SAND DETECTOR CALIBRATION

This invention relates to methods of operating and calibrating acoustic sand detectors, and a method of determining the life expectancy of a flowline. The invention is particularly suitable for implementation with production flowlines of hydrocarbon wells, for example subsea hydrocarbon production wells.

Production fluid from fluid extraction wells, for example underwater hydrocarbon extraction wells, typically have solid particles such as sand entrained within it. The impact of these particles on the walls of production fluid flowlines, which carry the fluid to the surface, is known to erode the walls. If this erosion is unchecked, the flowline may fail, and leak production fluid to the surrounding region.

The level of erosion will be dependent on various factors, with the most important being the quantity of sand entrained within the fluid. It is therefore desirable to be able to monitor the level of sand within the fluid, to estimate the erosion of the flowline.

To this end, acoustic sand detectors have been commonly used to detect sand, by listening to the impact of the particles on the pipe wall. However, the output of such detectors does not give a clear indication of the levels of sand within the flow, since not all the sand will create a detectable impact in the vicinity of the detector. It is therefore desirable to provide effective calibration of these detectors. However, proper calibration by the manufacturers is difficult due to a number of factors, for example:

- Different types of sand, e.g. with differing grain sizes or density;
- Different environments, e.g. pipe differences leading to differing levels of acoustic signal damping, or internal fluid differences, or background noise;
- Imprecise knowledge of the exact location where sand hits the wall, e.g. due to flow properties and sand type.

In addition, the above variables may not only be hard to predict, but may also change substantially over the life of a production field, making the measurement from the detectors even more inaccurate.

It is an aim of the present invention to overcome these problems. This aim is achieved by improving the operation and calibration of acoustic sand detectors using local flow characteristics.

The invention uses methodology that can enable more accurate determination of sand amounts in flowlines, e.g. production flowlines of a fluid extraction well, and the resulting erosion of equipment.

In accordance with a first aspect of the present invention there is provided a method of operating an acoustic sand detector deployed at a flowline within a flow system, the detector having an acoustic sensor and functioning to produce electrical output signals in dependence on acoustic signals detected by the acoustic sensor, the acoustic signals being at least partially produced by the impact of sand particles within the flow on an object, comprising the steps of:

a) estimating the location of particle impacts on the flowline; and

b) weighting the output signals according to the distance between the estimated location and the detector location.

In accordance with a second aspect of the present invention there is provided a method of calibrating an acoustic sand detector, comprising the method in accordance with the first aspect, and further comprising the steps of:

c) measuring the amount of sand collected at a location downstream of the detector within a certain time period;

d) calculating the amount of the collected sand which has been carried along the flowline based on both the amount of sand collected in step c) and the weighted output signals over a period of time corresponding to the time period of step c); and

e) calibrating the detector by integrating the weighted output signals over the period of time.

In accordance with a third aspect of the present invention there is provided a method of determining a life expectancy of a flowline, comprising the steps of:

i) calibrating an acoustic sand detector deployed at the flowline using the method in accordance with the second aspect;

ii) measuring the amount of sand passing through the flowline over a period of time using the acoustic sand detector;

iii) determining the level of erosion at an area of the flowline;

iv) correlating the level of erosion with the measured sand amount to determine a relationship therebetween; and

v) applying the relationship to the output of the acoustic sand detector.

The present invention provides various advantages, including:

- More accurate quantification of sand quantity through the flowline. This in turn can be used to indicate formation damage and possible impending flowline collapse, and accurate determination of erosion.

- Updatable or near real-time adjustment of calibration.

Using the above information, well operators are better placed to change operational parameters to increase the life of equipment and / or the hydrocarbon reservoir.

The invention will now be described with reference to the accompanying drawings, in which:

Fig. 1 schematically shows an acoustic sand detector deployed at a flowline, suitable for calibration in accordance with the present invention; and

Fig. 2 schematically shows a well system including a number of flowlines fitted with acoustic sand detectors suitable for calibration in accordance with the present invention.

Fig. 1 schematically shows an acoustic sand detector 1 deployed at a flowline 2, wherein the fluid flow direction is from the leftmost end to the lower right end as shown by the arrow. The acoustic sand detector 1 comprises an acoustic sensor 3 which picks up acoustic signals and transducer 4. The acoustic signals received by sensor 3 are fed to the transducer 4, which converts the acoustic signals into electrical output signals 5. Such acoustic sand detectors 1 are known in the art.

