

Description

Method and device for detecting moving objects in a gas stream during cryogenic gas separation

5

The invention relates to a method for detecting moved objects in a gas stream during cryogenic gas separation.

10 In direct-contact apparatuses, such as for example columns or packing columns, but also in boiling processes, gaseous and liquid phases are in direct contact. This may give rise to droplet entrainment, that is to say small droplets or mist being carried
15 along by the gas stream. This separating out of the liquid phase is generally undesired. To prevent droplet entrainment, droplet separators are used, such as for example baffle-based separators such as lamella separators, knitted-mesh separators, gravity separators
20 or cyclone separators. If the droplet separator does not work properly, droplet entrainment occurs. This may lead to serious damage to downstream parts of the plant that are dependent on having a gas flow without a liquid fraction.

25

Regular monitoring of the separator, that is to say detection of droplet entrainment, can usually be used in the case of knitted-mesh separators. This involves making use of the property of the wire mesh that a
30 pronounced increase in water entrainment from the knitted mesh is preceded first by a layer of bubbling water forming in the lower region of the mesh. This layer of bubbling water increases the pressure loss of the air as it passes through the mesh in proportion to
35 the height of the bubbling layer.

The indirect monitoring of water entrainment by way of the pressure loss has the disadvantage that froth that

cannot be held back in the case of a knitted-mesh separator does not result in any appreciable increase in pressure loss. Therefore, if froth is produced, the monitoring is inadequate. In addition, over the course
5 of time contaminants may be deposited in the mesh, such as for example algae or limescale if water is used. The pressure loss over the mesh thereby increases slowly and continuously. The rate of entrainment increases with

increasing soiling of the mesh, so that an alarm limit value for the pressure loss can only ever be given temporarily.

- 5 In the case of separators of other types, conclusions as to possible droplet entrainment can be drawn from other process parameters, such as for example the temperature downstream of the separator or the behavior of the medium in further steps of the process. However,
10 these methods are very susceptible to errors, since the mentioned deviations in the process parameters may also be caused by many other reasons.

For the direct detection of droplet entrainment in a
15 gas stream, until now only sophisticated optical measuring methods and devices with computer-aided pattern recognition have been commercially available.

US2008/0295609 A1 describes a possible way of
20 determining flow behavior of a multiphase mixture (in particular liquid droplets that are entrained in a gas) that is flowing through a conduit. For this purpose, a microwave signal is emitted through the conduit and two Doppler-shifted signals are received. The flow behavior
25 is determined from these received signals, for example as the velocity of the gas phase or of the liquid phase.

According to GB 2 322 987 A, objects that are moving
30 into a gas turbine or out of a gas turbine are detected. For this purpose, an electromagnetic signal is emitted and a reflected electromagnetic signal is detected and evaluated. The objects are detected by the Doppler shift of the reflected signal.

GB 2 026 276 A describes a possible way of detecting agglomerated dust in the flue gas in a factory chimney with Doppler radar.

- 5 The present invention is based on the object of providing a method and a device with which moving objects, in particular liquid droplets, in a gas stream can be reliably and easily detected.
- 10 This object is achieved by the methods and the device with the features of the independent patent claims.

The methods according to the invention are suitable for detecting moving objects in a gas stream. Referred to
15 here and hereinafter as such are moving objects that are entirely or partially surrounded by a gas stream, irrespective of whether the objects move with the gas stream or in relation to it. Hereinafter, moving objects in a gas stream are to be understood as meaning
20 in particular liquid droplets or mist in the gas stream. Moving objects in the gas stream accordingly describe in particular droplet entrainment in the gas stream. The phrase "moving objects" or "moved objects" is intended hereinafter to cover both the case of an
25 individual object and the case of multiple objects.

The detection of these moving objects in the gas stream, and consequently detecting droplet entrainment, comprises within the scope of the invention irradiation
30 of the gas stream with electromagnetically emitted radiation in the microwave or

tetrahertz range and
detection of resultant scattered radiation. This arises
due to scattering or reflection of the emitted
radiation at at least one object in the or with the gas
stream. The method according to the invention further
20 comprises detection of a difference in frequency
between the emitted radiation and the scattered
radiation. The presence of a moving object or multiple
moving objects in the gas stream is concluded from this
difference in frequency. A presence, a number and/or a
25 proportion of moving objects in the gas stream is/are
thereby determined from the difference in frequency and
the amplitude, in particular the amplitude of the
scattered radiation or of the reflected emitted
radiation.
30
This detection of moving objects in the gas stream is
used within the scope of the invention for the
separation of gases, in particular for cryogenic gas
separation.
35
According to the first method according to the
invention, the detection of moving objects in the gas
stream is used in the course of a method for separating

gases of a gas mixture. The gas mixture is in this case transported in the form of a gas stream, for example through a corresponding installation for gas separation. The conclusions as to whether there is a
5 moving object in the gas stream can consequently be used to determine a presence, a number and/or a proportion of moving objects in the gas stream. The separation of the gases of the gas mixture is carried out while taking into account these moving objects in
10 the gas stream that are determined in such a way.

