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Separation Device Comprising a Magnetic Separation Unit and Fluid Separation Method

Abstract

A fluid separation unit that comprises a housing having an inlet port for receiving a fluid, an outlet port for discharging fluid and a conduit extending between the inlet port and the outlet port is disclosed. The fluid separation unit comprises at least one permanent magnet arranged to attract magnetic or magnetizable particles in the fluid. The at least one permanent magnet is at least partly covered by a magnetizable covering structure. A flow entrainment section is arranged inside the housing. The flow entrainment section is arranged and configured to reduce the velocity of a portion of the fluid by at least 50% and recirculate fluid inside the conduit.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This application is a continuation under 35 U.S.C. 111 of International Patent Application No. PCT/EP 2023/076046, filed Sep. 21, 2023, which claims the benefit of and priority to Danish Application No. PA 2022 00981, filed Oct. 28, 2022, each of which is hereby incorporated by reference in its entirety.

FIELD OF INVENTION
[0002] The present invention relates to a fluid separation unit comprising a magnetic filtering unit that is capable of removing ferromagnetic particles from a fluid. The present invention also relates to a fluid filtration method for removing ferromagnetic particles from a fluid.
BACKGROUND
[0003] Humans are exposed to ferromagnetic particles in many places where they work and commute [Wang, J., Li, S., Li, H., Qian, X., Li, X., Liu, X., Lu, H., Wang, C. and Sun, Y., 2017. Trace metals and magnetic particles in PM2. 5: Magnetic identification and its implications. Scientific reports, 7 (1), pp. 1-11.]. At high concentrations, ferromagnetic particles are found in metro and train stations [N. Kappelt, H. S. Russell, D. Fessa, O. Hertel and M. S. Johnson, Particulate Air Pollution in the Copenhagen Metro Part 1: Mass Concentrations and Ventilation, Environment International, 2022 and Smith, J. D., Barratt, B. M., Fuller, G. W., Kelly, F. J., Loxham, M., Nicolosi, E., Priestman, M., Tremper, A. H. and Green, D. C., 2020. PM2. 5 on the London Underground. Environment international, 1, p. 105188]. These particles are found in high concentrations in steel workshops and foundries as well.
[0004] Mechanical fibrous filters can remove particles, but the energy usage is high due to the high-pressure drop over the filter [S. Kwiatkowski, M. Polat, W. Yu and M. S. Johnson, Industrial Emissions Control Technologies: Introduction, In: Meyers R. (eds) Encyclopedia of Sustainability Science and Technology, Springer, New York, NY, 2019, https://doi.org/10.1007/978-1-4939-2493-6_1083-1.]. Mechanical filters remove particles by blocking the passing particles. Therefore, the fiber structure should be very tight to capture the particles following the airflow.
[0005] There have been some attempts to use magnetic fields to remove ferromagnetic particles. For example, environmental researchers sometimes quantify the fraction of airborne particulate matter that is attracted by magnetic fields [Castaneda-Miranda, A. G., Böhnel, H. N., Molina-Garza, R. S. and Chaparro, M. A., 2014. Magnetic evaluation of TSP-filters for air quality monitoring. Atmospheric environment, 96, pp. 163-174.]. While electrostatic precipitators based on static electrical charges and electrophoresis are known [S. Kwiatkowski, M. Polat, W. Yu and M. S. Johnson, Industrial Emissions Control Technologies: Introduction, In: Meyers R. (eds) Encyclopedia of Sustainability Science and Technology, Springer, New York, NY, 2019, https://doi.org/10.1007/978-1-4939-2493-6_1083-1], relatively little is known about using magnetophoresis as the basis of filtration. One of the problems of the existing solutions is that the magnetic fields do not effectively trap particles due to high-velocity particles, and the Clean Air Delivery Rate (CADR) of such systems is low considering the energy input.
[0006] JP 2019209298 A discloses an air filter configured to adsorb and remove magnetic dust such as iron powder. The air filter is arranged in an air intake port of electric equipment. The air filter comprises permanent magnets arranged oppositely to sandwich air flow passing through the air intake port, and a magnetic filter arranged between the permanent magnets. The magnetic filter is made of thin wires made of magnetic materials. This filter tends to clog as magnetic or

magnetizable particles are caught by the magnetic filter. Hereby, an increased pressure difference is required to force air through the magnetic filter and thus the efficiency of the filter is significantly reduced.

[0007] US20140367340A1 discloses a magnetic particle separator suitable for separating magnetic and non-magnetic particles from a thermal fluid flowing in a heating system. The magnetic particle separator comprises a hollow body configured with an upper particle separation chamber and for circulation of the thermal fluid between an inlet and an outlet port. A quieting chamber exists beneath the particle separation chamber for accumulation of the particles separated from the fluid. An annular support element for permanent magnets is removably fastened outside the quieting chamber of the separator. The energy efficiency of this filter, however, is poor. Accordingly, it would be desirable to have an alternative to this solution.