Fig. 1 also shows possible flow paths for two sand particles A and B, which as a result of the complex fluid flow within flowline 2 are caused to impact on the side of the flowline 2. As shown, the flowline includes an elbow, and the impacts are likely to occur in the vicinity of the elbow as shown. Assuming that the particles A and B are of similar constitution, mass and speed at the time of impact with the side of the flowline 2, it is apparent that the impact of particle B will cause a greater acoustic signal to be picked up by sensor 3 than the impact of particle A, since the sensor 3 is closer to the impact site of particle B than the impact site of particle A.

Fig. 2 schematically shows an underwater, e.g. subsea, well flow system including a number of flowlines 2 with respective acoustic sand detectors 1 deployed thereat. As shown in Fig. 2, there are three flowlines 2_1, 2_2 and 2_3, equipped with detectors 1_1, 1_2 and 1_3 respectively. Each flowline 2 carries production fluid from a respective well via its "tree" and a production choke (not shown) to a common production flowline 6, which in turn carries production fluid to the surface (not shown). A separator 7 is provided on the common production flowline 6, at a position downstream of all the flowlines 2, which is effective to continuously separate the oil, water and gas. The solids (sand) also drop out and are collected periodically. It should be noted that Fig. 2 is schematic only, and the relative positions of the wells, detectors and sand separator are not to scale.

A method in accordance with the present invention, enabling improved operation and calibration of the or each sand detector, will now be described:

1. Particle impact location prediction

As mentioned above, the acoustic signal measured by each sand detector 1 will be dependent on:

i) the proximity of an impact to the sensor, such that, as shown in Fig. 1, an impact at location B will tend to produce a larger acoustic signal than an impact at location A;

ii) the quantity of sand impacting;

iii) the velocity of the sand at impact;

iv) the size of sand particles impacting; and

v) the density of the sand particles impacting.

It is clear that with a single acoustic measurement but five unknowns the matter is 'under-determined', i.e. there is more than one possible solution to the equation that relates all of the six variables.

In addition, some of these variables are inter-related, for example, the location of impact will vary with flow velocity and particle properties (size and density), as may the quantity of sand impacting.

Particle properties, including the size and density, meanwhile can be assessed for example by collecting samples, such as at the separator 7. In most cases it is reasonably safe to assume that these particle properties remain substantially constant, but they could also be updated periodically based on sand collected at the surface.

Using these determined parameters, it is possible to correlate the average impact location of particles within a flowline to the flow velocity.

This correlation can be achieved by using offline techniques such as computational fluid dynamics (CFD) (specifically particle tracking methods within the more general CFD), thus predicting where the particles impact on the flowline wall for given velocities.

The next stage is to determine a value for the flow velocity.

Some more advanced sand detectors use Doppler method to determine the velocity of the particles, to increase the accuracy. At present, only the 'high end' acoustic sensors have this

capability. If that data is available then it can be used 'as is', if not then the velocity may be estimated in various ways, e.g.:

- calculating the bulk density of the fluid using measured differential pressures, usually down-hole to the tree. The pressure drop across a known orifice (typically a choke, but could for example be a venturi) would be measured, and then these two bits of information may be used to calculate the bulk flow rate and hence the velocity. This is a well-known technique, typically termed 'virtual metering'.

- Using the output of a dedicated flow meter, which could be single or multi-phase.

- Making (relatively crude) assumptions about the velocity based on a determined production choke position or pressure drop across the choke.

With any of these methods it would be assumed that the particle velocity would be the same as the fluid velocity, which is considered a reasonable assumption.

The determined flow velocity may then be fed into the CFD correlation online to estimate the impact location for that velocity.

This means that all of the unknowns i) - v) listed above may be deduced, except for ii) the quantity of sand impacting. However, since the acoustic signal is also measured, there is now sufficient information to derive the sand quantity - in other words the equation relating the variables may now be solved.

This result can then be factored into the detector calculation to improve its accuracy. In other words, the acoustic signals picked up by a detector 1 can be weighted according to the estimated impact location according to the distance between the estimated location and the detector location. The degree of weighting required can be determined experimentally or by modelling.

Such predictive techniques may be selected for complexity. For example, although it is difficult to measure particle properties in real-time, the fluid flow properties can be so measured, and so the impact location prediction, and thus the detector weighting, can be updated relatively quickly. Simpler alternatives could be to assume that the flow properties are relatively constant. In this case, the prediction will be updated less regularly. In this respect it is noted that in the

short term, choke positions could vary by +/- 10% just for pressure balancing reasons. In the longer term (e.g. years) the changes may be more dramatic as the reservoir depletes. A 10% change in flow will change the location of impact of particles.