The terms "gas separation" and "cryogenic gas separation" and "separation of gases" are to be understood here as meaning in particular a complete
15 process for the separation of gases, it being intended in particular that all the steps of this process are included. In particular, the process for the separation of gases begins in this case with a first step, in which the gas mixture to be separated is sucked in, and
20 ends with a final step, in which the individual separated gases of the gas mixture are removed. In particular, the process for the separation of gases comprises the (pre)cleaning or scrubbing of the gas mixture, in order to filter out dust and other solid
25 particles. Furthermore, the individual steps of the process for the separation of gases comprise in particular repeated heating and cooling of the gas mixture or repeated compression and expansion of the gas mixture.

30

In the case of air separation, the process for the separation of gases may in particular be a low-temperature separation of air. In particular, the steps of the process for the separation of gases in the case
35 of air separation comprise in particular initially a precleaning of the air, in particular by a molecular sieve, in order in particular to filter water vapor, dust, hydrocarbons, nitrous oxide and carbon dioxide

out of the air. The further steps comprise in particular precooling to a certain temperature, compressing the air and allowing it to expand, cooling to the dew point, removal of the individual separated
5 gases of the air and possibly heating of the separated gases.

According to the second method according to the invention, a monitoring and/or control of elements or
10 components that are used in particular in the course of the operation of cryogenic gas separation is carried out by means of the detection of moving objects in the gas stream. Such elements may be formed as a droplet separator, a direct-contact cooler, an evaporator, an
15 inertia-force separator, a cyclone separator, an electrofilter or a gas scrubber.

If not only liquid droplets or mist but also for example solid particles (for example ash particles,
20 dust, ice) are detected by means of the method according to the invention as moving objects in the gas stream, such elements or components may in particular also be formed as a solids filter or a soot filter.

25 Such elements are used in the course of cryogenic gas separation in particular for precipitation processes, in order to prevent droplet entrainment. Nevertheless, droplet entrainment may occur at these elements. For example, in the case of an evaporator, incomplete
30 evaporation may have the effect that droplets are entrained.

Such elements are monitored by the detection of moving objects in the gas stream. In particular, the detecting
35 of moving objects may in this case be carried out downstream of the corresponding element, in order to monitor whether this element is functioning correctly and is preventing droplet entrainment.

Alternatively or in addition, the corresponding element may also be controlled. In this case, the detecting of moving objects may be carried out in particular
5 upstream of the element. If moving objects are detected in the gas stream, the element can be informed of this and activated correspondingly, in order for example to filter out the objects and prevent further droplet entrainment.

10

In the two methods according to the invention, consequently droplet entrainment is detected in the course of cryogenic gas separation. It is thereby prevented that droplet entrainment during cryogenic gas
15 separation can cause damage. The phrase "cryogenic gas separation" is intended hereinafter to include both cryogenic gas separation according to the first method according to the invention and also according to the second method according to the invention.

20

By analogy with the two methods according to the invention, the invention also comprises two devices. By analogy with the first method according to the invention, the first device according to the invention
25 serves for separating gases of a gas mixture in the gas stream.

A "device for separating gases" or a "device for gas separation" or a "device for cryogenic gas separation"
30 is formed in particular as an installation. This installation has in particular one or more cold boxes. In such cold boxes there may be integrated for example components or installation parts such as columns, plate heat exchangers, pressure vessels, separators,
35 associated pipework, instrumentation for temperature and pressure measurements, pressure-difference and liquid-level indicators and also housing bushings and fittings.

In the case of air separation, the installation for the separation of gases is formed in particular as an air separating installation. Such air separating installations have in particular distillation column systems, which may be formed for example as two-column systems, in particular as classic Linde double-column systems, but also as three- or multi-column systems. Furthermore, devices for obtaining further components of air, in particular the noble gases krypton, xenon and/or argon, may be provided.

The first device according to the invention has in this case elements which are designed for carrying out the detection of moving objects in a gas stream. In particular, the first device according to the invention comprises a pipe or a vessel through which a gas stream can be conducted. It also comprises at least one emitter, which is suitable for irradiating the gas stream with electromagnetically emitted radiation in the microwave or tetrahertz range. The device additionally has at least one receiver. This is designed for detecting scattered radiation (in particular reflected radiation) that arises if the emitted radiation is scattered (or even reflected) at at least one object. Finally, the device according to the invention comprises means that are suitable for detecting a difference in frequency between the emitted radiation and the detected scattered radiation (reflected radiation).