[0008] U.S. Pat. No. 4,529,517 A discloses an arrangement for cleaning a liquid containing particles, particularly for removing particles or objects such as magnetite, iron shavings, rust, etc., which can be attracted by magnetic fields and are contained in the liquid. The liquid is guided to traverse a magnetic field produced by a magnet placed separate from the liquid. At least one body which distributes the magnetic field in the liquid is provided in or near the flow path of the liquid. This body is designed as a removable plug combined with an aperture which is formed in the liquid container, and a further body which distributes the magnetic field is orientated on the outside of the liquid container. This solution is, however, neither practical nor efficient with respect to energy consumption.

[0009] U.S. Pat. No. 2,798,611 A discloses a magnetic separator comprising a liquid-tight housing adapted to be coupled into a fluid conduit, said housing having a fluid inlet and a fluid outlet passage extending in the same direction within the upper portion thereof, one said passage having a terminal end concentrically arranged within, but at a level above the level of the terminal end of the other passage and magnetic means within said housing. The magnetic means including an upwardly directed magnetic face at a spaced uniform distance opposite to and below the level of the terminal end of the encircled passage, said upwardly directed magnetic face extending transversely of the terminal end portion of the encircling passage over an area larger than the area of the terminal end of the encircled passage and adapted to reverse a stream issuing therefrom annularly around said stream in cooperation with said encircling passage. This solution is, however, neither practical nor efficient with respect to energy consumption.

[0010] Accordingly, there is a need for an apparatus which is to provide an alternative fluid separation unit while aiming at reducing or even eliminating the above-mentioned disadvantages of the prior art, and a method for using the apparatus.

BRIEF DESCRIPTION

[0011] A fluid separation unit according to the present disclosure is a fluid separation unit comprising: [0012] a housing having an inlet port for receiving a fluid, an outlet port for discharging fluid and a conduit extending between the inlet port and the outlet port; [0013] at least one permanent magnet arranged to attract magnetic or magnetizable particles in the fluid, wherein the at least one permanent magnet is one of a plurality of permanent magnets of a magnetic assembly and is at least partly covered by a magnetizable covering structure, wherein a flow entrainment section is arranged inside the housing, wherein in the flow entrainment section a magnetic assembly is provided, wherein the magnetic assembly comprises a plurality of parallel rod-shaped permanent magnets that are covered by a magnetizable metal section, [0014] the conduit comprises a main channel extending along the longitudinal axis of the housing, [0015] the housing is configured so that most of the fluid entering the main channel flows along a straight path from the inlet port to the outlet port, [0016] the outlet port has a larger width D.sub.4 than the width D.sub.2 of the inlet port, the flow entrainment section comprises an inner wall and an outer wall, wherein the inner wall is a converging diverging-nozzle configured to allow the fluid to pass through and to create, together with the outer wall, a bypass channel, [0017] the flow entrainment section is configured so that a portion of the fluid is sucked into the bypass channel and so that said portion of the fluid is recirculated into the main channel of the conduit after it has passed through the magnetic assembly.

[0018] Hereby, it is possible to provide a fluid separation unit that does not clog as easily as the prior art fluid separation units. Moreover, it is possible to provide a fluid separation unit having an improved efficiency.

[0019] The fluid separation unit is configured to filter a flow of a liquid or a gas or a combination thereof.

[0020] The housing may be made of various materials including plastic, wood, metal and ceramic materials. The housing comprises an inlet port for receiving a fluid, an outlet port for discharging fluid and a conduit extending between the inlet port and the outlet port.

[0021] At least one permanent magnet of the plurality of permanents magnets is arranged to attract magnetic or magnetizable particles in the fluid.

[0022] The at least one permanent magnet of the plurality of permanents magnets is at least partly covered by a magnetizable covering structure. In an embodiment, the magnetizable covering structure is made of steel. In an embodiment, the magnetizable covering structure is made of stainless steel.

[0023] In an embodiment, the flow entrainment section is arranged and configured to reduce the velocity of a portion the fluid by at least 50% and recirculate that portion of the fluid inside the conduit.

[0024] In an embodiment, the flow entrainment section is arranged and configured to reduce the velocity of a portion the fluid by at least 60%.

[0025] In an embodiment, the flow entrainment section is arranged and configured to reduce the velocity of a portion the fluid by at least 70%.

[0026] In an embodiment, the flow entrainment section is arranged and configured to reduce the velocity of a portion the fluid by at least 80%.

[0027] In an embodiment, the flow entrainment section is arranged and configured to reduce the velocity of a portion the fluid by at least 85%.

[0028] In an embodiment, the flow entrainment section is arranged and configured to reduce the velocity of a portion the fluid by at least 90%.

[0029] The magnetic or magnetizable particles may include ferromagnetic particles.

[0030] The current devices and methods use the least amount of energy to remove ferromagnetic particles compared to the existing technologies and, therefore, can be applied in spaces such as train/metro stations and steel workshops as an energy-efficient solution.

[0031] In an embodiment, the at least one permanent magnet extends (basically) along the direction of the flow of the inside the flow entrainment section. Hereby, the time for attracting and catching the magnetic or magnetizable particles can be maximized.

