(12) UK Patent Application (19) GB (11) 2 426 823 (13) A

(43) Date of A Publication 06.12.2006

(21) Application No: **0616567.4**

(22) Date of Filing: **12.11.2004**

Date Lodged: **21.08.2006**

(30) Priority Data:
(31) **20035031** (32) **13.11.2003** (33) **NO**

(62) Divided from Application No
0424969.4 under Section 15(4) of the Patents Act 1977

(71) Applicant(s):
Roxar Flow Measurement AS
(Incorporated in Norway)
PO Box 2364 Solheimsviken,
NO-5824 Bergen, Norway

(72) Inventor(s):
Warren Sneedon
Gunnar Wedvich
Morten Ivar Andersen

(continued on next page)

(51) INT CL:
G01N 29/22 (2006.01) **G01N 29/44** (2006.01)

(52) UK CL (Edition X):
G1G GPKX

(56) Documents Cited:
None

(58) Field of Search:
UK CL (Edition X) **G1G**
INT CL **G01F, G01N**
Other: **WPI, EPODOC**

(54) Abstract Title: **Acoustic detection of foam or liquid entrainment in the gas outlet of a separator tank**

(57) One or more passive acoustic sensors 1 are placed are fitted externally on a fluid carrying pipe, for example the gas outlet 2 of an oil/water/gas separator tank 3, preferably near a pipe bend 2a. The output signal from the sensor is compared with a threshold to detect foam or liquid entrainment in the gas outlet. The threshold is based on an adaptively adjusted reference level (or curve) for the signal from the detector which includes estimates of the average background noise level. A warning alarm may be provided so that dosing of antifoam chemicals may be increased. The method may also be used for sand and pig detection or detection of hydrate particles in wet gas.

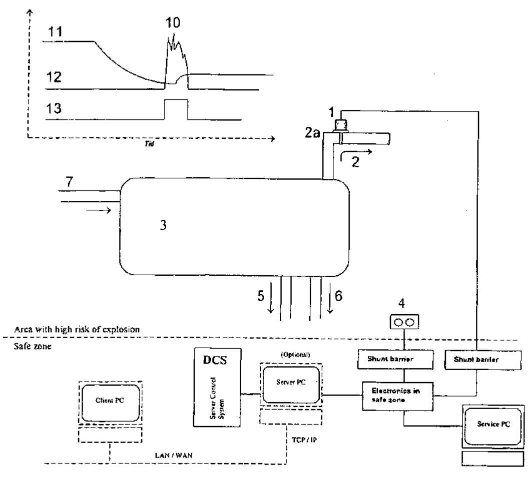
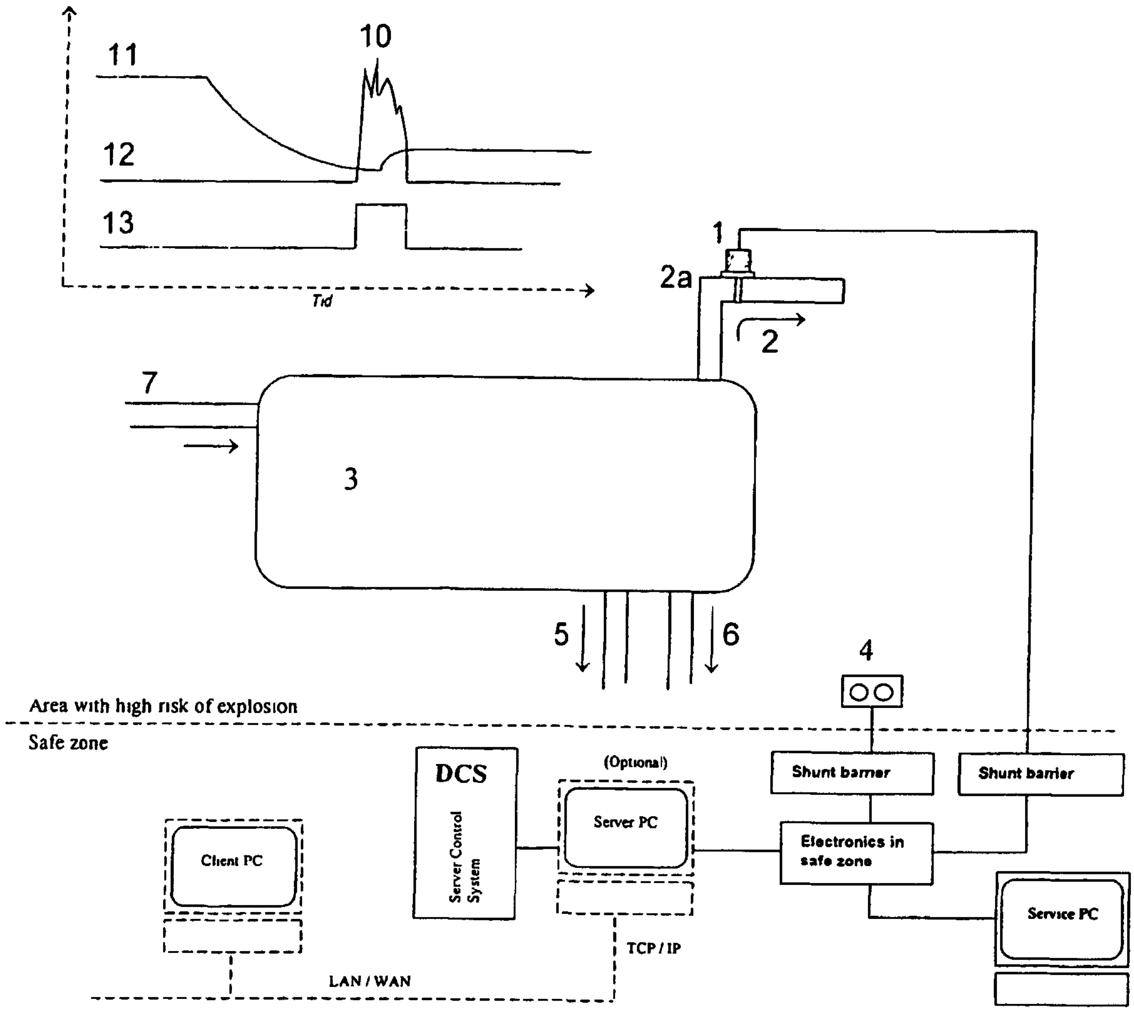