The means in this case also comprise data processing means for the evaluation of one or more parameters of the scattered radiation, for concluding from the difference in frequency whether there are moving objects in the gas stream. By analogy with the first method according to the invention, this conclusion is

used for determining in particular a presence, a number and/or a proportion of moved objects in the gas stream.

5 The first device according to the invention is designed for carrying out the separation of the gases of the gas mixture while taking into account the conclusions reached by the means for detecting the difference in frequency.

10 The separation of the gases of the gas mixture while taking into account the determined moving objects in the gas stream may comprise in particular measures for protecting components or elements that are sensitive to droplet entrainment and can be damaged by it.
15 Alternatively or in addition, it may also include measures by which the separation of the gases of the gas mixture is carried out more efficiently in dependence on the proportion of moving objects in the gas stream. For example, parameters of individual
20 components or elements may in this case be set and adapted specifically to the proportion of moving objects in the gas stream.

In particular the control or monitoring is carried out
25 in this way. The control or monitoring may in this case likewise be carried out by the means or by a further element, for example a controller. By analogy with the second method according to the invention, a second device according to the invention serves for monitoring
30 and/or controlling a droplet separator, a direct-contact cooler, an evaporator, an inertia-force separator, a cyclone separator, an electrofilter and/or a gas scrubber. In this case, the second device according to the invention comprises a pipe or a vessel
35 through which a gas stream can be conducted. By analogy with the first device according to the invention, the second device according to the invention also comprises at least one emitter, at least one receiver and means

for detecting a difference in frequency and for concluding whether there are moving objects in the gas stream.

5 Within the scope of the invention, consequently individual components or elements of cryogenic gas separation can be protected from droplet entrainment. The detection of moving objects in the gas stream may in this case be carried out one or more times during
10 the cryogenic gas separation. In particular, the detection of moving objects in the gas stream is carried out before the gas stream passes through components or elements that are sensitive to droplet entrainment and can be damaged by it. Consequently, in
15 the course of the invention, droplet entrainment is detected at an early time and corresponding measures can be initiated to protect the respective components or elements.

20 The following embodiments of the invention and the advantages presented apply in an analogous way to the two methods according to the invention and also to the two devices according to the invention.

25 An evaporator may in this case be formed for example as a bath evaporator, as a "block in kettle" heat exchanger, as a helically coiled heat exchanger, as a shell-and-tube heat exchanger or as a plate heat exchanger. In the context of the invention, it is
30 thereby possible to detect entrainment of the evaporator. Entrainment describes an uptake of particles in a fluid in general. In the context of the invention, entrainment describes in particular an uptake of objects in the gas stream. For example, the
35 evaporator may be used in particular for natural gas liquefaction or a propane refrigeration stage. By analogy, the first method according to the invention

may also be used for natural gas liquefaction or a propane refrigeration stage.

For the detection of moving objects in the gas stream,
5 and consequently for the detection of droplet
entrainment, the present invention makes use of the
Doppler effect, in that a relative velocity or relative
velocity distribution of the scattering/reflecting
10 object can be concluded from a possibly detected
frequency shift of a backscattered or reflected signal
with respect to the original emitted signal. In the
case of a comparatively large number of
scattering/reflecting objects, and consequently a
comparatively large number of scattering centers, the
15 conclusion relates in particular only to a relative
velocity distribution.

The at least one scattering or reflecting object may
be, for example, a fixed wall of the pipe or vessel (in
20 this case no frequency shift is detected) or a particle
or object moving with the gas stream, for example a
liquid droplet or a solid particle (such as in
particular for example an ash particle).

25 The measuring principle of the methods according to the
invention and of the devices according to the invention
has the advantage that it can also be used in the case
of separators with which detection of moving objects by
a pressure loss is not possible. For the detection, the
30 pipe or the vessel must merely be accessible from one
side. Since the principle is based on a direct
procedure, a high degree of reliability in the
detection of objects moving in the gas stream is
moreover achieved. When used in conjunction with a
35 direct-contact cooler, the invention allows the
measurement to be carried out further away from a
separator, for example directly upstream of a component
that is sensitive to water. By contrast with

commercially available rain sensors, in the case of the volume method on which the invention is based it is possible to discriminate and/or ignore marginal effects such as condensation of liquid on the tube or vessel wall. Since it is possible to dispense with movable mechanical parts, the device according to the invention has a long service life.