[0032] In an embodiment, the length of the at least one permanent magnet is at least 2 cm.

[0033] In an embodiment, the length of the at least one permanent magnet is at least 2.5 cm.

[0034] In an embodiment, the length of the at least one permanent magnet is at least 3 cm.

[0035] In an embodiment, the length of the at least one permanent magnet is at least 3.5 cm.

[0036] In an embodiment, the length of the at least one permanent magnet is at least 4 cm.

[0037] In an embodiment, the length of the at least one permanent magnet is at least 5 cm.

[0038] In an embodiment, the housing comprises: [0039] a first part constituting an arched portion; [0040] a second part constituting an arched portion and a straight portion; [0041] a cylindric front portion comprising the inlet port; and [0042] a conical outlet portion comprising the outlet port, wherein the first part is sandwiched between the front portion and the second part and the second part is sandwiched between the first part and the outlet portion, wherein the width of the first part is larger than the width of the second part.

[0043] In an embodiment, the at least one permanent magnet is arranged in the second part.

[0044] In an embodiment, the width of the front portion is smaller than the width of the outlet portion.
[0045] In an embodiment, the flow entrainment section is designed as a ring extending in the conduit along the inner wall of a portion of the first part and the second part.
[0046] In an embodiment, the distal portion of the low velocity reducing section comprises a conical inner wall.
[0047] In an embodiment, the volume of the flow entrainment section is less than 1000 ml.
[0048] In an embodiment, the volume of the flow entrainment section is less than 900 ml.
[0049] In an embodiment, the volume of the flow entrainment section is less than 800 ml.
[0050] In an embodiment, the volume of the flow entrainment section is less than 700 ml.
[0051] In an embodiment, the volume of the flow entrainment section is less than 600 ml.
[0052] In an embodiment, the volume of the flow entrainment section is less than 500 ml.
[0053] Since the magnetic force decreases by the cube of the distance, it may be an advantage to keep the ducts through which fluid passes in the magnetizable structure and/or magnetizable portion small. Accordingly, it may be an advantage to keep the volume of the flow entrainment section below a predefined level e.g. 1000 ml.
[0054] In an embodiment, the proximal portion of the low velocity reducing section comprises an inwardly arced inner wall.
[0055] In an embodiment, the proximal portion of the low velocity reducing section comprises an inwardly arced and concave inner wall.
[0056] In an embodiment, the magnetic assembly comprises a plurality of ducts arranged along the periphery of a portion of the housing, wherein each duct comprises one or more rod-shaped permanent magnets extending along the longitudinal axis of the duct, wherein each permanent magnet is covered by a magnetizable covering structure.
[0057] In an embodiment, a plurality of parallel rod-shaped permanent magnets are covered by a magnetizable metal section.
[0058] A method according to the present disclosure removes magnetic or magnetizable particles using a fluid separation unit disclosed herein. The method comprises the step of reducing the velocity of a portion the fluid and recirculating that portion of the fluid inside the conduit, wherein in the flow entrainment section a magnetic assembly is provided, wherein the magnetic assembly comprises a plurality of parallel rod-shaped permanent magnets that are covered by a magnetizable metal section.
[0059] Hereby, it is possible to provide a method for removing magnetic or magnetizable particles in an improved manner. The methods can significantly increase the time before the fluid separation unit clogs. Moreover, the method has an improved performance (a lower pressure difference is required to force a fluid through the fluid separation unit).
[0060] In an embodiment, the at least one permanent magnet extends basically along the direction of the flow inside the flow entrainment section.
[0061] In an embodiment, the at least one permanent magnet extends along the direction of the flow inside the flow entrainment section.
[0062] In an embodiment, the length of the at least one permanent magnet is at least 2 cm.
[0063] In an embodiment, the fluid separation unit comprises a flow entrainment section comprising a magnetic assembly that comprises a plurality of parallel rod-shaped permanent magnets that are covered by a magnetizable metal section.
[0064] In an embodiment, the method comprises the step of reducing the velocity of a portion the fluid by at least 50% and recirculating that portion of the fluid inside the conduit.
[0065] In an embodiment, the distal portion of the low velocity reducing section comprises a conical inner wall.
[0066] In an embodiment, the volume of the flow entrainment section is less than 1000 ml.
[0067] In an embodiment, the proximal portion of the low velocity reducing section comprises an