Figure 1.

GB 2 426 823 A

(74) Agent and/or Address for Service:
Appleyard Lees
15 Clare Road, HALIFAX, West Yorkshire,
HX1 2HY, United Kingdom



11
10
12
13
Tid
1
2a
2
7
3
5
6
4
Area with high risk of explosion
Safe zone
DCS
Server Control System
(Optional)
Server PC
Client PC
Shunt barrier
Shunt barrier
Electronics in safe zone
Service PC
TCP / IP
LAN / WAN

Figure 1.

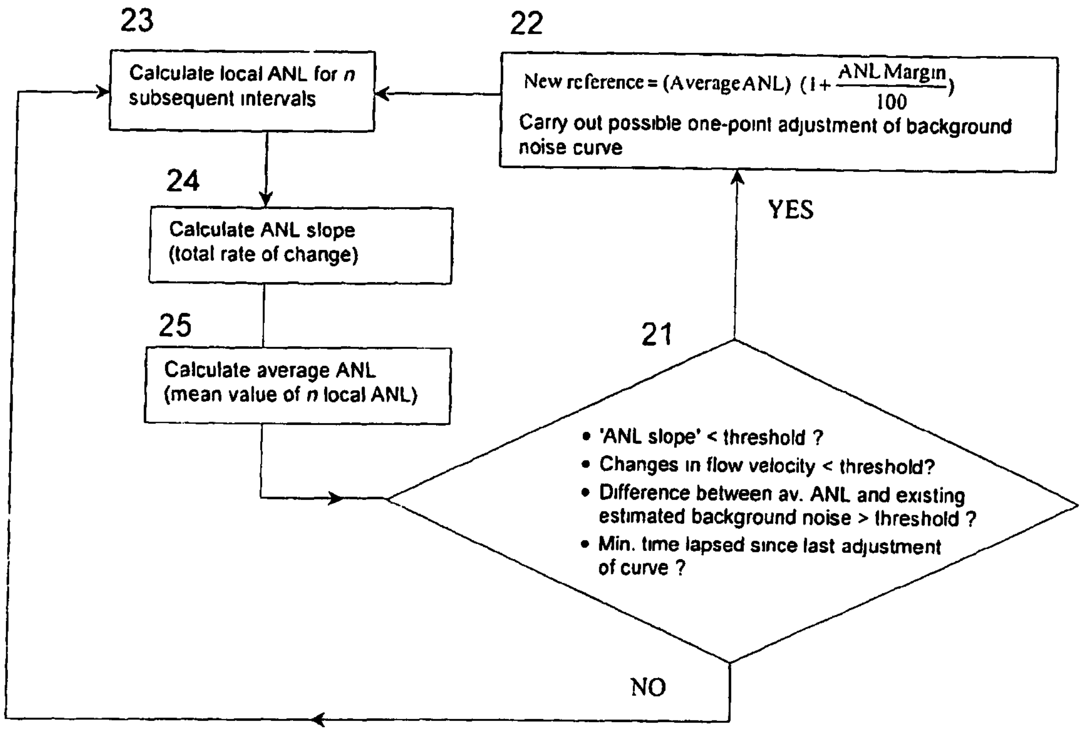

23
Calculate local ANL for n subsequent intervals
22
New reference = (Average ANL) (1 + ANL Margin / 100)
Carry out possible one-point adjustment of background noise curve
24
Calculate ANL slope (total rate of change)
25
Calculate average ANL (mean value of n local ANL)
YES
21
• 'ANL slope' < threshold ?
• Changes in flow velocity < threshold?
• Difference between av. ANL and existing estimated background noise > threshold ?
• Min. time lapsed since last adjustment of curve ?
NO

Figure 2.

SYSTEM AND METHOD FOR DETECTION OF FOAM IN PIPE FLOW

In general, the present invention relates to a system and a method for detection of rapid flow changes in a fluid carrying pipe, and also application of this. More specifically, but not exclusively, the invention relates to detection of foam or other unwanted liquid entrainments in the gas outlet of separators of oil, water and gas.

Formation of foam in oil separators/water separators/gas separators is a well known problem, and any entrainment of foam and fluid particles in the gas outlet can lead to much damage to downstream equipment, such as compressors. Therefore, costly antifoam chemicals (inhibitors) are employed to reduce this problem.

Coriolis flowmetres are used at some installations for the detection of possible foam or fluid entrainment, but this is a relatively costly and space demanding technology. Thus, instrumentation for continuous monitoring is often missing and 'measurements' can be carried out in the simplest way possible: by manually opening a small valve, holding a cloth in front of the outlet and checking if this get moist/discoloured (a so-called rag test).

There are a number of known techniques and sensor systems for measuring flow in pipes, whether it is for detection of the presence of a given medium, detection of movement, measuring of mass flow or the like. A common feature is that one or more sensors directly or indirectly measure specific physical properties of the flow media and that they send out raw signals or processed signals which reflect these properties, or possibly derived measurement parameters.