2. Sand transport time estimation

In this step, the sand transport time t_s, i.e. the time taken for sand to travel from the vicinity of a detector (i.e. a location at which it is possible for the detector to detect an impact involving the sand) to the separator 7, is estimated. Since a typical installation practice may be to install the sand detectors on or close to the tree (i.e. one per well), in practice t_s will approximate towards the time taken for the sand to travel from a well to the separator 7.

Typically, t_s will be different for each flowline 2.

Again, there are various techniques of differing complexities which can be used to estimate the sand transport time. A simple technique for example could be to assume that the particles are carried along with the fluid flow at the fluid flow speed.

A more accurate method would be to use a model, such as the "OLGA" (oil and gas simulator) model, described for example at

http://www.ife.no/main_subjects_new/petroleum_research/flowas?set_language=en&cl=en

It should be noted that in some cases, e.g. where the flow rates and sand production are substantially constant over time, then it may not be necessary to estimate t_s, as set out in paragraph 5 below.

3. Physical sand measurement

In this step, sand is collected from sand separator 7. This is then measured to determine a total sand volume for the field collected within a certain time period (i.e. the time since the sand was last collected in this way), noting that as shown in Fig. 2, the separator 7 is downstream of all the wells in the field system, and cannot discriminate between sources of sand.

4. Readings from acoustic sand detectors

In this step, readings from each acoustic detector 1 in the system are taken. These readings are weighted according to step 1 above. For the subsequent steps, only those readings which have been taken over a period of time corresponding to that of step 3 above are required.

5. Correlate readings

In this step, the weighted readings from step 4 are correlated with a physical sand measurement, using both the time difference estimated in step 2, and the time which has elapsed since the sand was last collected from separator 7. In this way the amount of collected sand which has been carried along the or each flowline may be calculated from the weighted output signals and the amount of collected sand.

To understand this process more easily, a simple example is now set out:

Suppose the field is as shown in Fig. 2, i.e. it includes three wells, such that the fluid from each is analysed by a separate respective acoustic detector 1, and the flow from each well passes through a separator 7.

As an example, the total sand collected from the separator 7 after a particular time period T could be 6kg, and it is assumed that separation of sand by separator 7 is perfect. Here, $T = t_{c2} - t_{c1}$, where t_{c1} and t_{c2} are successive times at which sand is collected from the separator.

Now, when the separator 7 is emptied, it will include a volume of sand which has already passed by a detector 1. Furthermore, additional sand which has passed by detector 1 will be located in the flowline 2 but will not yet have reached separator 7. Therefore, it is preferable not to directly correlate the detector signal over the time period T with the amount of sand collected by separator 7 over the same period, but instead, to take the sand transport time t_s determined in step 2 into account to select the required time period used. On the other hand, if the flow rates and sand production are substantially constant over time, then it may not be necessary to correct for t_s.

In detail, the sand collected over time period T should be correlated with the detector readings commencing at a time $t_{c1} - t_s$ and ending at a time $t_{c2} - t_s$.

The average weighted reading over the relevant time period from each detector is measured, and a simple relationship between the readings from each detector is calculated to enable the proportion of sand collected at the separator 7 which has been carried along the flowline to be calculated, for example:

Average weighted signal (i.e. total estimated sand which has passed in time period T taking into account the sand transport time t_s calculated in step 2 as set out above) from Well 1 = a

Average weighted signal from Well 2 = 2a

Average weighted signal from Well 3 = 3a

where "a" is a parameter in kg.

Here, equating the amount of sand collected at separator 7 with the total amount of sand carried by each flowline over the relevant time period, gives:

The total readings: a + 2a + 3a = 6kg, therefore a = 1kg.

It is then necessary to calculate the relative amounts of sand carried along each flowline using the relative average acoustic signal output from each detector 1 over the relevant period of time. In the present example, the total sand which has passed by the detector 1 in time period T of Well 1 = a = 1kg,

the total sand which has passed by the detector 1 of Well 2 = 2a = 2kg, and

the total sand which has passed by the detector 1 of Well 3 = 3a = 3kg.

6. Perform calibration

In this step, the reading from the relevant acoustic sand detector 1 is correlated to the sand amount determined in step 5, in order to calibrate the detector 1. This is achieved by integrating the detector's output signal with respect to time, over the period of time commencing at a time $t_{c1} - t_s$ and ending at a time $t_{c2} - t_s$ as described previously.

7. Use the new calibration

Once calibration has been effected as set out above, the or each sand detector may be used to directly measure sand passage in the respective flowlines.