inwardly arced (concave) inner wall.
[0068] In an embodiment, the magnetic assembly comprises a plurality of ducts arranged along the periphery of a portion of the housing, wherein each duct comprises one or more rod-shaped permanent magnets extending along the longitudinal axis of the duct, wherein each permanent magnet is covered by a magnetizable covering structure.
[0069] In an embodiment, a plurality of parallel rod-shaped permanent magnets are covered by a magnetizable metal section.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0070] The devices and methods will become more fully understood from the detailed description given herein below. The accompanying drawings are given by way of illustration only, and thus, they are not limitative of the present devices and methods. In the accompanying drawings:
[0071] FIG. **1**A shows a cross-sectional side view of a fluid separation unit according to an embodiment;
[0072] FIG. **1**B shows a side view of the fluid separation unit shown in FIG. **1**A;
[0073] FIG. **2** shows a prior art air filter device for removing ferromagnetic particles from air;
[0074] FIG. **3** shows a magnetic assembly of a fluid separation unit according to an embodiment;
[0075] FIG. **4** shows a cross-sectional side view of a magnetic assembly of a fluid separation unit according to an embodiment;
[0076] FIG. **5**A shows a front view of a magnetic assembly of a fluid separation unit according to an embodiment;
[0077] FIG. **5**B shows a permanent magnet and the surrounding magnetizable structure of the magnetic assembly shown in FIG. **5**A;
[0078] FIG. **6**A shows a front view of a magnetic assembly of a fluid separation unit according to an embodiment;
[0079] FIG. **6**B shows a permanent magnet and the surrounding magnetizable structure of the magnetic assembly shown in FIG. **6**A;
[0080] FIG. **7**A shows a front view of a magnetic assembly of a fluid separation unit according to an embodiment;
[0081] FIG. **7**B shows a plurality of permanent magnets and the surrounding magnetizable structures of the magnetic assembly shown in FIG. **7**A;
[0082] FIG. **8**A shows a perspective side view of a fluid separation unit according to an embodiment; and
[0083] FIG. **8**B shows a perspective side view of a fluid separation unit corresponding to the one shown in FIGS. **1**A and **1***n* FIG. **1**B.
DETAILED DESCRIPTION
[0084] Referring now in detail to the drawings for the purpose of illustrating embodiments of the present devices and methods, a fluid separation unit **2** is illustrated in FIG. **1**.
[0085] FIG. **1** illustrates a cross-sectional side view of a fluid separation unit **2** according to an embodiment. The fluid separation unit **2** comprises a housing **4** having an inlet port **6** for receiving a fluid **8**, an outlet **30** comprising an outlet port **12** for discharging fluid **8** and a conduit **10** extending between the inlet port **6** and the outlet port **12**.
[0086] In an embodiment, the fluid separation unit **2** is configured to filter air. In an embodiment, the fluid separation unit **2** is configured to filter a liquid (e.g. water).
[0087] The fluid separation unit **2** comprises a plurality of permanent magnets (not shown) arranged to attract magnetic or magnetizable particles **16** in the fluid **8**. The permanent magnets are at least partly covered by a magnetizable covering structure **18**.

[0088] The fluid separation unit **2** comprises a flow entrainment section **20** arranged inside the housing **4**. The flow entrainment section **20** is arranged and configured to reduce the velocity of a portion of the fluid **8** and recirculate fluid inside the conduit **10**. In an embodiment, the flow entrainment section **20** is arranged and configured to reduce the velocity of a portion of the fluid **8** with by least 50%.
[0089] Inside the central portion of the housing **4** a main channel of the conduit **10** extends along the longitudinal axis of the housing **4**. A fluid **8** (e.g. air) enters the housing **4** via the inlet port **6**. The inlet port has a width D.sub.2 large enough to receive a predefined desired flow (e.g. 1-10 L/min) of the fluid **8**. When the fluid **8** has entered the main channel, most of the fluid continues along a straight path, through which the fluid **8** leaves the housing **4** through an outlet port **12** having a larger width D.sub.4 than the width D.sub.2 of the inlet port **6**. Hereby, the velocity of the fluid **8** is continuously reduced from the inlet port **6** to the outlet port **12**. Section **20** acts as an entraining flow section.
[0090] A minor percentage of the fluid (e.g. 10%) **8** will, however, be sucked into a flow entrainment section **20**. The flow entrainment section **20** comprises a first portion **24** and a second portion **26**. The second portion comprises an arched part arranged next to a straight part. A magnetic assembly **32** comprising a plurality of permanent magnets (not shown) being at least partly covered by a magnetizable covering material **18** is arranged in the straight part of the second portion.
[0091] The first portion **24** comprises a straight part and an arched portion **22**. The straight part of the first portion **24** is arranged next to the straight part of the second portion **26**. The arched portion **22** of the first portion is configured to guide the fluid **8** that has passed through the magnetic assembly **32** to be recirculated into the main channel of the conduct **10**.
[0092] The magnetic field generated by the magnetic assembly **32** will attract metal particles from the flow passing from the conduit **10**. Hereby, the efficiency of the fluid separation unit **2** can be increased.
[0093] The flow entrainment section **20** comprises an inner wall and an outer wall. The inner wall is a converging-diverging nozzle configured to allow the fluid **8** to pass through and, together with the outer wall, creates the bypass channel. The main flow enters the nozzle from the inlet port **6** and entrains the fluid molecules from the bypass fluid flow.
[0094] The nozzle outlet area A.sub.nozzle outlet is given by width D.sub.5 of the nozzle outlet:
[00001] $A_{\text{nozzleoutlet}} = (1/2D_5)^2 \quad (1)$
[0095] A.sub.nozzle outlet will typically be between 0.8 to 1.2 times the area A.sub.outlet port of the outlet port **12**.
[00002] $A_{\text{outletport}} = (1/2)^2 \quad (2)$
[0096] The narrow area of the nozzle has an area A.sub.narrow nozzle that is larger than the area A.sub.inlet port of the inlet port **6** but smaller than the area A.sub.nozzle outlet of the outlet port.
[00003] $A_{\text{narrownozzle}} = (1/2D_3)^2 \quad (3) \quad A_{\text{inletport}} = (1/2D_2)^2 \quad (4)$
[0097] The distance L between the inlet region of the conduit **10** and the inlet of the nozzle is between 40% to 60% of the inlet's effective width. The effective width is the area A.sub.inlet port of the inlet port **6** squared.
[0098] Therefore, the fluid pressure gradually increases along the center channel of the conduit **10** due to the increase in the cross-sectional area. The lowest pressure value can be found at the end of the nozzle (in which the width is D.sub.5) due to the flow, which induces a wake at this point.
[0099] The width D.sub.1 of the magnetic assembly **32** is indicated. The width D.sub.1 of the magnetic assembly **32** is smaller than half the width D.sub.2 of the inlet port **6**. Typically, the width D.sub.1 of the magnetic assembly **32** corresponds to 25-40% of the width D.sub.2 of the inlet port **6**. In an embodiment, the width D.sub.1 of the magnetic assembly **32** corresponds to 30-35% of the