Measurement and analysis of acoustic flow noise in the ultrasound range has been found to be a robust technology for detection of sand in pipe transport of fluids. Sand that collides with or possibly scrapes along the inside of the pipe wall at a pipe bend generates a characteristic broadband noise which is detected by one or several acoustic sensors fitted to the outside of the pipe. However, this type of sand-generated noise will always be superimposed on a backdrop of broadband noise from the fluid flow itself, that contributes within the same relevant frequency bands. Today's passive acoustic sand detectors are therefore based on relative measurements and must normally be calibrated against actual flow conditions and flow rates.

In sand measurements, undesired sand noise can be especially pronounced and problematic when an 'unfortunate' gas-liquid-ratio (GLR) results in turbulent and uneven flow, and in measurements on gas wells it is a well known problem that even small liquid particles can lead to pronounced noise effects. These are normal conditions that can put limitations onto these types of systems, but when used (indirectly) as measuring parameters they are, on the other hand, well suited to detection of foam entrainment or liquid entrainment in gas outlets on separators. The system according to the present invention is based on existing basic technology for sand and pig detection, but with adapted mounting, detection methods and software for this new application area. An example of an actual sand measuring instrument is shown in Norwegian Patent Application No. 1997 4904.

The present invention aims to make possible continuous monitoring of flow in pipes with a compact and cost effective technology, and with robust and immediate detection of any incidents. The equipment is fitted externally and can be installed on existing pipes without shutting down the process. The potential gains are considerable:

- General reduction in the consumption of antifoam chemicals without increased risk of fluid entrainment or shutting down the process. Reduction in expenses for chemicals, reduced environmental load.
- Increased safety for downstream processing equipment.
- Improved control when wells are taken from testing to processing and a new minimum rate of antifoam chemicals is to be established.
- Fewer and shorter incidents of liquid entrainment into the gas pipe. This will contribute to keep the pipe line cleaner, and to maintain low pressure drop and high through flow.
- Reduce risk for plugging of glycol systems at planned or unplanned shutting down. (Based on a cleaner pipeline corresponding to above.)

