on the product-air flow path (7) after passage (7b) of the drying sector (2a). The drying system (10b) and the cooler (32) are often implemented where extra cooling is needed for increasing the efficiency of the desiccant dryer (2). The coolers (31,32) may provide cooling only but may also be coolers and condensers in one unit such as the cooling and condensation unit (3), but this is not required in contrast to the cooling and condensation unit (3) arranged in the intake-air flow path (6).

Further to the above elements, the drying systems (10) comprise (not shown) one or more air moving means, such as pumps, bellows, or fans, which one or more air moving means are arranged in the flow paths (6-9) for moving air in the drying systems according to the needs and uses of the drying system.

Throughout the present disclosure, all drying systems (10,20,30,40,50) and embodiments thereof comprise air moving means such as detailed above. However, in the context of the present disclosure, the person of art is considered capable of applying such air moving means in flow paths for moving air in accordance with his general knowledge, and accordingly the comprised air moving means are not detailed further in the present disclosure.

1-rotor drying systems (10) for production of technical air having a very low dew point are, while being the most expensive to operate, considered less complicated to manufacture and install and therefore enjoy widespread use despite the abovementioned problems. However, for reasons of process economy they are constructed for operation at or close to their limits, which leaves very little room for extra capacity if needed.

2-rotor drying systems (20) of the prior art, such as shown in Figures 2A and 2B, suffer from a number of the same drawbacks as 1-rotor drying system (10) but are also in widespread use. In general their construction is more complicated than for 1-rotor systems, and hence also more expensive, however their operating costs are generally lower and they can be installed with surplus capacity compared to the 1-rotor systems of the prior art.

The 2-rotor drying systems (20a,20b) for producing technical air having very low dew point of the prior art each comprise two rotary desiccant dryers (2,21), each rotary dryer (2,21) comprising a drying sector (2a,21a) and a regeneration sector (2b,21b), with the rotary dryers (2a,21a) arranged in sequence and sharing a common regeneration-air flow path (9) for passing regeneration-air through the respective regeneration sectors (2a,21b) of the rotary dryers (2,21) and a common intake-air flow path (6,7) for passing intake-air through the respective drying sectors (2a,21a) of the rotary dryers (2,21) for dehumidifying the intake-air. A mixing point (1) for return-air is arranged on the common intake-air flow path (6,7) between the two dryers (2,21), thereby defining a product-air flow path (7) for providing dehumidified product-air having a very low dew point to a location of use (4) downstream from the mixing point (1) for return-air, where on the product-air flow path (7) the drying sector (2a) of the first rotary desiccant dryer (2) is arranged; and defining an intake-air flow path (6) upstream from the mixing point (1) for return-air for providing intake-air air to the mixing point (1), where on the intake-air flow path (6) the drying sector (21a) of the second rotary desiccant dryer (21) is arranged. A splitting point (11) for mixed-air is arranged between the mixing point (1) for return-air and the first dryer (2) on a first section (7a) of the product-air flow path (7) upstream from the first dryer (2), from which splitting point (11) mixed-air is diverged as regeneration-air along the regeneration flow path (9) via a mixed-air flow path (9a). Between the mixing point (1) and the splitting point (11) a cooler (32) is arranged. A purge sector (2c) and the regeneration sector (2b) of the first dryer (2) are arranged on the regeneration flow path (9) such that the regeneration-air first traverses the purge sector (2c) and subsequently the regeneration sector (2b) via a heater (5) arranged on the regeneration flow path (9) between (9b) the purge sector (2c) and the regeneration sector (2b). Further, the regeneration sector (21b) of the second dryer (21) is arranged subsequent to the regeneration sector (2) of the first dryer (2) on the regeneration flow path (9), and on the regeneration flow path (9) between (9c) the first (2) and the second (21) dryer there is arranged an inter-heater (52) for inter-heating regeneration-air prior to traversing the regeneration sector (21b) of the second dryer (21). Further, the 2-rotor drying system of the prior art also comprise a return-air flow path (8) for providing return-air from a location of use (4) to the mixing point (1) for return air and one or more air moving means.

Depending on the circumstances of use, the 2-rotor drying systems (20a,20b) of the prior art may comprise respectively (20a) a heater (51) arranged on the product air flow path (7) downstream (7b) of the first dryer (2) (Figure 2A) or (20b) a cooler (31) arranged on the product air flow path (7) downstream (7b) of the first dryer (2) (Figure 2B). In both figures, additional flow path(s) (4a) for exit-air may be present.

As observed for the 1-rotor drying systems, in use the product-air flow path (7), the location of use (4) and the regeneration flow path (8) form a semi-closed loop for air circulation, within which a substantially constant volume flow of air circulates during operation of the drying systems (20). The purpose of the semi-closed loop for air circulation is to reduce the need for fresh intake-air to the amounts needed for system loss, including controlled loss, and rotary dryer regeneration. In general, the circulated return-air will have a dew point, which is close to the target dew point of the drying system (hence is of higher value than the intake-air) and therefore can be recirculated without mandatory treatment prior to mixing with the intake-air at the mixing point (1).

In general, the 2-rotor drying systems of the prior art require entry air at about 10°C for use as intake-air, and accordingly cooling is often needed prior to permitting ambient air to serve as intake-air for the prior art drying systems (20). Accordingly, the cooling and condensation unit (3) shown in Figure 2B arranged upstream on the intake-air flow path (6) to the second dryer (21) is usually present in both systems of the prior art (20a,20b). Regardless thereof, the cooling in cooler (52) of the 2-rotor systems has to be quite intensive in order to increase the efficiency of the desiccant and to provide mixed-air for the purge section (2c) of the first rotary dryer (2), which is sufficiently cooled for compensating for the heating by the regeneration-air leaving the heater (5). The temperature of the regeneration-air after leaving the heater (5) remains high, about 130°C to 140°C, and also the temperature of the regeneration-air after passage of the inter-heater (52) must remain high, typically above 100°C.

The present invention builds on the above observations by the present inventors for existing installations wherein no adequate balance between installation and operating costs have been found for the drying systems (10,20) currently in use.

It is the aim of the present invention to introduce 3-rotor drying systems (30,40,50) for producing technical air having a very low dew point, such as having a dew point below -30°C, below -40°C, preferably below -50°C, more preferably below -55°C, and even more preferably below -60°C, wherein for the reduced operation costs for the drying systems of the invention, the added cost of installation by using a 3-rotor system can be amortized within a timespan of about 3 years. In some embodiments of the present invention, the dew point of the resulting product-air may be below -65°C, below -70°C, below -75°C, below -80°C, or even below -85°C. These systems are particularly suitable for the subsequent production of technical gasses having a very low moisture content, but the increase in gas quality is at the cost of increase energy consumption for the dehumidification.

The present invention further builds on the observation by the present inventors that it is a common problem of the prior art drying systems (10,20), that to obtain the above 100°C regeneration-air temperatures of the inter-heater (52), and the above 130°C regeneration-air temperatures of the heater (5), high exergy sources of heat are needed, such as high power electricity, steam, combustive gas heating, which sources are typically expensive both in installation and operation costs.

Likewise, the present invention further builds on the observation by the present inventors that it is a common problem of the prior art drying systems (10,20), that low-value intake-air is mixed with high-value return-air prior to the final dehumidification in the aforementioned first rotary dryer (2) thereby causing pollution of the air circulating the semi-closed loop for air circulation formed in use by the product-air flow path (7), the location of use (4) and the regeneration flow path (8). Thereby the load on the first rotary dryer (2) is increased as more of the high-value return-air is diverted for regeneration-air from the semi-closed loop.