width D.sub.2 of the inlet port **6**.
[0100] The inlet port **6** is designed as a cylindrical portion. The outlet port **12**, however, is conical. The distal end of the outlet port **12** is larger than the proximal end of the outlet port **12**. Accordingly, the velocity of the fluid **8** will gradually be reduced as indicated by the arrows indicating the velocity of the fluid **8**. The cross-sectional area of the outlet port **12** will typically be 2 to 7 times the cross-sectional area of the inlet port **6**.
[0101] In an embodiment, the width D.sub.4 of the outlet port **12** is more than 50% larger than the width D.sub.2 of the inlet port **6**.
[0102] In an embodiment, the magnetic assembly **32** consists of a multi-channel duct, wherein one or more permanent magnets are arranged in each duct.
[0103] In an embodiment, the fluid separation unit **2** may comprise a ventilator arranged to provide a pressure differential that can suck fluid **8** into the inlet port **6** of the fluid separation unit **2** and/or outlet cleaned fluid **8** out through the outlet port **12**.
[0104] The fluid separation unit **2** comprises a front portion **28** comprising the inlet port **6**. The front portion **28** may be straight or conical. By having a front portion **28**, it is possible to achieve a fully developed velocity profile (a homogeneous flow along the cross section of the end portion of the front portion **28**). If front portion **28** is removed, the velocity profile would not be homogeneous as the central portion having largest distance to the wall would have significantly higher velocity than the regions near the wall.
[0105] FIG. **1**B illustrates a side view of the fluid separation unit **2** shown in FIG. **1**A. The fluid separation unit **2** comprises a housing **4** having an inlet port **6** and an outlet port **12**. The inlet port **6** has a width D.sub.2 and the outlet port **12** has a larger width D.sub.4. A fluid **8** enters the inlet port and exits the fluid separation unit **2** via the outlet port **12**.
[0106] FIG. **2** illustrates a prior art air filter device for removing ferromagnetic particles **48** from air. The prior art air filter device comprises several permanent magnets **46**, **46**′ and a magnetizable material **44**. The magnetizable material **44**, which is typically steel wool is arranged between adjacent magnets **46**, **46**′. Accordingly, the magnetizable material **44** is magnetized and capable of attracting ferromagnetic particles **48** from air. It, however, is important to both have a low flow velocity and a high density of the magnetizable material **44** to be able to catch the ferromagnetic particles **48** from air because the extension of the magnetizable material **44** along the flow path is quite small. Accordingly, the prior art air filter device will get clogged quite easily. Moreover, a large pressure is required to pass the magnetizable material **44**. Therefore, it is desirable to have a filter device that is more efficient (requires less pressure) and does not get clogged quite as easily.
[0107] FIG. **3** illustrates a magnetic assembly **32** of a fluid separation unit according to an embodiment. The magnetic assembly **32** comprises a cylindrical duct **40** having a longitudinal axis X. A plurality of rod-shaped permanent magnets **14**, **14**′ extend along the longitudinal axis X. Since the flow direction extends along the longitudinal axis X, the magnetic assembly **32** is designed to provide the longest possible time to catch magnetic or magnetizable particles in the fluid to be filtered using the magnetic assembly **32**.
[0108] Each of the permanent magnets **14**, **14**′ is cylindrical. A magnetizable structure **36** surrounds the axial periphery of each of the permanent magnets **14**, **14**′. The magnetizable structure **36** may be made of steel. In an embodiment, the magnetizable structure **36** is shaped as steel brushes protruding radially from the periphery of the magnet **14**, **14**′ that it surrounds.
[0109] The magnets **14**, **14**′ are attached to a magnetizable portion **38** arranged inside the duct **40**. In an embodiment, the magnetizable portion **38** is made of steel. In an embodiment, the magnetizable portion **38** is shaped as a grate.
[0110] A free space **42** is provided between the inner wall of the duct **40** and the magnetizable portion **38**. Fluid passing through the magnetic assembly **32** may travel via the space **42**. The magnetic or magnetizable particles in the fluid will, however, be attracted to the magnetizable structure **36** surrounding the axial periphery of each of the permanent magnets **14**, **14**′.