More specifically, the aims of the present invention are attained as described in the independent claims.

As mentioned above, the invention can be used mainly with a starting point in already existing measuring equipment used in a new application.

The invention will be described below with reference to the enclosed drawings, which describe the invention with the help of examples.

Figure 1 Principle diagram of a possible implementation of 'RFM Carryover Detector'

Figure 2 Simplified flow diagram for estimating existing background noise, and any adjustment of the reference level / reference curve.

Some characteristic features of the mentioned system are given below, and a possible implementation is outlined in Figure 1, which shows a diagram of a preferred application of the invention.

The figure shows a separation system comprising an inlet 7 of a separator tank 3 which is equipped with three outlet pipes 2,5,6 for gas, water and oil, respectively.

One or more passive acoustic sensors 1 are fitted externally on an actual fluid carrying pipe, in the shown example the gas outlet 2. The sensor or the sensors are not in direct contact with the process, are not penetrating, and can be fitted onto existing pipes. Removal of any paint or other surface treatment at the contact point on the pipe is the only necessary adjustment; to ensure the best possible acoustic connection and to meet any possible requirements for galvanic contact for intrinsically safe equipment.

As mentioned, the sensor can be of the type that is described in the abovementioned Patent Application No. 1997 4904. The sensor 1 can be fitted in its own base on pipes; the base is attached to the pipe with steel wire and tension rods, adjustable clamps or other flexible and safe appliances. Sensor and base can also be one integrated unit.

The sensor is primarily fitted in, or near a pipe bend 2a, or possibly at other obstructions that contribute to turbulent flow. The functionality can also be maintained by fitting onto straight pipe sections, but weaker readings will then normally be obtained.

According to this embodiment of the invention, the sensor constitutes one unit with at least one passive acoustic probe and one or more amplification steps and filter modules, and also any A/D converter(s), a signal processing module with one or more DSP or microcontrollers/processors and associated software, a memory module, a communication module, etc.

Typically, the sensor(s) operate within one or more frequency bands in the ultrasound range, but for this type of application detection in the audible range (<20 kHz) is also relevant. It is possible to adjust the choice of frequency band to the individual application.

The output signal from the sensor can be filtered raw values that reflect measured acoustic noise level, pretreated data, or processed data in the form of alarm signals or control signals. As an alternative to a fully integrated unit, data processing, data storing, configuration or other functionality can completely or partially be placed in a separate module. Figure 1 illustrates such a solution for an area with a risk of explosion, where the sensor is intrinsically safe but parts of the electronics are placed in a safe zone.

The output signal from the sensor system can be connected to a pc communication port for possible further processing, display of result, handling of the alarm etc, possibly be connected directly to an external control system for the process, possibly to the control system via a pc, possibly to alarm lamps or noise generators 4.

Preferably, the detecting methods include an option for automatic adjustment of the reference level and possible reference curve against the background noise of the process and adjustable thresholds w.r.t both duration and level of the noise deflection. The thresholds can also be made adaptive. This gives a robust system, at the same time as the operator or service personnel get great flexibility w.r.t the setting of the tolerance limits and alarm functions. This will be described in more detail below.

How antifoam agents reduce 11 is illustrated in figure 1a, something which will contribute to increased foam formation. At a certain point in time, a marked increase in the level of the raw signal 10 from the sensor 1 indicates entrainment of foam in the gas outlet 2. The alarm signal 13 is activated and this ensures an increase in the amount of antifoam agent 11. The technical execution of the process itself will not be described in more detail here, as it is only an example of one application of the invention.

The method according to the invention is described with reference to figure 2. In this context, the methods described are directed especially to robust detection of foam entrainment or liquid entrainment in the gas outlet of separators of oil, water and gas, but is generally not limited to this type of application. (Different sides of the processing will, for example, be directly applicable to both sand and pig detection, detection of hydrate particles in pipe transport of wet gas etc). The methods cover two main points:

- Adaptive adjustment of reference level and possible reference curve against the background noise in the process (ABA function)
- Detection

The words 'background noise' are used here as a collective term for noise contributions that do not constitute the useful signal in the measurements. This will, for example, in connection with sand measurements, reflect the sum of contributions from the sensor set noise and flow generated noise when sand is not present in the pipe flow, in addition to any noise from nearby valves etc. All noise that exceeds the background noise for a given flow velocity will afterwards be interpreted as contributions from sand. For detection of foam entrainment or liquid entrainment in a gas outlet it will correspond, but the useful signal is then constituted by a marked increase in flow noise above and beyond the normal level at the relevant velocity.