Hence, according to the invention there is herein disclosed:

A 3-rotor drying system (30) for producing technical air having a very low dew point comprising three rotary desiccant dryers (2,21,22), each rotary desiccant dryer (2,21,22) comprising a drying sector (2a,21a,22a) and a regeneration sector (2b,21b,22b), the rotary desiccant dryers (2,21,22) arranged in sequence and sharing a common regeneration-air flow path (9) for passing regeneration-air through the respective regeneration sectors (2a,21b,22b) of the rotary desiccant dryers (2,21,22) and a common intake-air flow path (6,7) for passing intake-air through the respective drying sectors (2a,21a,22a) of the rotary desiccant dryers (2,21,22) for dehumidifying the intake-air to product-air having a very low dew point;

- wherein a mixing point (1) for return-air is arranged on the common intake-air flow path (6,7) between a first (2) and a second (21) rotary desiccant dryer, thereby defining
  - a product-air flow path (7) for providing dehumidified product-air having a very low dew point to a location of use (4) downstream from the mixing point (1) for return-air, and where on the product-air flow path (7) the drying sector (2a) of the first rotary desiccant dryer (2) is arranged, and
  - an intake-air flow path (6) upstream from the mixing point (1) for return-air for providing intake-air to the mixing point (1), and where on the intake-air flow path (6) the drying sector (21a) of the second rotary desiccant dryer (21) is arranged;
- wherein a splitting point (12) for intake-air is arranged between the mixing point (1) for return-air and the second rotary desiccant dryer (21) on a first section (6a) of the intake-air flow path (6), from which splitting point (12) intake-air is diverged as regeneration-air along the regeneration flow path (9);

- wherein a purge sector (2c) and the regeneration sector (2b) of the first rotary desiccant dryer (2) are arranged on the regeneration flow path (9) such that the regeneration-air via an air flow path (9e) first traverses the purge sector (2c) and subsequently the regeneration sector (2b) via a heater (5) arranged on the regeneration flow path (9) between (9b) the purge sector (2c) and the regeneration sector (2b);
- wherein the regeneration sector (21b) of the second (21) rotary desiccant dryer is arranged subsequent to the regeneration sector (2) of the first dryer (2) on the regeneration flow path (9), and
- where upstream on the intake-air (6) flow path and downstream on the regeneration flow path (9) from the second rotary desiccant dryer (21) is arranged an initial rotary desiccant dryer (22), where on the regeneration flow path (9) between (9d) the second (21) and the initial (22) rotary desiccant dryer is arranged an inter-heater (53) for inter-heating regeneration-air prior to traversing the regeneration sector (22b) of the initial rotary desiccant dryer (22);
- the 3-rotor drying system (30) further comprising a return-air flow path (8) for providing return-air from a location of use (4) to the mixing point (1) for return air and one or more air moving means.

It is a particular advantage of the drying systems (30,40,50) of the invention that they can be operated without comprising coolers, in particular without comprising cooling and condensation units, yet still provide product-air having a very low dew point, e.g. below -30°C.

The underlying reason is in part that the present invention overcomes the problem of regeneration-air pollution of the air circulating the semi-closed loop for air circulation formed in use by the product-air flow path (7), the location of use (4) and the regeneration flow path (8) by diverging the regeneration-air prior to the mixing point (1) for return-air but also that most of the humidity is removed by the initial rotary desiccant dryer (22) at low cost before the intake-air has undergone further process steps, and wherein the exit-air comprising the largest moisture content is removed at the last station in the drying process.

In a preferred embodiment, the initial rotary desiccant dryer (22) removes at least 90% by weight of the initial moisture content comprised in the intake-air, removes at least 95% by weight, at least 96% by weight, at least 97% by weight, at least 98% by weight, or preferably at least 98.5% by weight of the initial moisture content comprised in the intake-air.

However, for obtaining product-air having the lowest dew points, such as e.g. below -50°C, cooling may be necessary, both for product-air quality and for air conditioning if the location of use (4) is a room or a building space for human use. In Figure 3, preferred embodiments of the 3-rotor drying system (30) of the invention comprising a cooler (33) are exemplified.

In accordance with one embodiment of the invention, the 3-rotor drying system (30) further comprises a cooler (33) arranged on the intake-air flow path (6) between (6b) the second (21) and the initial (22) rotary desiccant dryers. In the examples below we present simulation values for a 3-rotor drying system (30) of the invention implementing the embodiment comprising a cooler (33) and comparative data for corresponding embodiments of the prior art (10a,20b).

A particular advantage of the embodiment further comprising a cooler (33) is that since the majority of the initial moisture content has been removed from the intake-air by adsorption in the initial rotary dryer the cooler (33) only needs to provide low intensity cooling, such as cooling from below 60°C, from below 55°C, from below 50°C, from below 45°C, from below 40°C, or from below 35°C and down to room temperature, such as e.g. between 15°C to 25°C or 20°C.

Particularly, it is an advantage of the present invention that it does not require pre-cooled intake-air for efficient production of technical air having a very low dew point. The prior art drying systems (10,20) generally require pre-cooled intake-air, which in accordance with the standards of the business has been cooled to 10°C before entering the drying systems of the prior art. The drying systems (30,40,50) of the present invention are functional even, when the intake-air is at ambient temperature.

Likewise, it is a particular advantage of the present drying systems (30,40,50) of the invention that the intake-air volume can be reduced compared to the drying systems (10,20) of the prior art when the same target dew point is contemplated for product-air for a given location of use (4). In Example 2 the situation is shown where for same volume flows, the improvement to the dew point by using the drying systems (30,40,50) of the invention is between 6-8°C, and accordingly, by lowering the volume flows in the systems of the present invention, some of this beneficial difference in dew point can be used to lower volume flows and hence increase the economic benefits of the drying systems of the invention compared to the prior art.

As the temperature after passage of the cooler (33) is not significantly increased by passage of the further two rotary desiccant dryers (2,21), further cooling or heating for controlling the temperature of the final product-air prior to entry to a location of use (4) such as a room or a building space can, in general, be dispensed with.

In an embodiment of the invention, the 3-rotor drying system (30) further comprises a splitting point (11) for mixed-air arranged between the mixing point (1) for return-air and the first rotary desiccant dryer (2) on a first section (7a) of the product-air flow path (7) upstream from the first rotary desiccant dryer (2), from which splitting point (11) mixed-air is diverged as regeneration-air along the regeneration flow path (9) via a mixed-air flow path (9a).

As can be observed from Figure 3, when a splitting point (12) in accordance with the invention is provided, the semi-closed loop for circulating air can in fact be a closed loop. Accordingly, and to prevent pressure buildup in a location of use (4), the location of use (4) must either comprise a flow path (4a) for exit air or surplus circulation air can be used for regeneration air by diverging the surplus circulation air at the splitting point (11) for mixed-air along the mixed-air flow path (9a) connecting to an air-flow path (9e) of the regeneration-air flow path (9) prior to regeneration-air passage of the purge sector (2c) of the first rotary desiccant dryer (2).

In some embodiments of the present invention, the splitting point (11) for mixed-air may replace the splitting point (12) for intake-air in the drying systems (30,40,50) of the invention. Thereby it becomes possible e.g. to improve existing 2-rotor drying systems by adding the initial rotary desiccant dryer (22) arranged as detailed herein. The variant system of the invention, however, will be less efficient than the preferred systems (30,40,50) of the invention detailed herein.

In an embodiment of the invention, the 3-rotor drying system (40a) further comprises an inter-heater (52) for inter-heating regeneration-air prior to traversing the regeneration sector (21b) of the second rotary desiccant dryer (21) arranged on the regeneration flow path (9) between (9c) the first (2) and the second (21) rotary desiccant dryers. An exemplary embodiment (40a) thereof is detailed in Figure 4A.

In general, the regeneration-air leaving the regeneration sector (2b) of the first rotary desiccant dryer (2) remains hot and very dry, even after regenerating the first rotary dryer (2), and under normal operation, it is not necessary to provide an inter-heater between the first (2) and second (21) rotary dryers, however, where operation is intended to approach the limits of the drying systems (40a) of the invention, providing the mentioned inter-heater (52) can be particularly beneficial.

In some embodiments of the invention, the inter-heater (52) may replace the inter-heater (53) arranged between the second (21) and the initial (22) rotary desiccant dryer. Thereby it becomes possible e.g. to improve existing 2-rotor drying systems by adding the initial rotary desiccant dryer (22) arranged as detailed herein. The variant system of the invention, however, will be less efficient than the preferred systems (30,40,50) of the invention detailed herein.