Accordingly, the magnetic or magnetizable particles will, in most cases, get caught (due to the magnetic attraction) and thus removed from the fluid.
[0111] Since there is a large space between adjacent magnetizable structures **36**. The magnetic assembly **32** has a very large capacity for collecting magnetic or magnetizable particles without getting clogged.
[0112] FIG. **4** illustrates a cross-sectional side view of a magnetic assembly **32** of a fluid separation unit according to an embodiment. The magnetic assembly **32** comprises a plurality of parallel cylindrical permanent magnets **14**, **14′**, **14″**. The permanent magnets **14**, **14′**, **14″** extend along the longitudinal axis X of the magnetic assembly **32**.
[0113] Each of the permanent magnets **14**, **14′**, **14″** is surrounded by a magnetizable structure **36**. The magnetizable structures **36** are shaped as brushes comprising a plurality of brush members extending radially. The magnetizable structures **36** extend radially from a structure that is in contact with or connected to a structure that is in contact with a magnet **14**, **14′**. Accordingly, the magnetizable structures **36** are magnetized by the magnets **14**, **14′**. Therefore, the magnetizable structures **36** will attract and catch magnetic or magnetizable particles in the fluid being filtered.
[0114] The magnetizable portion **38** illustrated may optionally be arranged between the brush structures of the magnetizable structures **36** and optionally in at least some of the other spaces of the magnetic assembly **32**.
[0115] FIG. **5**A illustrates a front view of a magnetic assembly **32** of a fluid separation unit according to an embodiment. FIG. **5**B illustrates a permanent magnet **14** and the surrounding magnetizable structure **36** of the magnetic assembly **32** shown in FIG. **5**A.
[0116] The magnetic assembly **32** comprises an inner wall **34** and an outer wall **35**. The magnetic assembly **32** comprises a plurality of parallel cylindrical permanent magnets **14**. Each of the permanent magnets **14** is surrounded by a magnetizable structure **36** shaped as brushes comprising a plurality of brush members extending radially.
[0117] A space **42** is provided between the magnetizable structures **36** and the wall **35** of the magnetic assembly **32**.
[0118] In FIG. **5**B, one can see that the magnetizable structures **36** extend radially from a surrounding portion **50** (surrounding the magnet **14**) that is in contact with the magnet **14** via attachment structures **52** extending between the inside of the surrounding portion **50** and the magnet **14**. Accordingly, the magnetizable structures **36** are magnetized by the magnet **14**. Thus, the magnetizable structures **36** will attract and catch magnetic or magnetizable particles in the fluid being filtered.
[0119] It is possible to arrange a magnetizable portion **38** between the structures arranged between the inner wall **34** and the outer wall **35**.
[0120] FIG. **6**A illustrates a front view of a magnetic assembly **32** of a fluid separation unit according to an embodiment. FIG. **6**B illustrates a permanent magnet **14** and the surrounding magnetizable structure **36** of the magnetic assembly **32** shown in FIG. **6**A. It is important to emphasize, the permanent magnet **14** may be replaced with an electromagnet. Accordingly, in an embodiment, the magnetic assembly **32** of the fluid separation unit comprises an electromagnet (not shown) surrounded by a magnetizable structure **36** of the magnetic assembly **32**.
[0121] By having an electromagnet, it is possible to shut off the power and hereby turn off the magnetic field generated by the electromagnet. This may be an advantage when cleaning the filter (removing the collected particles).
[0122] The magnetic assembly **32** comprises an inner wall **34** and an outer wall **35**. The magnetic assembly **32** comprises a plurality of parallel cylindrical permanent magnets **14**. The permanent magnets **14** are surrounded by a magnetizable structure **36** shaped as brushes comprising a plurality of brush members extending radially.
[0123] A space **42** is provided between the magnetizable structures **36** and the wall **35** of the magnetic assembly **32**. Even though it is not shown, it is possible to arrange a magnetizable portion