For sand systems with access to process parameters (for example, rates, pressure, temperature, etc), a reference curve is normally established for background noise vs. flow velocity (typically increasing steadily) for example, by polynomial adaptation to empirical measurements. Then one shall later be able to isolate the useful signal by 'inquiry' to the curve with flow velocity as input. However, use of a fixed curve over time assumes implicitly that the processing conditions do not change much with respect to the reference measurements. Such an assumption will have a time limited validity, and the need for manual readjustments of reference curves has until now been the norm for these types of passive-acoustic systems. The present invention includes a new function for adaptive readjustment of reference level and possible reference curve against background noise. This is denoted 'ABA' after Automatic Background Noise Curve Adjustment', and is activated and configured through Service Software. Note that ABA functionality must not necessarily be tied up to a curve, in spite of the name. For systems without access to process parameters it is only the last updated reference level that has any practical significance whatever the flow velocity.

The ABA function is based on frequent calculations of an estimated average background noise level, 'ANL', short for Average Background Noise Level. Under given assumptions an evaluation of ANL over time will be able to give a basis for an automatic readjustment of reference level and possible reference curve, also called background noise curve.

A possible readjustment of reference level assumes that ANL has been relatively stable over time. The degree of stability is in practice measured by determination of an 'ANL Slope' (rate of change), which is calculated from ANL over a given number of consecutive time intervals. The 'ANL Slope' is obtained as the sum of two terms, an estimated mean ANL rate of change for the whole period and a term that shall reflect the spread of the ANL values that are included. The total shall thereby give a better estimate for the rate of change, with 'penalty increments' for local variations. (A low mean rate of change will alone not be a good indicator for stable conditions, periodic noise fluctuations can, for example, arise under certain flow conditions, with significant variations around an approximately constant level). In a preferred embodiment of the invention, mean ANL rates of change over the intervals in a period are found as the absolute value of the gradient of a first order fit, found by the so-called least squares method. The 'penalty increment' is calculated as twice the standard uncertainty of the estimate; it shall correspond to a 95% confidence interval for an assumed normal distribution.

The calculated 'ANL Slope' is held up against a defined threshold. If it is lower than the threshold, stable conditions are assumed, and average ANL over the evaluation period are taken to be representative for the existing background noise. It is this average value which is used for readjustment of the reference level and possible curve, given that all criteria are satisfied. Possible curve fitting is carried out by a so-called 'one point adjustment'.
A background noise curve can, for example, be represented with a third order polynomial of the form:

$$G(v) = A\,v^3 + B\,v^2 + Cv + D, \qquad (1)$$

where v is the flow velocity and A to D are coefficients. With 'one point adjustment' one assumes that D is constant, while the other coefficients are scaled linearly with a common multiplication factor determined by the curve having to go through the new reference point. This retains the constant term which shall reflect the zero reading of the sensor at no flow conditions, and at the same time maintains the general form of the curve. Only the slope of the curve is fitted.

ANL for one simple interval is calculated as the mean value of a selection of the lower measurement values. The measurement values are first sorted in increasing order, and a certain percentage of the very low values are discarded as possible rejects. ANL is thereafter found as the mean value of a new percentage of the lowest (remaining) measurement values.

If all criteria for adjustment of reference level and possible curve are satisfied, an average ANL (for an evaluation period of n intervals) is assumed to be representative of the level of existing background noise. However, before use as a references point, ANL is scaled up by a small percentage factor. This shall ensure that the reference level lies somewhat above the noise floor, to accommodate more or less insignificant noise fluctuations.

Figure 2 shows a simplified flow diagram for the ABA function.

According to the embodiment shown in the figure, local ANL is calculated over a number of intervals 23 and the 'ANL Slope' 24 is calculated based on these.