In an embodiment of the invention, the 3-rotor drying system (40b) further comprises at least one filter (41-43) arranged on the common intake-air flow path (6,7) for removing airborne particles from the intake-air. In the exemplary and preferred embodiment (40b) of the invention detailed in Figure 4B, the drying system (40b) of the invention comprises at least three filters (41-43), each respective filter arranged downstream from a preceding respective rotary desiccant dryer (2,21,22) in ascending order of filter class. In general, it is considered that it is within the skills of the person in the art to provide filtered product-air to a location of use (4) in response to a given technical specification. In a particularly preferred embodiment (40b), filter 3 (43) is a class F6 filter, filter 2 (42) is a filter selected from filter classes F6 to F9, and filter 1 (41) is a class F9 filter. In embodiments of the present drying systems (40b) for locations of use (4) requiring particularly low particle classes, a HEPA-filter is arranged downstream from filter 1 (41).

In an embodiment of the invention, the 3-rotor drying system (50) further comprises a cooler (32) arranged on the product-air flow path (7) prior to the first rotary desiccant dryer (2).

In an embodiment of the invention, the 3-rotor drying system (50a) further comprises an inter-heater (51) arranged on the product-air flow path (7) downstream (7b) of the first rotary desiccant dryer (2) (cf. Figure 5A). In another embodiment of the invention, the 3-rotor drying system (50a) further comprises a cooler (31) arranged on the product-air flow path (7) downstream (7b) of the first rotary desiccant dryer (2) (cf. Figure 5B). Thereby, and in accordance with the prior art, the product-air supplied to the location of use (4) can be air-conditioned prior to use, which is particularly suitable for use of the product-air in building spaces and rooms, such as clean rooms.

In accordance with current standards for rotary desiccant dryers of the art, the desiccants comprised in the desiccant wheels can be silica gels, zeolites, activated alumina or likes, or any combinations thereof. Preferred, the rotary desiccant dryers (2,21,22) for use with the invention comprise desiccants selected from silica gels, zeolites or combinations thereof, and particularly preferred are silica gels. Calculations presented herein below are based on rotary desiccant wheels comprising silica gels.

The intake-air can be ambient air; however, it is preferable that the intake-air is pretreated ambient air, which has been pretreated to remove e.g. particles of dust, microbial or bacteriological contaminants etc. In some embodiments of the present invention, the drying systems (30,40,50) of the invention may comprise means for pretreating air to provide intake-air arranged on the intake-air flow path (6) prior to the initial rotary desiccant dryer (22).

EXAMPLES

For documenting the performance of the drying system (30) of the invention in its broadest aspect, we have simulated the overall performance of the present drying system (30) with 1 1-rotor and 2-rotor drying systems of the prior art, where in the simulations, the sizes of the rotors were kept constant between respective drying systems. Likewise, the intake-air volume flow and the target product-air volume flow were kept constant.

The simulations were based on calculations of dynamic mass and heat transfer between air and the rotor material, where in the calculations desiccant sorption isotherms, dynamic heat and mass transfer are taken into account as well as experimentally determined parameters and input data proprietary to the simulation tool producers. For consistency, we tested on two different simulation tools from two different producers. The simulations were considered convergent, if the resulting data after 6-8 iterations did not diverge more than the one standard variation between two consecutive iterations.

The results of the simulations are shown in Example 1 and Figure 6 and in Example 2 and Table 1 below.

Example 1:

Using standard intake-air specifications for 1-rotor and 2-rotor systems of 4300 m^3/h, 10°C @ 90% RH (7.6 g/kg H_2O) for exchanging 1300 m^3/h of air to a semi-closed loop circulating 30,000 m^3/h, wherein the product-air has a very low dew point of -68°C after passage of the last rotary dryer (2), the simulation of the drying system (30) of the present invention in its broadest aspect, shows (cf. Figure 6) that it is not necessary to heat beyond 73°C nor to cool below 10°C at any point in the drying system (30). In fact, the air leaving the cooler (33) is not heated by more than 1.1°C in the further two (2,21) rotary dryers and hence is suitable for air-conditioning of a location of use (4), when the location of use (4) is e.g. a clean room or a building space for lithium battery production.

It is a particular advantage of the drying systems (30,40,50) of the present invention that only low temperature heating is required for regenerating the first rotary dryer (2), seldom above 75°C. Thereby the system can utilize sources of low heat for regeneration, such as heated water from other local heating, solar energy, district heating etc.

A further and significant, advantage of the increased air temperature of the intake-air is that problems of water condensation, heat/cold loss, thermal bridges to the exterior are significantly minimized by being able to operate the drying systems (30,40,50) of the invention at about room temperature. This further provides for savings in the construction of the cabinet for the drying systems, as less insulation will be needed for maintaining desired operation temperatures.

Example 2 – Comparative

Using the above specifications, but using a more realistic production flow rate of air of 48,000 m^3/h as entry air, a comparative study between a 1-rotor drying system (10a), a 2-rotor drying system (20a) and the drying system of the present invention in its broadest aspect (30). The results are reported below in Table 1:

As can be observed from the comparative data, the 3-rotor solution of the invention is more cost efficient over the 1-rotor already after two years, and more cost efficient over both the 1-rotor and the 2-rotor drying systems already after 3 years, while providing product-air having a lower dew point compared to the 1-rotor and 2-rotor drying systems by between 6-8°C.

This extra capacity with respect to dew point can be used, not just for minimizing quality problems of the product-air at the intended location of use (4) but also, if the intended location of use (4) is a production space for lithium

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batteries, provide increase mitigation of explosion risks at the production space for the batteries. As discussed above, it can also be used for reducing the total flow volume of air through the drying systems of the invention.

Table 1: Comparative Results

System	1-rotor	2-rotor	3-rotor
Air flow	48,000 m³/h	48,000 m³/h	48,000 m³/h
Dew point of product-air	-55 °C	-57 °C	-63 °C
Energy consumption	113 kW	80 kW	37 kW
Amperes	164 A	116 A	54 A
Cost to install (index)	100	109.6	112.5
Cost after 1 year (index)	270.5	288.1	318.0
Cost after 2 year (index)	341.2	338.0	341.3
Cost after 3 year (index)	411.8	388.0	**364.4**

CLOSING COMMENTS

The term "comprising" as used in the claims does not exclude other elements or steps. The term "a" or "an" as used in the claims does not exclude a plurality. Although the present invention has been described in detail for purpose of illustration, it is understood that such detail is solely for that purpose, and variations can be made therein by those skilled in the art without departing from the scope of the invention.

CLAIMS

1. A 3-rotor drying system (30,40,50) for producing technical air having a very low dew point comprising three rotary desiccant dryers (2,21,22), each rotary desiccant dryer (2,21,22) comprising a drying sector (2a,21a,22a) and a regeneration sector (2b,21b,22b), the rotary desiccant dryers (2,21,22) arranged in sequence and sharing a common regeneration-air flow path (9) for passing regeneration-air through the respective regeneration sectors (2a,21b,22b) of the rotary desiccant dryers (2,21,22) and a common intake-air flow path (6,7) for passing intake-air through the respective drying sectors (2a,21a,22a) of the rotary desiccant dryers (2,21,22) for dehumidifying the intake-air to product-air having a very low dew point;
   - wherein a mixing point (1) for return-air is arranged on the common intake-air flow path (6,7) between a first (2) and a second (21) rotary desiccant dryer, thereby defining
     - a product-air flow path (7) for providing dehumidified product-air having a very low dew point to a location of use (4) downstream from the mixing point (1) for return-air, and where on the product-air flow path (7) the drying sector (2a) of the first rotary desiccant dryer (2) is arranged, and
     - an intake-air flow path (6) upstream from the mixing point (1) for return-air for providing intake-air to the mixing point (1), and where on the intake-air flow path (6) the drying sector (21a) of the second rotary desiccant dryer (21) is arranged;
   - wherein a splitting point (12) for intake-air is arranged between the mixing point (1) for return-air and the second rotary desiccant dryer (21) on a first section (6a) of the intake-air flow path (6), from

which splitting point (12) intake-air is diverged as regeneration-air along the regeneration flow path (9);

- wherein a purge sector (2c) and the regeneration sector (2b) of the first rotary desiccant dryer (2) are arranged on the regeneration flow path (9) such that the regeneration-air via an air flow path (9e) first traverses the purge sector (2c) and subsequently the regeneration sector (2b) via a heater (5) arranged on the regeneration flow path (9) between (9b) the purge sector (2c) and the regeneration sector (2b);
- wherein the regeneration sector (21b) of the second (21) rotary desiccant dryer is arranged subsequent to the regeneration sector (2) of the first dryer (2) on the regeneration flow path (9), and
- where upstream on the intake-air (6) flow path and downstream on the regeneration flow path (9) from the second rotary desiccant dryer (21) is arranged an initial rotary desiccant dryer (22), where on the regeneration flow path (9) between (9d) the second (21) and the initial (22) rotary desiccant dryer is arranged an inter-heater (53) for inter-heating regeneration-air prior to traversing the regeneration sector (22b) of the initial rotary desiccant dryer (22);

the 3-rotor drying system (30) further comprising a return-air flow path (8) for providing return-air from a location of use (4) to the mixing point (1) for return air and one or more air moving means.