The method according to the invention and the device according to the invention are moreover largely insensitive to deposits on the pipe or vessel walls. In particular, limescale deposits or damp layers of algae are sufficiently transmissive for the electromagnetically emitted radiation, so that they do not adversely affect the functional capability.

Advantageous configurations of the present invention are the subject of the subclaims, this description and the figure.

In an advantageous embodiment of the method according to the invention, the step of detecting a difference in frequency comprises discriminating such scattered (for example reflected) radiation that has been scattered (or reflected) by at least one stationary object, for example by drops on a wall of the pipe or vessel or by the wall itself. The discrimination may take place for example with the aid of a suitable filter. Alternatively or in addition, in the course of an evaluation of the frequencies of scattered radiation (for example with the aid of suitable analysis software), that scattered radiation that has been scattered by the at least one stationary object can be detected.

By means of suitable data preparation, the scattered radiation, or else directly a resultant Doppler signal, can be analyzed. The measured relative velocity, a

temporal modulation of the scattered radiation imparted by the individual moved objects and/or an absolute signal strength can be included here in the data preparation and analysis. This allows the certainty of
5 detection to be increased.

In a preferred embodiment, the substance-dependent variables permeability μ and permittivity ϵ of the moved objects to be observed and of the gas are
10 included in the data analysis. They influence the scattering or reflection of the emitted radiation. In the case of water and air, the relative permittivities (dielectric constants) are about $\epsilon=77$ and $\epsilon=1$, respectively.

15 In a preferred embodiment, one or more parameters of the scattered radiation is/are evaluated; the device may comprise data processing means suitable for this. For example, concluding whether there are moving
20 objects in the gas stream may comprise comparing at least one parameter of the detected scattered radiation with one or more predetermined threshold value(s). The parameter or parameters may for example be one or more frequencies or amplitudes of the scattered radiation.
25 The threshold value or values may delimit one or more intervals that are tolerance ranges for the parameter or parameters with respect to the indication of moving objects in the gas stream.

30 This embodiment allows flexible application of the method. For example, concluding may include detection of an unintended minimum amplitude of the scattered radiation. If the amplitude lies below this minimum, a measuring error or a negligible number of moving
35 objects can be assumed. What number is to be regarded as insignificant in the respective case can be variably set by way of fixing the threshold value.

Information concerning the moving objects can be derived from the parameter or parameters of the scattered radiation. For example, a relative velocity of the moving objects in the direction of the emitted radiation can be concluded from a frequency of the scattered radiation. Alternatively or in addition, an upper or lower barrier for the number of objects per unit of volume in the gas stream and/or an average object size can be derived from a signal strength (i.e. the amplitude) of the scattered radiation. In particular, an integral scattering cross section can be calculated from an amplitude of the scattered radiation, that is to say a characteristic variable that corresponds to an average size and/or a number of moving objects per unit of volume in the gas stream. This allows information about the processes occurring in the pipe or vessel to be obtained.

Deriving the amount or number or proportion of objects or the (average) size of the objects in the gas stream is first of all only possible here by way of the intensity of the Doppler signal or of the scattered radiation.

Since the size of the objects (in particular in the submillimeter range) may sometimes be well below the wavelength of the emitted radiation (if for example radar radiation is used as emitted radiation, the wavelength of the emitted radiation is in the cm range), the backscattering of the emitted radiation would have to be described as Mie radiation or as Rayleigh radiation. In this case, usually an effective cross section is set. Since, within the scope of the invention, the wavelength and a backscattering angle or an observation angle at which the backscattered radiation is emitted are constant, a description analogous to direct scattering at individual particles is appropriate.

The following applies here for the contribution of an individual object or droplet to the intensity of the Doppler signal or the scattered radiation:

$$I \propto \frac{A}{d^2} \propto \frac{r^2}{d^2}$$

5 with the intensity I, the distance d of the objects from one another and the cross-sectional area A or the radius r of the objects. It consequently applies that, given the same distance d, a few large objects or droplets provide greater water transport than many
10 small objects or droplets.

It can be assumed that the objects in the gas stream in an expedient volume are distributed evenly or at least distributed constantly over time. The distance
15 consequently has no influence, as a result of which there is only a dependence on the size of the objects.

In order thus to determine quantitatively the amount of objects, a size distribution of the objects must
20 accordingly also be known, or at least be constant. This can be assumed for droplets in the form of droplet entrainment in the gas stream. Consequently, the system according to the invention can be calibrated experimentally from sensors.