According to a preferred embodiment of the invention, adjustment of reference level and possible background noise curve will only be activated under the assumption that all of the following criteria 21 are met:

- Calculated 'ANL slope' 24 is below a defined threshold value. (Indicates stable conditions).
- The flow velocity (if known) has not changed 'significantly' within the evaluation period. The tolerance for the velocity change is determined by a defined threshold value, and shall accommodate smaller variations which, for example, can be due to mildly fluctuating pressure.
- The absolute difference between average ANL 25 and background noise level w.r.t existing reference must exceed a defined minimum value. (Marginal changes are ignored to avoid repeated adjustments under approximately constant conditions).
- A defined minimum time has lapsed since any last adjustment. (Auto-adjustment only aims to compensate for long term trends in the process conditions).

If all criteria are met, a new reference level is established, possibly a one-point adjustment 22 of the background noise curve is also carried out – as described. If not, no further action is taken. In both cases, the system goes straight into a new ANL evaluation period.

The ABA function can be flexibly configured with the following adjustable parameters:

- ANL Interval Length [min] : Duration of each individual (local) interval.
- ANL Selection Fraction [%] : Fraction of measurement values that are included in the calculation of local ANL (after first filtering).
- # of Intervals : Number of ANL-intervals, *n*, that are included in the evaluation of ANL trend / existing background noise level.

- Velocity Variation Tolerance [m/s] : Tolerance threshold for velocity variations within the evaluation period for ANL. (Only relevant for systems with access to the flow velocity).
- Maximum ANL Slope [100 nV / hour] : Tolerance threshold for ANL rate of change within the evaluation period.
- Minimum Δ ANL [100 nV] : Relates to difference between a new average ANL and background noise level w.r.t. existing reference. If absolute difference is lower than the threshold, no adjustment of the reference level and possible reference curve, will be carried out.
- ANL Margin [%] : Percentage factor for scaling up of calculated average ANL, before possible use as a reference point and possible adjustment of the background noise curve.

Detection

In entrainment of liquid or foam in the gas outlet, the useful signal will be characterised by a marked increase in flow noise above and beyond the normal level at the actual flow velocity. For this type of application, one can therefore prepare for robust detection without an accurate calibrated background noise curve, and it will not even necessarily be appropriate to connect the system up to process inputs from external sources. A frequent readjustment of the reference level, which ABA functionality can ensure, shall be sufficient. A simple comparison with sand detection can enlarge on this: The accuracy in sand measurements will be directly dependent on the accuracy of the reference level that is used. A level that is too low or too high can lead to overestimation or underestimation, respectively, of produced amount of sand, and corresponding possibility for false sand indication under sand free conditions or reduced sensitivity for small amounts of sand, respectively. Therefore, it is important that the reference level is as accurate as possible at all times, and process inputs must ideally continuously reflect the flow velocity – so that 'inquiry' to the reference curve/background noise curve is correct. In detection of foam entrainment /liquid entrainment one does not have the same strict need for accuracy. One refers only to detection / non-detection and the typical detection threshold will exceed the effect of normal velocity variations. Thereby, one is not dependent on accurate calibration or continuous updating of the reference level against velocity and use of, and process inputs from, external sources are strictly unnecessary.

The system finds adaptively an estimate for existing background noise level and uses this as a reference for *relative* thresholds. (A detection threshold will, for example, relate to additional noise beyond existing estimated reference noise level/background noise level.) The detection itself can be configured with the following adjustable parameters:

- Carryover Onset Threshold [Δ 100 nV] : Noise threshold for detection of entrainment, relative to existing reference level.
- Minimum Duration [Sec.] : Minimum duration of detection above absolute threshold level before a possible alarm condition is activated . With this one can avoid possible false alarms due to short-lived noise from other sources. (Clocks / counters will be zeroed out as soon as the noise level falls back below 'Carryover End Threshold'. Any active alarms will be deactivated at the same time).
- Carryover End Threshold [Δ 100 nV] : Noise threshold to exit from detection mode and possible alarm condition caused by entrainment, relative to existing reference level. ('Carryover End Threshold' cannot be set larger that 'Carryover Onset Threshold').

Together with ABA functionality, the simple detection method provides a robust and adaptive system.

Alarm function and control signals

- The system will detect entrainment of liquid / foam if measured noise level exceeds the sum of 'Carryover Onset Threshold' and existing reference level. In addition, activation of an alarm presumes that the detection continuously persists in a minimum period determined by 'Minimum Duration'.
- The system will exit from an alarm condition when the noise level falls back below the sum of existing reference level and 'Carryover End Threshold'.