2. A 3-rotor drying system (30) according to claim 1 further comprising a cooler (33) arranged on the intake-air flow path (6) between (6b) the second (21) and the initial (22) rotary desiccant dryers.

3. A 3-rotor drying system (30) according to either claim 1 or claim 2, further comprising a splitting point (11) for mixed-air arranged between the mixing point (1) for return-air and the first rotary desiccant dryer (2) on a first section (7a) of the product-air flow path (7) upstream from the first rotary desiccant dryer (2), from which splitting point (11) mixed-air is diverged as regeneration-air along the regeneration flow path (9) via a mixed-air flow path (9a).

4. A 3-rotor drying system (40a) according to any of the claims 1 to 3, further comprising an inter-heater (52) for inter-heating regeneration-air prior to traversing the regeneration sector (21b) of the second rotary desiccant dryer (21) arranged on the regeneration flow path (9) between (9c) the first (2) and the second (21) rotary desiccant dryers.

5. A 3-rotor drying system (40b) according to any of the preceding claims, further comprising at least one filter (41-43) arranged on the common intake-air flow path (6,7) for removing airborne particles from the intake-air.

6. A 3-rotor drying system (50) according to any of the preceding claims, further comprising a cooler (32) arranged on the product-air flow path (7) prior to the first rotary desiccant dryer (2).

7. A 3-rotor drying system (50a) according to any of the preceding claims, further comprising an inter-heater (51) arranged on the product-air flow path (7) downstream (7b) of the first rotary desiccant dryer (2).

8. A 3-rotor drying system (50b) according to any of the preceding claims, further comprising a cooler (31) arranged on the product-air flow path (7) downstream (7b) of the first rotary desiccant dryer (2).

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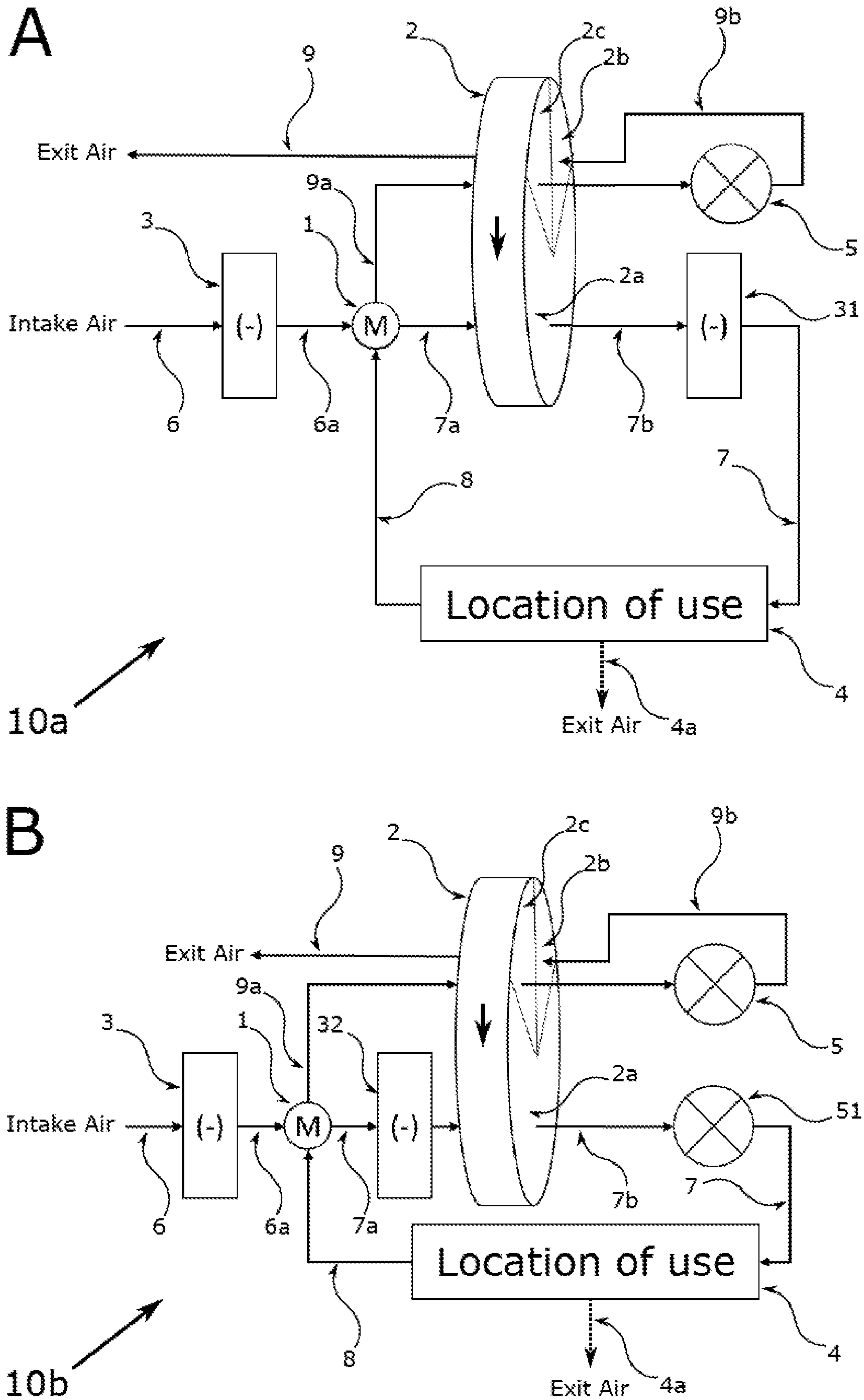