25 An advantageous embodiment of the present invention comprises a data fusion of the information acquired from the detected scattered radiation with data that have been obtained on the basis of other measuring
30 principles, for example optical or sound-based techniques. Thus, a corresponding analysis can deliver even more comprehensive and more reliable results concerning the moving objects in the gas stream.

35 The irradiation of the gas stream with emitted radiation is preferably performed obliquely in relation

to the direction of flow of the gas stream and/or at different irradiating angles (at the same time or alternately) and/or at different frequencies (at the same time or alternately). In particular, in this way
5 redundancies can be created, and thus the reliability can be increased. Alternatively or in addition, the irradiation may be directed at the same time onto different lines of flow of the gas in the pipe or vessel, in that for example multiple emitters are
10 distributed around the pipe or the vessel or are arranged at different positions along the pipe or vessel. In this way, information concerning the distribution of the moving objects in the pipe or vessel can be obtained.

15 The at least one emitter and the at least one receiver may be integrated in a common sensor or be arranged separately from one another. In the first case, the sensor preferably comprises a mixer, which superposes
20 the emitted radiation and the scattered radiation on one another and from this forms and outputs an integrated signal (i.e. the Doppler signal); such sensors are commercially available at low cost and in a robust form. With the aid of frequency filtering,
25 unsuitable frequencies, such as for example Doppler frequencies that are too low or interfering frequencies, can be eliminated. The step according to the invention of detecting a difference in frequency can be performed by only considering the integrated
30 signal. For example, the Doppler frequency in the case of customary flow velocities occurring in air separating installations lies at 10 Hz to 100 Hz. Particularly suitable for irradiating the gas stream with emitted radiation and/or for receiving the
35 scattered radiation is/are one or more radar devices.

The emitted radiation is preferably pulsed radar radiation or FMCW radar radiation. The method may

comprise determining a distance of the moving objects from a predetermined reference value (for example a selected position, in particular that of an emitter). For example, a time interval between sending a radar

5 pulse and

detecting its scattered radiation can be detected and used for such a calculation, or a frequency modulation can be used for marking the emitted radiation, and consequently for distance determination.

5

Particularly preferred is an embodiment in which the pipe or the vessel is part of a direct-contact cooler. The moving objects are in this case preferably water droplets. In the case of customary vessel diameters of
10 between approximately 0.1 m and approximately 5 m, suitable in particular is a radar sensor that irradiates at 24 GHz at an angle of 45° with respect to a longitudinal axis of the vessel or with respect to the direction of the gas stream.

15

It is particularly advantageous if the pipe or the vessel is made of electrically nonconducting material. The emitted radiation can then be radiated from outside through the pipe or vessel wall, and associated means
20 of emission can thus be attached to the outside of the pipe or the vessel, and in particular it is possible to dispense with a flange or the like. This allows low-cost retrofitting of a corresponding installation, for example a direct-contact cooler. Alternatively, the at
25 least one emitter and/or the at least one receiver may be arranged inside the pipe or vessel.

In particular, the devices according to the invention (or the methods according to the invention) may be used
30 for detecting solid particles (such as for example ash particles) in gas phases, for example if they are used as mentioned for monitoring and/or controlling the filters mentioned.

35 According to the invention, the gas mixture in the form of the gas stream is compressed in a compression process and allowed to expand in an expansion process.

This compression process and this expansion process are part of the cryogenic gas separation. The detecting of moving objects in the gas stream is expediently carried out before and/or after the compression process and/or

5 the expansion process. Depending on the configuration of the cryogenic gas separation, the elements used and any sensitivity of the individual elements with respect to droplet entrainment, it may be expedient to carry out the detecting of moving objects in the gas stream

10 before and/or after the compression process and/or the expansion process.

In the course of the cryogenic gas separation, an (at least partially) liquefied gas mixture may also be evaporated in an evaporation process and converted back into a gaseous state in the form of the gas stream. Furthermore, the gas mixture in the form of the gas stream may be liquefied again (at least partially) in a condensation process. In this case, the detecting of moving objects in the gas stream may be carried out particularly expediently before and/or after the evaporation process and/or the condensation process. For example, it is particularly appropriate in this respect to carry out the detecting of moving objects in the gas stream after the evaporation process. It can consequently be detected whether liquid droplets are still present in the gas stream in the course of the evaporation process. Furthermore, it may be particularly appropriate to carry out the detecting of moving objects in the gas stream before the condensation process. It can consequently be detected whether there is in the gas stream droplet entrainment that could damage the elements for the condensation of the gas stream.

Alternatively or in addition, the detecting of moving objects may be carried out before and/or after a precipitation process in the gas stream.