38 between the structures arranged between the inner wall **34** and the outer wall **35**.
[0124] FIG. **6**B illustrates that the magnetizable structures **36** extend radially from a surrounding portion **50** (surrounding the magnet **14**) that is in contact with the magnet **14** via attachment structures **52** extending between the inside of the surrounding portion **50** and the magnet **14** so that the magnetizable structures **36** are magnetized by the magnet **14**. Thus, the magnetizable structures **36** will attract and catch magnetic or magnetizable particles in the fluid being filtered. The magnetizable structure **36** is arranged inside a duct **40**.
[0125] FIG. **7**A illustrates a front view of a magnetic assembly **32** of a fluid separation unit according to an embodiment. FIG. **7**B illustrates a plurality of permanent magnets **14** and the surrounding magnetizable structures **36** of the magnetic assembly **32** shown in FIG. **7**A.
[0126] The magnetic assembly **32** comprises an inner wall **34** and an outer wall **35**. The magnetic assembly **32** comprises a plurality of ducts **40** corresponding to the one shown in FIG. **7**B.
[0127] Each duct **40** comprises a plurality of permanent magnets **14** that are surrounded by a magnetizable structure **36** shaped as brushes comprising a plurality of brush members extending radially. The magnets **14** are attached to a magnetizable portion **38**. A space **42**′ is provided between the magnetizable portion **38** and the inner wall of the duct **40**.
[0128] A space **42** is provided between the ducts **40** and the wall **35** of the magnetic assembly **32**. Even though it is not shown, it is possible to arrange a magnetizable portion between the ducts **40**, the inner wall **34**, and the outer wall **35**.
[0129] The brushes shown in and explained with reference to FIG. **5**A, FIG. **5**B, FIG. **6**A, FIG. **6**B, FIG. **7**A and FIG. **7**B are designed to facilitate the capture and removal of ferromagnetic particles from the fluid flow. In this way, the magnetic assembly **32** removes ferromagnetic particles from the flow. The arrows shown in FIG. **1**A illustrate the fluid flow directions.
[0130] A steel brush provided with cylindrical permanent magnet **14** extending along the central line of the brush, generates a uniform magnetic field. This magnetic field is capable of capturing particles while the fluid **8** can pass the brush hairs with the smallest possible pressure drop. In an embodiment, a magnetizable portion of steel wool is placed between the brushes and around them. Since the magnetic assembly **32** is placed at the diverging part of the nozzle, it can attract the ferromagnetic particles **16** passing through the nozzle and increase the probability of directing them to the bypass channel.
[0131] In an embodiment, the fluid separation unit **2** is configured to be installed and applied in train and metro stations to remove ferromagnetic particles from the air.
[0132] In an embodiment, the fluid separation unit **2** is configured to be installed in series on the walls or the ceilings of spaces with high ferromagnetic particle concentrations.
[0133] In an embodiment, the fluid separation unit **2** is configured to be installed on the body of the trains to remove the ferromagnetic particles from the tunnels' air. Tunnels are full of ferromagnetic particles, and their air enters stations due to the piston effect. Cleaning the air in tunnels by trains can be very effective as the cleaning is close to the pollution source.
[0134] In an embodiment, the fluid separation unit **2** is configured to be installed outside of the trains. The fluid separation unit **2** will start removing ferromagnetic particles when trains start braking. The air will pass through the system due to the movement of the train, and therefore, it does not need to have any fan to move air.
[0135] In an embodiment, the fluid separation unit **2** is configured to be installed on the walls of train/metro tunnels to remove ferromagnetic particles. The air can move through the fluid separation unit **2** due to the movement of trains, a fan, or any other type of air-moving mechanism.
[0136] A fan will typically be used if the device is used as a standalone device. Such standalone device may be installed at a train station or at a wall by way of example.
[0137] In an embodiment, the fluid separation unit **2** is configured to be used in combination with mechanical filters, such as fibrous filters, to remove all types of particles from the air of tunnels, stations, steel workshops, or foundries.

[0138] In an embodiment, the fluid separation unit **2** is configured to be used with gas removal technologies to remove gas pollutants and particulate matter.
[0139] FIG. **8**A illustrates a perspective side view of a fluid separation unit **2** according to an embodiment. The fluid separation unit **2** comprises similar features as the fluid separation unit shown in and explained with reference to FIG. **1**A. The geometry of the structures is, however, different. The fluid separation unit **2** comprises a housing having a planar bottom surface.
[0140] The fluid separation unit **2** comprises a box-shaped front portion **28** shaped as a tubular structure designed to receive the fluid and provide a fully developed velocity profile (a homogeneous flow along the cross section of the end portion of the front portion **28**).
[0141] The fluid separation unit **2** comprises a flow entrainment section comprising a first portion **24** and a second portion **26**. The fluid separation unit **2** comprises an outlet portion **30** designed to discharge fluid.
[0142] FIG. **8**B illustrates a perspective side view of a fluid separation unit corresponding to the one shown in FIG. **1**A and in FIG. **1**B. The fluid separation unit **2** comprises a housing **4** having an inlet port **6** for receiving a fluid **8**, an outlet **30** comprising an outlet port **12** for discharging fluid **8**. The fluid separation unit **2** comprises a conduit extending between the inlet port **6** and the outlet port **12**.
[0143] The fluid separation unit **2** comprises a flow entrainment section comprising a first portion **24** and a second portion **26**. The second portion comprises an arched part arranged next to a straight part (see FIG. **1**A).
[0144] The first portion **24** comprises a straight part and an arched portion (see FIG. **1**A). The straight part of the first portion **24** is arranged next to the straight part of the second portion **26**.
LIST OF REFERENCE NUMERALS
[0145] **2** Fluid separation unit [0146] **4** Housing [0147] **6** Inlet port [0148] **8** Fluid [0149] **10** Conduit [0150] **12** Outlet port [0151] **14**, **14′**, **14″**, **14″** Permanent magnet [0152] **16** Particle [0153] **18** Covering structure [0154] **20** Flow entrainment section [0155] **22** Arched portion [0156] **24** First portion [0157] **26** Second portion [0158] **28** Front portion (tubular structure) [0159] **30** Conical portion [0160] **32** Magnetic assembly [0161] **34** Inner wall [0162] **35** Outer wall [0163] **36** Magnetizable structure [0164] **38** Magnetizable portion [0165] **40** Duct [0166] **42**, **42′** Space [0167] **44** Magnetizable material [0168] **46**, **46′** Permanent magnet [0169] **48** Particle [0170] **50** Surrounding portion [0171] **52** Attachment structure [0172] D.sub.1, D.sub.2, D.sub.3, D.sub.4, D.sub.5 Width [0173] X Axis [0174] L Distance