Prior Art

Figure 1

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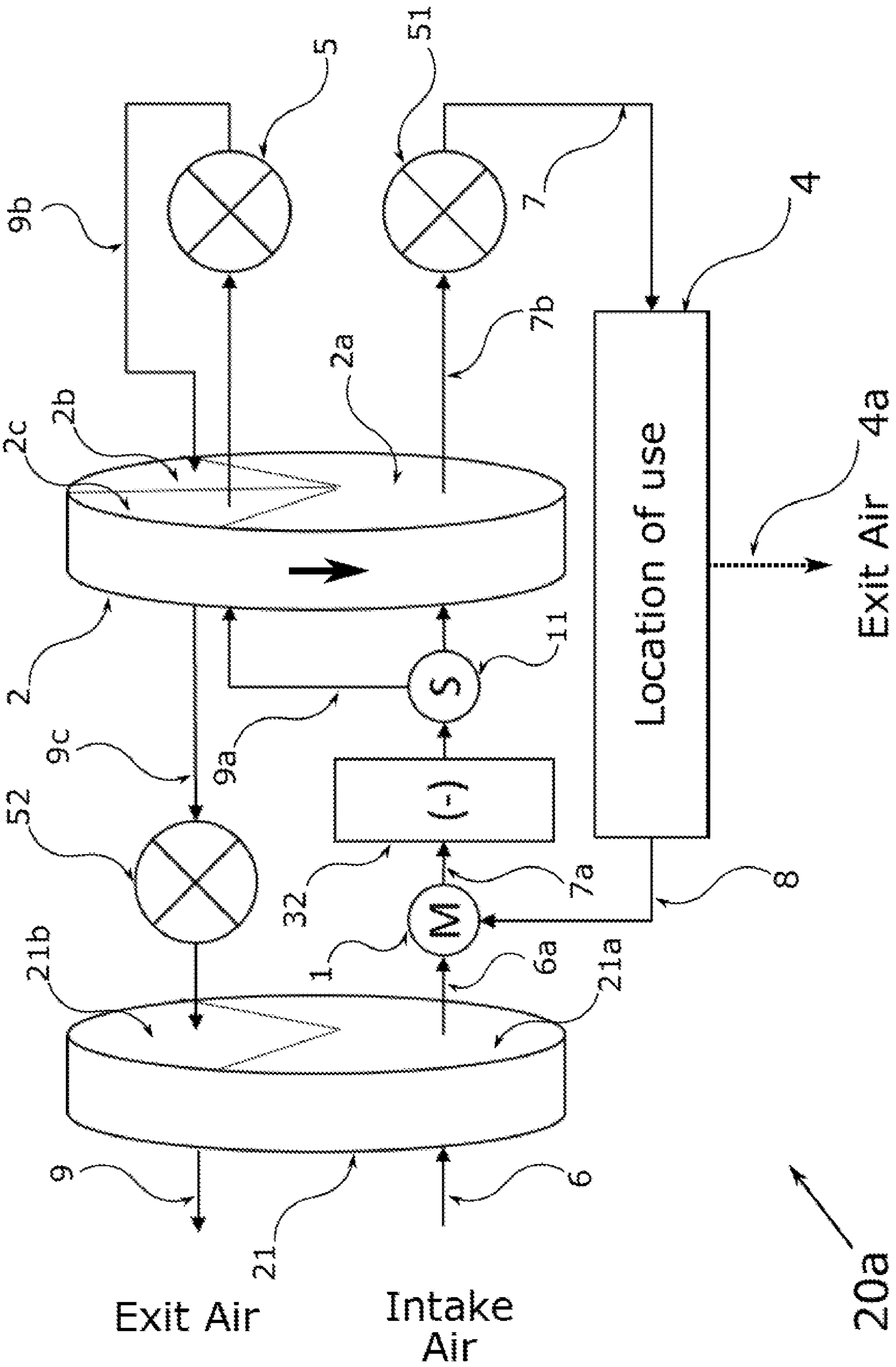
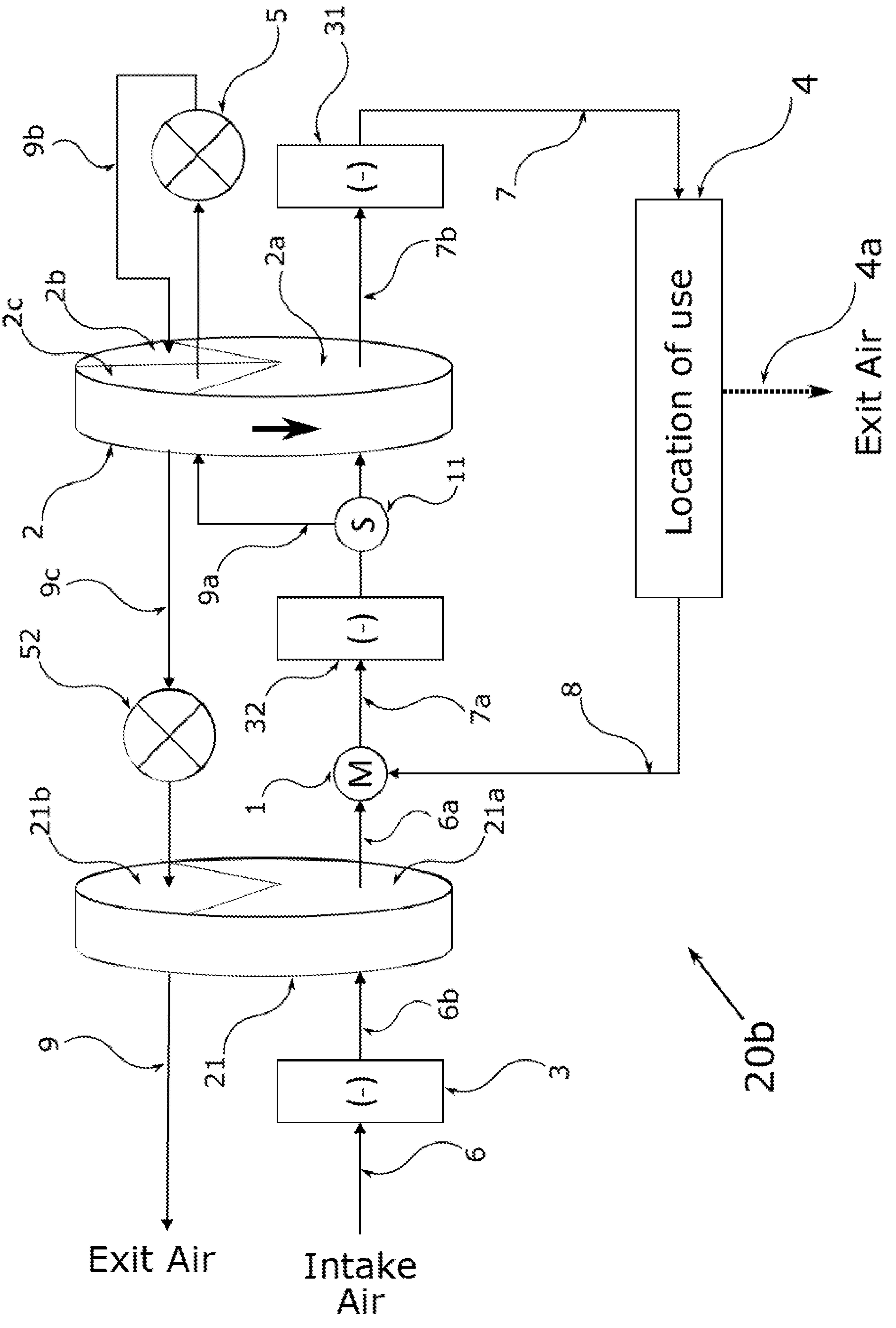