5

With preference, the gas mixture is allowed to expand by means of a throttle valve, an expansion turbine, a pressure loss at a pipeline and/or a bend. Also with preference, the gas mixture is compressed and cooled in a multistage compressor, in particular with coolers. Alternatively or in addition, with preference a dew point of the gas mixture is monitored. The invention allows protection of various stages of the compression process and/or of the expansion process to be ensured.

15

Advantageously, the moving objects are filtered out from the gas stream while taking into account the determined presence, the determined number and/or the determined proportion of moving objects in the gas stream. The moving objects may also only be filtered out when the determined presence, the determined number and/or the determined proportion reaches a threshold value. A limit value from which damage to an element of the cryogenic gas separation can occur may be chosen for example as this threshold value. Alternatively or in addition, further expedient measures may also be carried out in dependence on the determined presence, the determined number and/or the determined proportion of moving objects in the gas stream. The determined presence, the determined number and/or the determined proportion of moving objects in the gas stream may also be used for determining a purity or a degree of contamination of the separated gases of the gas mixture.

35

In particular, this configuration is appropriate for a separator, in particular for a separator downstream of direct-contact apparatuses. In particular, such a

separator may be used in the first method according to the invention or the first device according to the invention for the separation of gases of the gas mixture. The filtering out of the moving objects can in
5 this case be carried out by means of the separator. The separator may be monitored and/or controlled by means of the determined presence, the determined number and/or the determined proportion of moving objects in the gas stream.

10

With particular preference, the invention is formed for direct-contact coolers or for direct-contact apparatuses for an air separating installation or as an air separating installation itself. In this case, the
15 second device according to the invention is formed in particular as a direct-contact cooler of an air separating installation. By analogy, the second method according to the invention is performed in particular in a direct-contact cooler of an air separating
20 installation. The first device according to the invention is in this case formed in particular as an air separating installation or the first method according to the invention is carried out in an air separating installation. In particular, it is
25 appropriate within the scope of the invention to carry out the detecting of moving objects in the gas stream in an air separating installation between a molecular sieve and a cold box.

30 Description of figures

Figure 1 shows an embodiment of a device according to the invention that is given by way of example.

35

In Figure 1, a device 1 for detecting moving objects in a gas stream is schematically represented. The device comprises a pipe 2, through which a gas stream 10 is

conducted at a velocity v from bottom to top (in the case presented). Objects 11, for example water droplets or solid particles, are entrained by the gas stream.

5 The pipe 2 is in this case formed in particular as part of an air separating installation. In the air separating installation, gases of a gas mixture in the form of the gas stream are separated. For example, the gas stream in the pipe 2 may be fed to a compressor, in
10 order to be compressed in a compression process. For example, the gas stream in the pipe 2 may also be fed to a throttle valve, in order to be allowed to expand in an expansion process. In particular, the pipe 2 may also be arranged between a molecular sieve and a cold
15 box of the air separating installation.

Outside the pipe 2 there is a radar device 14, which comprises an emitter 18 for electromagnetically emitted radiation 12 in the microwave or tetrahertz range. At
20 an irradiating angle α , the emitter irradiates the gas stream with the emitted radiation. In the example shown, the irradiating angle is measured with respect to the direction of gas flow, but it could also be determined with respect to any desired direction for
25 comparison that is chosen as fixed, for example with respect to the horizontal or vertical (which in the example shown coincides with the direction of gas flow).

30 The objects 11 moving with the gas stream 10 reflect the emitted radiation. The movement of the objects thereby gives rise to a Doppler signal, the frequency of which depends on the relative velocity of the objects 11 in the direction of the radar radiation 12,
35 and consequently on the flow velocity.

The scattered radiation 13 is detected by the radar device 14, which has a suitable receiver (not shown).

Connected to the radar device is a computing unit 15, which is designed for detecting the difference in frequency between the emitted radiation 12 and the detected scattered radiation 13. This is represented in the figure by schematic wave graphs 16a (for the emitted radiation) and 16b (for the scattered radiation) placed alongside one another. The difference can be used to determine the presence of objects 11 moving in the gas stream and their velocity or their velocity distribution. An evaluation of the amplitude 17 of the scattered radiation allows conclusions to be drawn concerning the number of moved objects in the gas stream (per unit of volume).

By means of this number of moved objects in the gas stream (per unit of volume), a proportion of the moved objects in the gas stream is determined. This determined proportion is taken into account for the air separation in the air separating installation. The computing unit 15 can pass on this determined proportion, for example to a control device of the air separating installation. The control device activates individual elements or components of the air separating installation in dependence on this determined proportion.