It will be possible to deliver the present invention in a series of different versions, with a wide register of technical solutions and electronic interfaces. With today's hardware, the alarm signal can, for example, be communicated as digital messages with serial communication (directly from the sensor system or via a pc with dedicated software), possibly be delivered as a current signal of 4-20 mA output or voltage signal via a galvanic isolated 'Volt Free Contact'. The type of interface and communication link are otherwise subordinate to the function of the system itself.

Alarm signals will typically be connected up to an overriding control system to warn the operator who can take the necessary actions, possibly for automated control via a dedicated control loop. Actions at entrainment of foam or liquid in gas outlets will typically be increased dosing of antifoam chemicals and/or increasing pump rates for the fluid outlets, for general lowering of the top level.

With optimal utilisation of the present invention, one wishes primarily to achieve a general reduction of the use of expensive antifoam chemicals , without increased risk for foam entrainment/liquid entrainment and shutting down of the process. The potential economic gains for the end user shall be considerable.

Claims

1. Application of an acoustic sensor arranged to receive acoustic signals within a given frequency range, for detection of foam entrainment or liquid entrainment in the gas outlet of a separator tank, where the detection is obtained when the acoustic signal exceeds a given threshold value.

2. A method of applying an acoustic sensor according to claim 1, wherein the acoustic sensor is positioned at the gas outlet pipe of the separator tank.

3. Application according to claim 1 or 2, where the threshold value acts dynamically with respect to a regular adjustable reference value, said reference value being calculated based on measured acoustic noise at the connection to the pipe.

4. A method of applying an acoustic sensor according to any of claims 2 or 3, characterised by the sensor being placed in connection with the pipe for reading of acoustic information from the fluid flow,

the definition of a reference value for the signal from the sensor and definition of a threshold value in relation to the reference value, and

detection of change when the level of the received acoustic signal exceeds the threshold value.

5. A method according to any of claims 1-4, where acoustic noise level is continuously estimated and evaluated for persistent changes, and where the reference value is readjusted as a consequence of such changes during a predetermined time period.

6. A method according to any of claims 1-5, where a reference curve for background noise $G(v)$ is defined as a function of the flow velocity v, where the curve $G(v)$ is adjusted automatically based on measured change in the noise situation so that it goes through a new reference value for the noise at actual flow velocity.

7. A method according to any of claims 1-6, where the curve for background noise is given by $G(v) = A v^3 + B v^2 + Cv + D$, where v is the flow velocity, D is the constant noise contribution, while A, B and C define the course of the curve,

where the coefficients A, B and C are adjusted based on the measured change in the noise situation to adapt the curve to go through the new reference value for the noise $G(v)$ at a given flow velocity, and where the adjustment of the coefficients A, B and C is carried out by multiplication of all three coefficients with the same factor.

8. A method according to any of claims 1-7, where the reference value is changed as a consequence of the following assumptions being met:

- Calculated rate of change for noise level is below a chosen first threshold value
- Changes in flow velocity (if availazble) are below a chosen second threshold value
- The difference between new, average reference value and existing estimated value for background noise is above a chosen third threshold value
- The time since the last change has exceeded a chosen time period.

9. A method according to any of claims 1-8, where calculated/estimated rate of change can include increments for the uncertainty of the estimate, for example, corresponding to a 95% confidence interval at assumed normal distribution.

10. A method according to any of claims 1-9, where the reference value used can be a chosen percentage larger than estimated mean reference value.

11. System for detection of irregularities in a fluid flow, especially related to foam formation in a separator tank, comprising at least one acoustic sensor arranged to be fitted to the outside of a pipe containing the fluid flow, said sensor being connected to signal processing means to carry out the method according to any of claims 1-10, characterised in that the signal processing means are arranged to provide a warning signal when the mentioned threshold value is exceeded.

12. A system according to claim 11, where the signal processing means are also arranged to measure the duration of the threshold value being exceeded, and to provide the warning signal after the threshold value has been exceeded for longer than a predetermined period.

13. A system according to claim 11, where the acoustic sensor is placed at the downstream side of a pipe bend.

Application No: GB0616567.4 **Examiner:** Stephen Jennings
Claims searched: 1-13 **Date of search:** 27 September 2006

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
		None

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

G1G

Worldwide search of patent documents classified in the following areas of the IPC

G01F; G01N

The following online and other databases have been used in the preparation of this search report

WPI, EPODOC