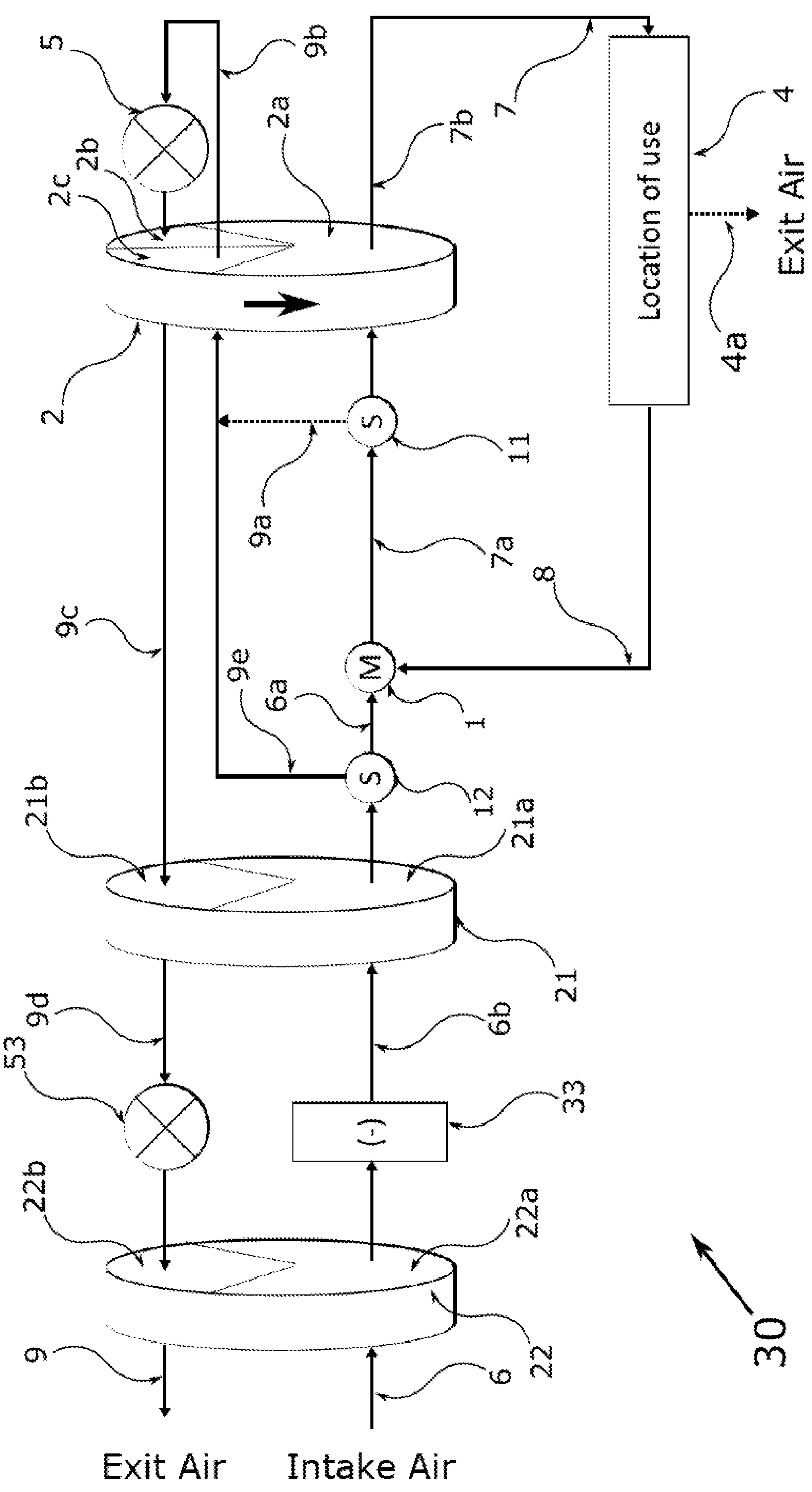
Prior Art

Figure 2A



Prior Art

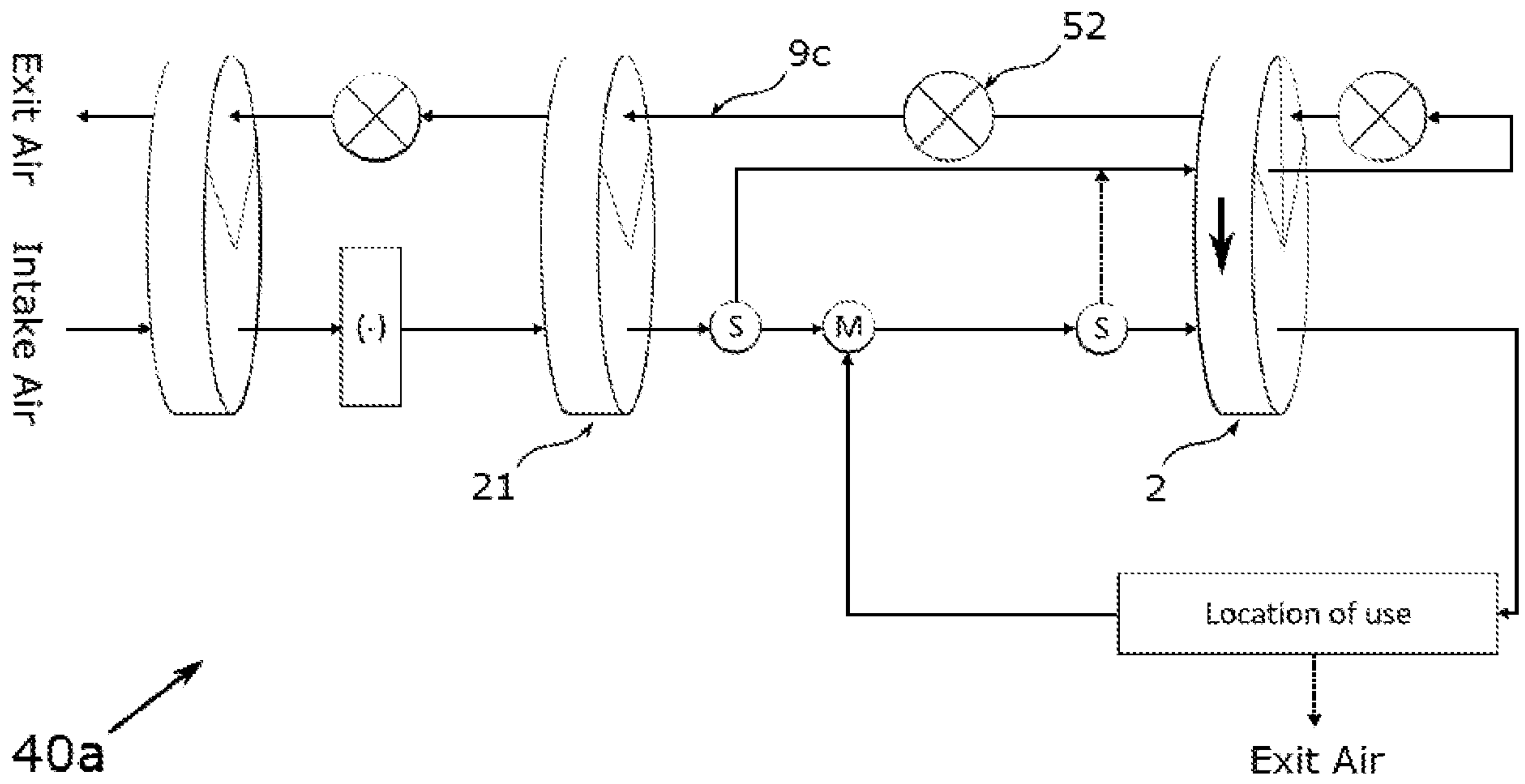
Figure 2B



Location of use
Exit Air
Exit Air
Intake Air
M
S
S
(-)
1
2
2a
2b
2c
4
4a
5
6
6a
6b
7
7a
7b
8
9
9a
9b
9c
9d
9e
11
12
21
21a
21b
22
22a
22b
30
33
53