8. Long term application

With each detector calibrated, they may be used to provide additional information on the well system.

For example, it is possible to use the detectors, for example 'intrusive probes' subsea, with other methods on surface (e.g. ultrasonic) or periodic inspection, to assess erosion occurring within the system. In this case, the cumulative amount of sand passing through the flowline over a period of time is measured by the detector. Additionally, the level of erosion at an area of the flowline is determined from readings taken from a flowline wall thickness monitor, which may for example take the form of an intrusive probe. The measured amount of sand may be correlated with the level of erosion to determine a relationship therebetween, for example a rate at which erosion occurs per quantity of sand, for example an 'erosion per kg' value. This in turn enables a prediction of the remaining life expectancy of flowline equipment to be made, based on current or predicted sand production.

Areas of the flowline more at risk of erosion, which are therefore most suitable for having their levels of erosion determined, may be selected using CFD modelling, as is described in B2009005 NO for example.

9. Redundancy

It is noted that systems such as that shown in Fig. 2 provide a level of redundancy for the detector equipment. For example, even if the sand detector 1_1 fails, it is possible to determine the amount of sand being produced by Well 1 by taking the amount of sand collected at separator 7 and substracting the sand measured by detectors 1_2 and 1_3 over the collection period.

If more than one detector fails then additional information is lost, however it is still possible to produce an estimate of the sand produced, using the relationship previously established in step 5.

Using the example described above, suppose that detectors 1_1 and 1_2 both fail. In this example, the amount of sand collected by separator 7 over a time period T is 12kg. It is known from the

earlier measurement that Well 3 accounts for about half of the produced sand, i.e. about 6kg. Well 2 accounts for about twice as much of the remainder as Well 1, i.e. Well 2 produces about 4kg, while Well 1 produces about 2kg.

Of course, this estimation depends on the relative amounts of sand produced by each well remaining substantially constant.

The above-described embodiments are exemplary only, and other possibilities and alternatives within the scope of the invention will be apparent to those skilled in the art.

Claims

1. A method of operating an acoustic sand detector deployed at a flowline within a flow system, the detector having an acoustic sensor and functioning to produce electrical output signals in dependence on acoustic signals detected by the acoustic sensor, the acoustic signals being at least partially produced by the impact of sand particles within the flow on an object, comprising the steps of:

a) estimating the location of particle impacts on the flowline; and

b) weighting the output signals according to the distance between the estimated location and the detector location.

2. A method according to claim 1, wherein step a) includes determining a value for the flow velocity.

3. A method according to claim 2, wherein the determination comprises estimating the velocity of the flow.

4. A method according to claim 2, wherein the determination comprises measuring the velocity of the flow.

5. A method of calibrating an acoustic sand detector, comprising the method according to any of claims 1 to 4, and further comprising the steps of:

c) measuring the amount of sand collected at a location downstream of the detector within a certain time period;

d) calculating the amount of the collected sand which has been carried along the flowline based on both the amount of sand collected in step c) and the weighted output signals over a period of time corresponding to the time period of step c); and

e) calibrating the detector by integrating the weighted output signals over the period of time.

6. A method according to claim 5, comprising the step of estimating the time taken for sand to travel from the vicinity of the detector to the downstream location, and using this estimated time to select the period of time used in step d).

7. A method according to either of claims 5 and 6, wherein the flow system comprises a plurality of flowlines, each having an acoustic detector deployed thereat.

8. A method according to claim 7, wherein step d) comprises equating the amount of sand collected in step c) with the total amount of sand carried by each flowline over the period of time.

9. A method according to claim 8, wherein step d) further comprises calculating the relative amounts of sand carried along each flowline using the relative average acoustic signal output from each detector over the period of time.

10. A method of determining a life expectancy of a flowline, comprising the steps of:

i) calibrating an acoustic sand detector deployed at the flowline using the method of any of claims 5 to 9;

ii) measuring the amount of sand passing through the flowline over a period of time using the acoustic sand detector;

iii) determining the level of erosion at an area of the flowline;

iv) correlating the level of erosion with the measured sand amount to determine a relationship therebetween; and

v) applying the relationship to the output of the acoustic sand detector.

11. A method according to claim 10, wherein step iii) comprises measuring the thickness of a flowline wall.

12. A method according to either of claims 10 and 11, wherein the location of the area of flowline for which the level of erosion is determined is selected using computational fluid dynamic modelling.

13. A method according to any preceding claim, wherein the flow system comprises an underwater hydrocarbon well.