Alternatively or in addition, the pipe 2 may be part of one of the following elements: a droplet separator, a direct-contact cooler, an evaporator, an inertia-force separator, a cyclone separator, an electrofilter or a gas scrubber. This corresponding element is then a component part of the air separating installation. By means of the determined proportion of the moved objects in the gas stream, the corresponding element is controlled by the computing unit 15.

List of designations:

- 1 device for detecting moved objects in a gas stream
- 2 pipe
- 10 gas stream
- 11 moved objects
- 12 emitted radiation
- 13 scattered radiation
- 14 radar device
- 15 computing unit
- 16a graph of the emitted radiation
- 16b graph of the scattered radiation
- 17 amplitude of the scattered radiation
- α irradiating angle

- 27 -

Patent claims

1. A method for separating gases of a gas mixture in
the form of a gas stream,
5 wherein
 - the gas mixture in the form of the gas stream is
compressed in a compression process and allowed
to expand in an expansion process,
 - the gas stream is irradiated with
10 electromagnetically emitted radiation (12) in the
microwave or terahertz range,
 - scattered radiation (13) is detected, the
scattered radiation arising due to scattering of
the emitted radiation at at least one object (11)
15 in the gas stream,
 - a difference in frequency between the scattered
radiation and the emitted radiation is detected,
characterized in that
 - a presence, a number and/or a proportion of
20 moving objects in the gas stream is/are
determined from the difference in frequency
before and/or after the compression process
and/or the expansion process and
 - the separation of the gases of the gas mixture is
25 carried out while taking into account the
determined presence, the determined number and/or
the determined proportion of moving objects in
the gas stream, measures for protecting elements
that could be damaged by the moving objects in
30 the gas stream being carried out in dependence on
the determined presence, the determined number
and/or the determined proportion.
2. A method for monitoring and/or controlling elements
35 that are used in the course of cryogenic gas
separation, wherein, during the cryogenic gas
separation, a gas mixture in the form of a gas

- 28 -

stream (10) is compressed in a compression process and allowed to expand in an expansion process, **characterized in that**

- 5 - moving objects (11) in the gas stream (10) are detected, in that
 - the gas stream is irradiated with electromagnetically emitted radiation (12) in the microwave or terahertz range,
 - scattered radiation (13) that arises due to
10 scattering of the emitted radiation at at least one object (11) in the gas stream is detected,
 - a difference in frequency between the scattered radiation and the emitted radiation is detected and
 - 15 - a presence, a number and/or a proportion of moving objects in the gas stream is determined from the difference in frequency before and/or after the compression process and/or the expansion process.
- 20 3. The method as claimed in claim 2, wherein the elements that are used in the course of cryogenic gas separation are formed as a droplet separator, a direct-contact cooler, an evaporator with which
25 droplets are entrained in the case of incomplete evaporation, an inertia-force separator, a cyclone separator, an electrofilter or a gas scrubber.
- 30 4. The method as claimed in one of the preceding claims, the gas mixture being allowed to expand by means of a throttle valve, an expansion turbine, a pressure loss at a pipeline and/or a bend.
- 35 5. The method as claimed in one of the preceding claims, the gas mixture being compressed and cooled in a multistage compressor and/or a dew point of the gas mixture being monitored.

6. The method as claimed in one of the preceding claims, the moving objects being filtered out from the gas stream while taking into account the determined presence, the determined number and/or the determined proportion of moving objects in the gas stream.
7. The method as claimed in one of the preceding claims, the determining of the presence, the number and/or the proportion of moving objects in the gas stream comprising:
comparing one or more parameters (17) of the detected scattered radiation with one or more predetermined threshold values; and
establishing that the parameter or parameters respectively lies/lie within or outside a comparison interval given by the threshold value or values.
8. The method as claimed in one of the preceding claims, which additionally comprises:
determining a frequency of the scattered radiation and/or a frequency of a Doppler signal resulting from the emitted radiation and the scattered radiation;
determining from the frequency of the scattered radiation or the Doppler signal a relative velocity of the moving objects in the direction of the emitted radiation and/or a flow velocity of the moving objects in the direction of the gas stream.
9. The method as claimed in one of the preceding claims, which additionally comprises:
determining a signal strength (17) of the scattered radiation and/or a signal strength of a Doppler

- 30 -

signal resulting from the emitted radiation and the scattered radiation;

5 determining from the signal strength of the scattered radiation or the Doppler signal a characteristic variable that corresponds to an average size of moving objects and/or a number of moving objects per unit of volume in the gas stream.

10 10. The method as claimed in one of the preceding claims, the emitted radiation being emitted obliquely or parallel or perpendicularly in relation to the direction of the gas stream and/or at changing irradiating angles (α) and/or at
15 changing emission frequencies.