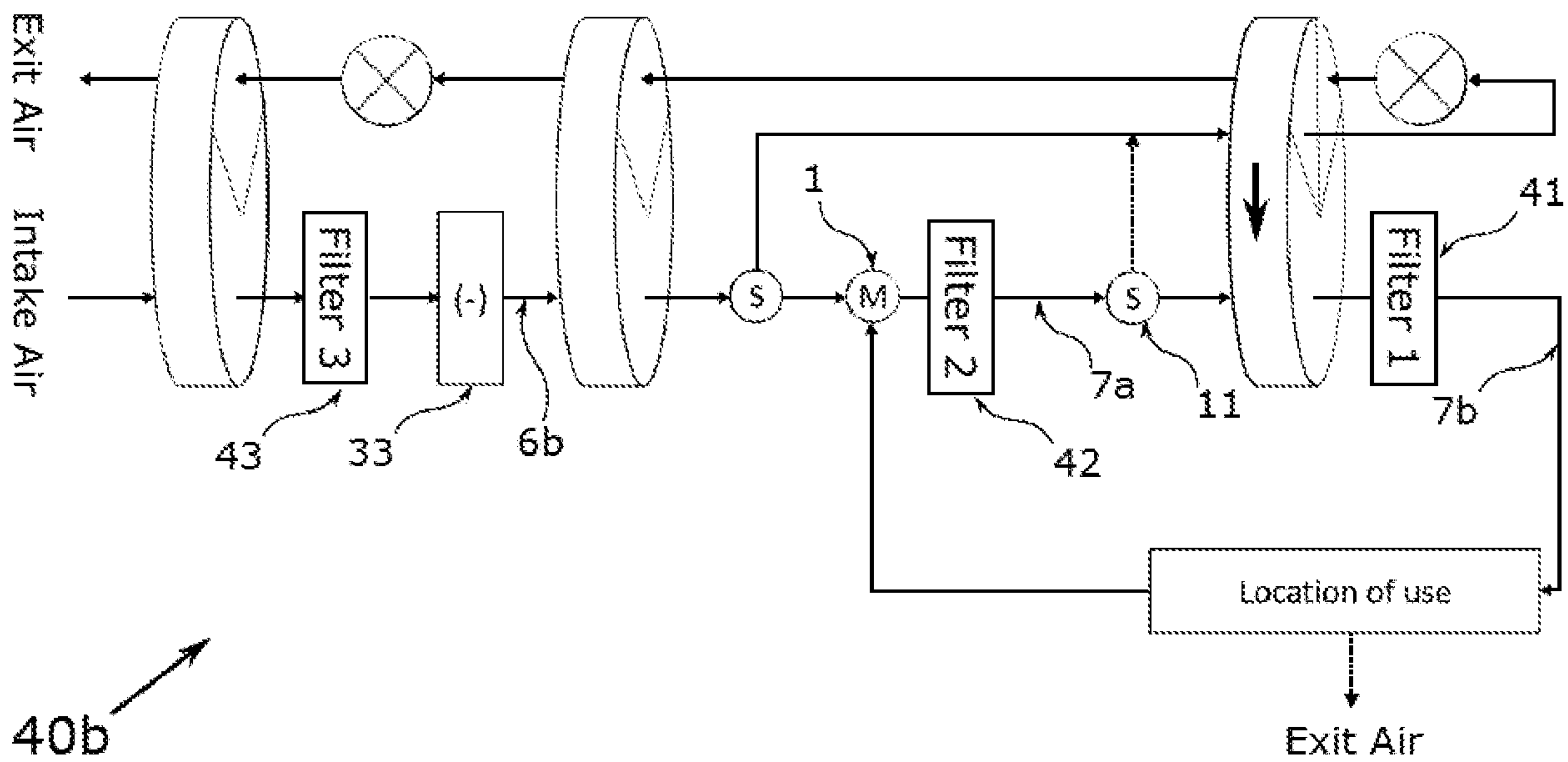
Figure 3

A



40a

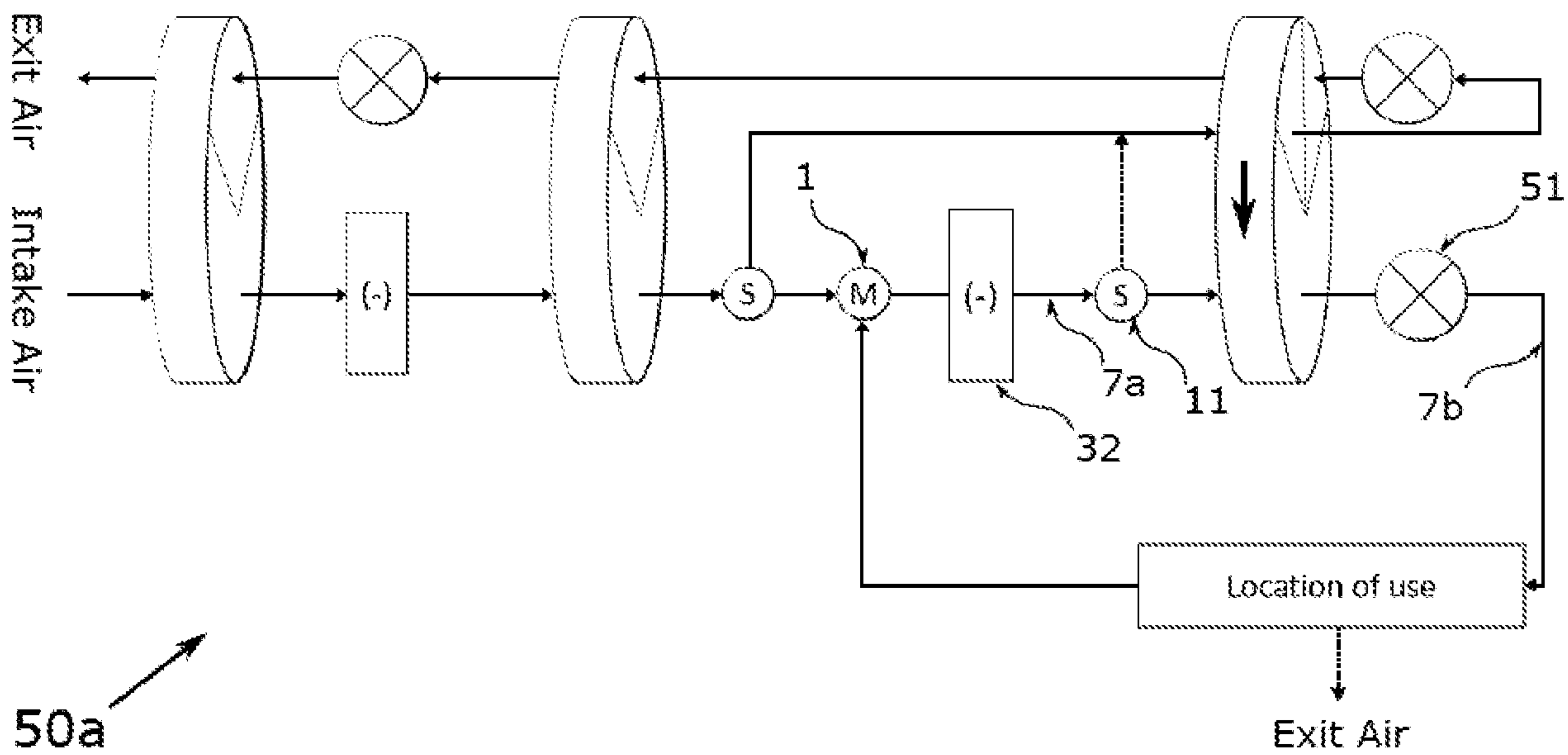
B



40b

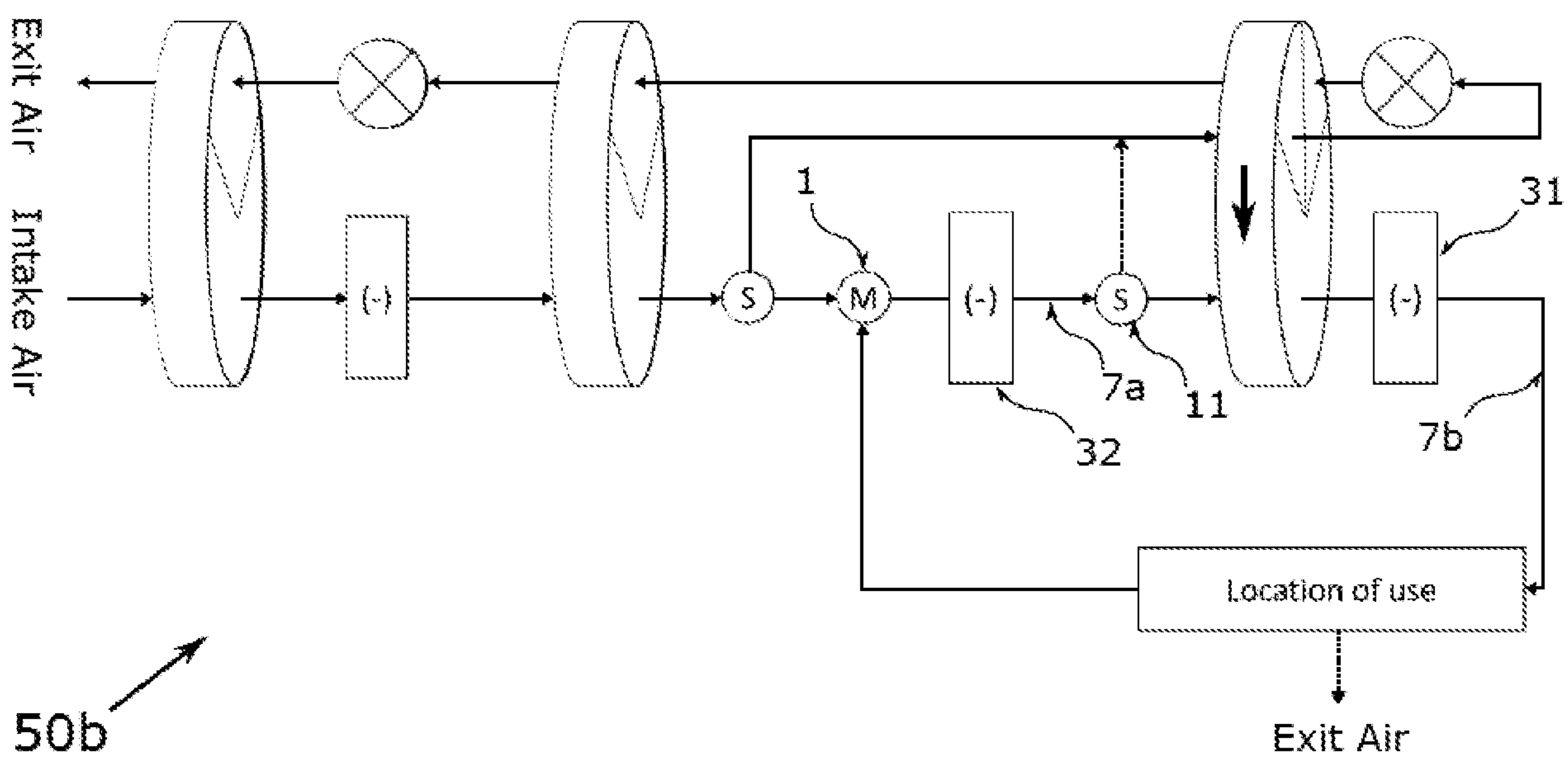
Figure 4

A



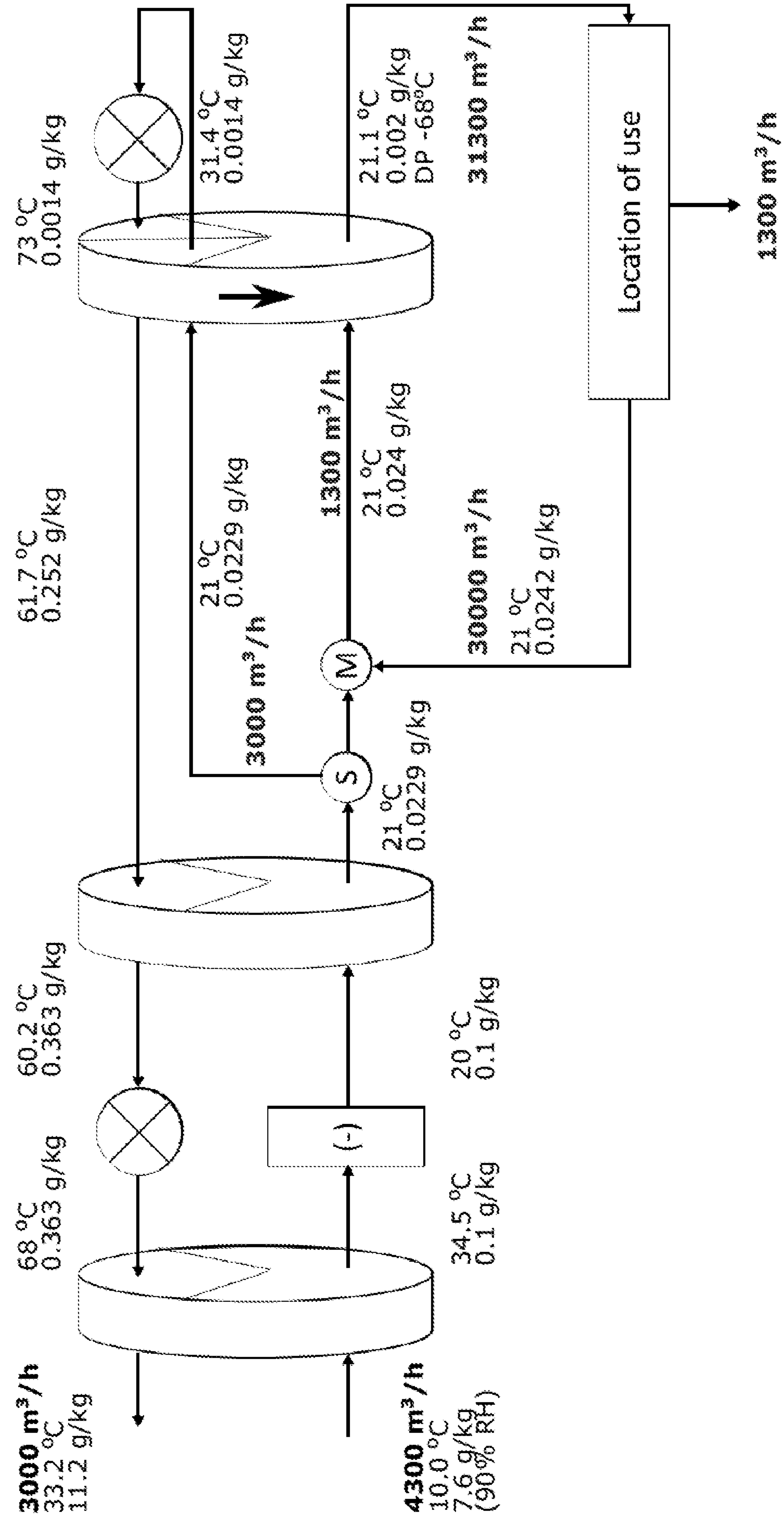
50a

B



50b

Figure 5



73 °C
0.0014 g/kg
31.4 °C
0.0014 g/kg
21.1 °C
0.002 g/kg
DP -68°C
31300 m^3/h
Location of use
1300 m^3/h
61.7 °C
0.252 g/kg
21 °C
0.0229 g/kg
3000 m^3/h
1300 m^3/h
21 °C
0.024 g/kg
30000 m^3/h
21 °C
0.0242 g/kg
M
S
21 °C
0.0229 g/kg
60.2 °C
0.363 g/kg
20 °C
0.1 g/kg
(-)
68 °C
0.363 g/kg
34.5 °C
0.1 g/kg
3000 m^3/h
33.2 °C
11.2 g/kg
4300 m^3/h
10.0 °C
7.6 g/kg
(90% RH)

Figure 6

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SEARCH REPORT - PATENT	Application No. PA 2019 70157

1. ☐ Certain claims were found unsearchable (See Box No. I).

2. ☐ Unity of invention is lacking prior to search (See Box No. II).

A. CLASSIFICATION OF SUBJECT MATTER

F24F 3/14; B01D 53/06; B01D 53/26 (All version 2006.01)

According to International Patent Classification (IPC)

B. FIELDS SEARCHED

PCT-minimum documentation searched (classification system followed by classification symbols)

IPC/CPC: B01D, F24F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

DK, NO, SE, FI: IPC-classes as above.

Electronic database consulted during the search (name of database and, where practicable, search terms used)

EPODOC, WPI, FULL TEXT: ENGLISH

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant for claim No.
X Y	JP 2001038137 A (TAKASAGO THERMAL ENGINEERING) 2001.02.13 See figures 1 and 2; abstract; paragraphs [0007], [0008], [0012], [0017]-[0019], [0022], [0023], [0025], [0027], [0028], [0030], [0038]	5, 7, 8 1-4, 6
Y, D	WO 2011/161693 A1 (BRY AIR ASIA PVT LTD) 2011.12.29 See figure 6; page 5, line 33- page 6, line 9	1-4, 6
X Y	JP H11188224 A (TAKASAGO THERMAL ENGINEERING) 1999.07.13 See figures	5, 7, 8 1-4, 6
X Y	JP 2000300935 A (TAKASAGO THERMAL ENGINEERING) 2000.10.31 See figures	5,7,8 1-4,6

☒ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" Document defining the general state of the art which is not considered to be of particular relevance.