Claims

1. A fluid separation unit comprising: a housing having an inlet port for receiving a fluid, an outlet port for discharging the fluid and a conduit extending between the inlet port and the outlet port; at least one permanent magnet arranged to attract magnetic or magnetizable particles in the fluid, wherein the at least one permanent magnet is at least partly covered by a magnetizable covering structure, and the at least one permanent magnet is one of a plurality of permanent magnets of a magnetic assembly; a flow entrainment section arranged inside the housing, wherein in the flow entrainment section the magnetic assembly is provided, the magnetic assembly comprising a plurality of parallel rod-shaped permanent magnets that are covered by a magnetizable metal section, wherein the conduit comprises a main channel extending along a longitudinal axis of the housing, and the housing is configured so that most of the fluid entering the main channel flows along a straight path from the inlet port to the outlet port, the outlet port having a larger width D.sub.4 than a width D.sub.2 of the inlet port, the flow entrainment section comprising an inner wall and an outer wall, wherein the inner wall is a converging diverging-nozzle configured to allow the fluid to pass through and to create, together with the outer wall, a bypass channel, wherein the flow entrainment section is further configured so that a portion of the fluid is sucked into the

bypass channel and so that said portion of the fluid is recirculated into the main channel of the conduit after it has passed through the magnetic assembly.
2. The fluid separation unit according to claim 1, wherein a cross-sectional area of the outlet port is more than 50% larger than a cross-sectional area of the inlet port.
3. The fluid separation unit according to claim 1, wherein at least one of the permanent magnets of the plurality of permanent magnets of the magnetic assembly extends along a direction of flow inside the flow entrainment section.
4. The fluid separation unit according to claim 1, wherein a length of at least one of the permanent magnets of the plurality of permanent magnets of the magnetic assembly is at least 2 cm.
5. The fluid separation unit according to claim 1, wherein the housing comprises: a first portion of the housing that comprises a minor straight part and a major arched portion; a second portion that comprises an arched part arranged next to a straight part; a cylindrical front portion comprising the inlet port; and a conical outlet portion comprising the outlet port, which is conical; wherein the first portion is sandwiched between the front portion and the second portion and the second portion is sandwiched between the first portion and the outlet portion, wherein a width of the first portion is larger than a width of the second portion.
6. The fluid separation unit according to claim 5, wherein at least one of the plurality of permanent magnets of the magnetic assembly is arranged in the second portion.
7. The fluid separation unit according to claim 5, wherein a width (D.sub.2) of the front portion is smaller than a width (D.sub.4) of the outlet portion.
8. The fluid separation unit according to claim 5, wherein the flow entrainment section forms a ring extending in the conduit along an inner wall of a portion of the first portion and the second portion.
9. The fluid separation unit according to claim 8, wherein a distal portion of the flow entrainment section, creating a velocity-reducing section, comprises a conical inner wall.
10. The fluid separation unit according to claim 1, wherein a volume of the flow entrainment section is less than 1000 ml.
11. The fluid separation unit according to claim 9, wherein a proximal portion of the flow entrainment section, creating the velocity-reducing section, comprises an inwardly arced inner wall.
12. The fluid separation unit according to claim 5, wherein the magnetic assembly comprises a plurality of ducts arranged along a periphery of said second portion of the housing, wherein each duct comprises one or more rod-shaped permanent magnets extending along a longitudinal axis of the duct, wherein each permanent magnet is covered by a magnetizable covering structure.
13. A method for removing magnetic or magnetizable particles using a fluid separation unit according to claim 5, the method comprising: reducing the velocity of a portion of the fluid; and recirculating that portion of the fluid inside the conduit, wherein in the flow entrainment section a magnetic assembly is provided, wherein the magnetic assembly comprises a plurality of parallel rod-shaped permanent magnets that are covered by a magnetizable metal section.
14. The method according to claim 13, wherein the plurality of permanent magnets of the magnetic assembly extends along a direction of the flow inside the flow entrainment section.