11. The method as claimed in one of the preceding claims, the emitted radiation being emitted by one or more radar devices (14),
20 the method comprising determining a distance or a distance range of the moving objects from a predetermined reference value.

12. The method as claimed in one of the preceding
25 claims, which comprises determining a flow velocity of the gas stream.

13. The method as claimed in one of the preceding
30 claims, the moving objects being solids or droplets of a liquid.

14. A device for separating gases of a gas mixture in a gas stream, having
- the device being designed for compressing the gas
35 mixture in the form of the gas stream in a compression process and allowing it to expand in an expansion process,

- 31 -

- at least one emitter (18) for irradiating the gas stream with electromagnetically emitted radiation (12) in the microwave or terahertz range,
 - at least one receiver for detecting scattered radiation (13) when the latter arises due to scattering of the emitted radiation at at least one object (11) in the or at the gas stream and
 - means (15) for detecting a difference in frequency between the scattered radiation and the emitted radiation,
- characterized in that**
- the means are designed for determining a presence, a number and/or a proportion of moving objects (11) in the gas stream from the detected difference in frequency before and/or after the compression process and/or the expansion process,
 - the device being designed for carrying out the separation of the gases of the gas mixture while taking into account the determination of the means (15) for detecting the difference in frequency, the device being designed for carrying out measures for protecting elements that could be damaged by the moving objects (11) in the gas stream in dependence on the determined presence, the determined number and/or the determined proportion.

15. A device (1) for monitoring and/or controlling elements that are used in the course of cryogenic gas separation, wherein, during the cryogenic gas separation, a gas mixture in the form of a gas stream (10) is compressed in a compression process and allowed to expand in an expansion process, which device has:
- a pipe (2) or a vessel for conducting the gas stream through;
- characterized in that**

- 32 -

- the device (1) also has:
at least one emitter (18) for irradiating the gas stream with electromagnetically emitted radiation (12) in the microwave or terahertz range;
- 5 at least one receiver for detecting scattered radiation (13) when the latter arises due to scattering of the emitted radiation at at least one object (11) in the or at the gas stream; and
means (15) for detecting a difference in frequency
- 10 between the scattered radiation and the emitted radiation before and/or after the compression process and/or the expansion process, the means (15) comprising data processing means for the evaluation of one or more parameters (17) of the
- 15 scattered radiation, in order to determine a presence, a number and/or a proportion of moving objects (11) in the gas stream from the difference in frequency.
- 20 16. The device as claimed in claim 14 or 15, the at least one emitter and the at least one receiver being components of one or more radar devices (14).
- 25 17. The device as claimed in one of claims 14 to 16, the emitter or emitters being designed for irradiating the gas stream obliquely or parallel or perpendicularly in relation to the direction of flow.
- 30 18. The device as claimed in one of claims 14 to 17, the emitter or emitters being designed for irradiating the gas stream obliquely variably from different directions and/or at the same time from a number of directions.
- 35 19. The device as claimed in one of claims 14 to 18, the means (15) for detecting a difference in

- 33 -

frequency comprising data processing means for the evaluation of one or more parameters (17) of the emitted radiation and/or being formed

5 for comparing one or more parameters of the detected scattered radiation (13) with one or more predetermined threshold values and for establishing that the parameter or parameters respectively lies/lie within a comparison interval given by the threshold value or

10 values; and/or

for determining a frequency of the scattered radiation and/or a frequency of a Doppler signal resulting from the emitted radiation and the scattered radiation, and for determining

15 from the frequency of the scattered radiation or the Doppler signal a relative velocity of the moving objects in the direction of the emitted radiation; and/or

for determining a signal strength (17) of the scattered radiation and/or a signal strength of

20 a Doppler signal resulting from the emitted radiation and the scattered radiation, and for determining from the signal strength of the scattered radiation or the Doppler signal a

25 characteristic variable that corresponds to an average size of moving objects and/or a number of moving objects per unit of volume in the gas stream; and/or

for determining a distance of the moving objects

30 from the receiver (14); and/or

for determining a flow velocity of the gas stream; and/or

for fusing the parameter or parameters with data that are supplied by one or more external

35 sensors, the external sensor or sensors being based on measuring principles other than Doppler radar.

- 34 -

20. The device as claimed in one of claims 14 to 19,
which also comprises a filter that is suitable for
discriminating radiation that arises due to
5 scattering of the emitted radiation at stationary
objects (2).
21. The device as claimed in one of claims 14 to 20,
which is formed as a direct-contact cooler for an
10 air separating installation or as an air separating
installation.