"D" Document cited in the application.

"E" Earlier application or patent but published on or after the filing date.

"L" Document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified).

"O" Document referring to an oral disclosure, use, exhibition or other means.

"P" Document published prior to the filing date but later than the priority date claimed.

"T" Document not in conflict with the application but cited to understand the principle or theory underlying the invention.

"X" Document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone.

"Y" Document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" Document member of the same patent family.

Danish Patent and Trademark Office
Helgeshøj Allé 81
DK-2630 Taastrup
Denmark

Telephone No. +45 4350 8000
Facsimile No. +45 4350 8001

Date of completion of the search report

05 August 2019

Authorized officer
Morten Munch Nielsen
Telephone No. +45 43 50 81 00

SEARCH REPORT - PATENT		Application No. PA 2019 70157
C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant for claim No.
A	KR 20110000211 A (PARK, S. T.) 2011.01.03 See abstract; figures 1, 3, 5, 7, and 9; claims 1, 3	5
A	JP 2011064439 A (SHINKO KOGYO KK) 2011.03.31	5

SEARCH REPORT - PATENT	Application No. PA 2019 70157

Box No. I Observations where certain claims were found unsearchable

This search report has not been established in respect of certain claims for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched, namely:

2. ☐ Claims Nos.:
because they relate to parts of the patent application that do not comply with the prescribed requirements to such an extent that no meaningful search can be carried out, specifically:

3. ☐ Claims Nos.:
because of other matters.

Box No. II Observations where unity of invention is lacking prior to the search

The Danish Patent and Trademark Office found multiple inventions in this patent application, as follows:

SEARCH REPORT - PATENT	Application No. PA 2019 70157

SUPPLEMENTAL BOX

Continuation of Box [.]