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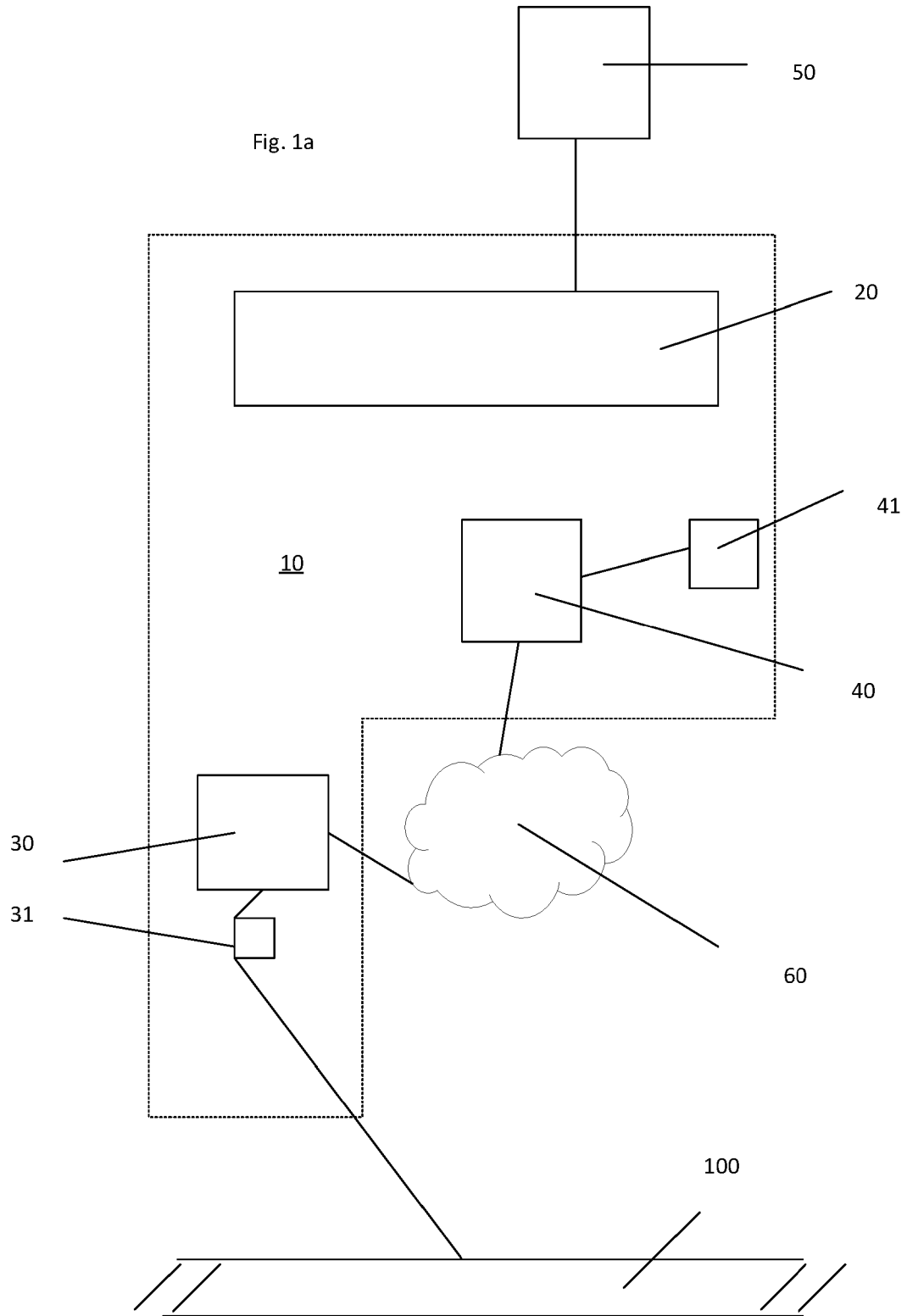
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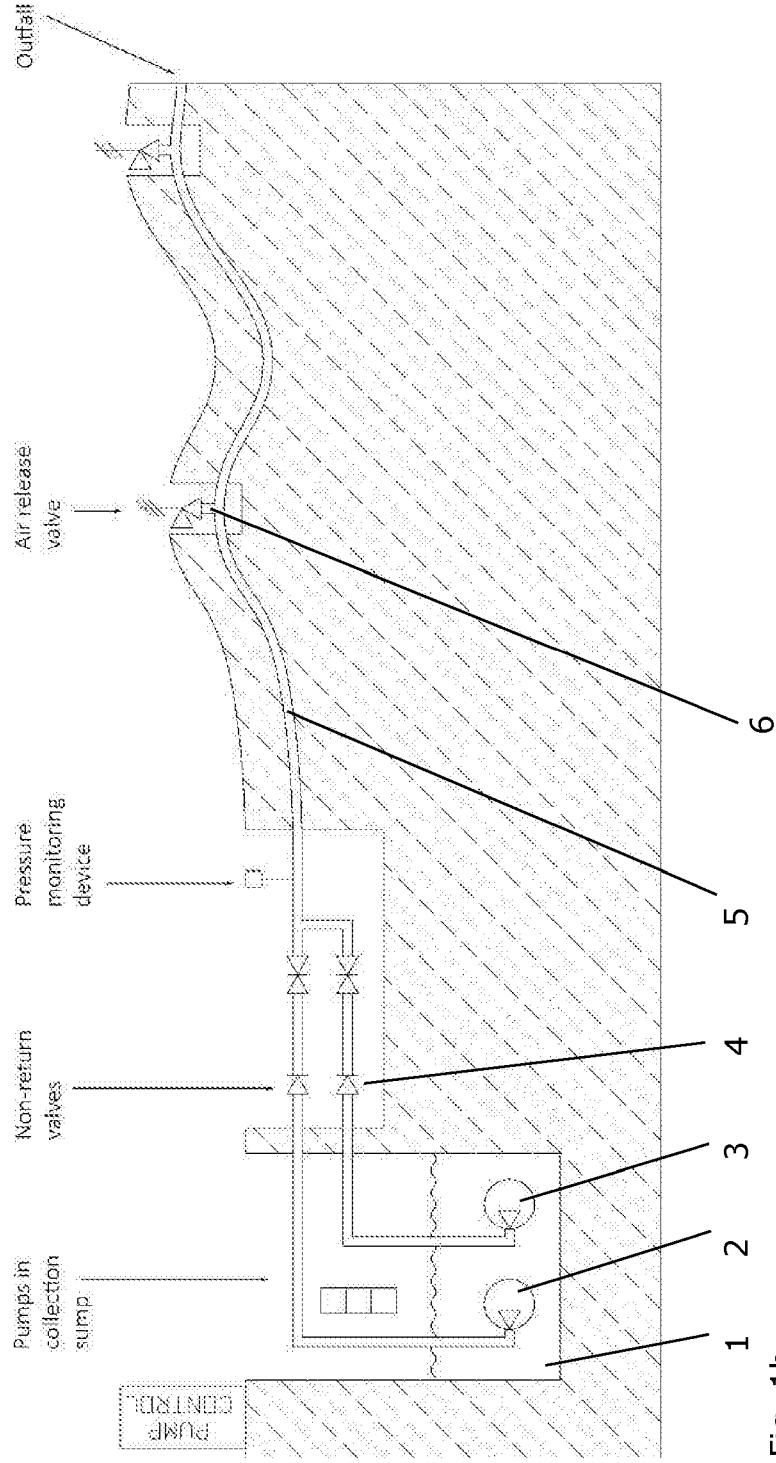


Fig. 1b

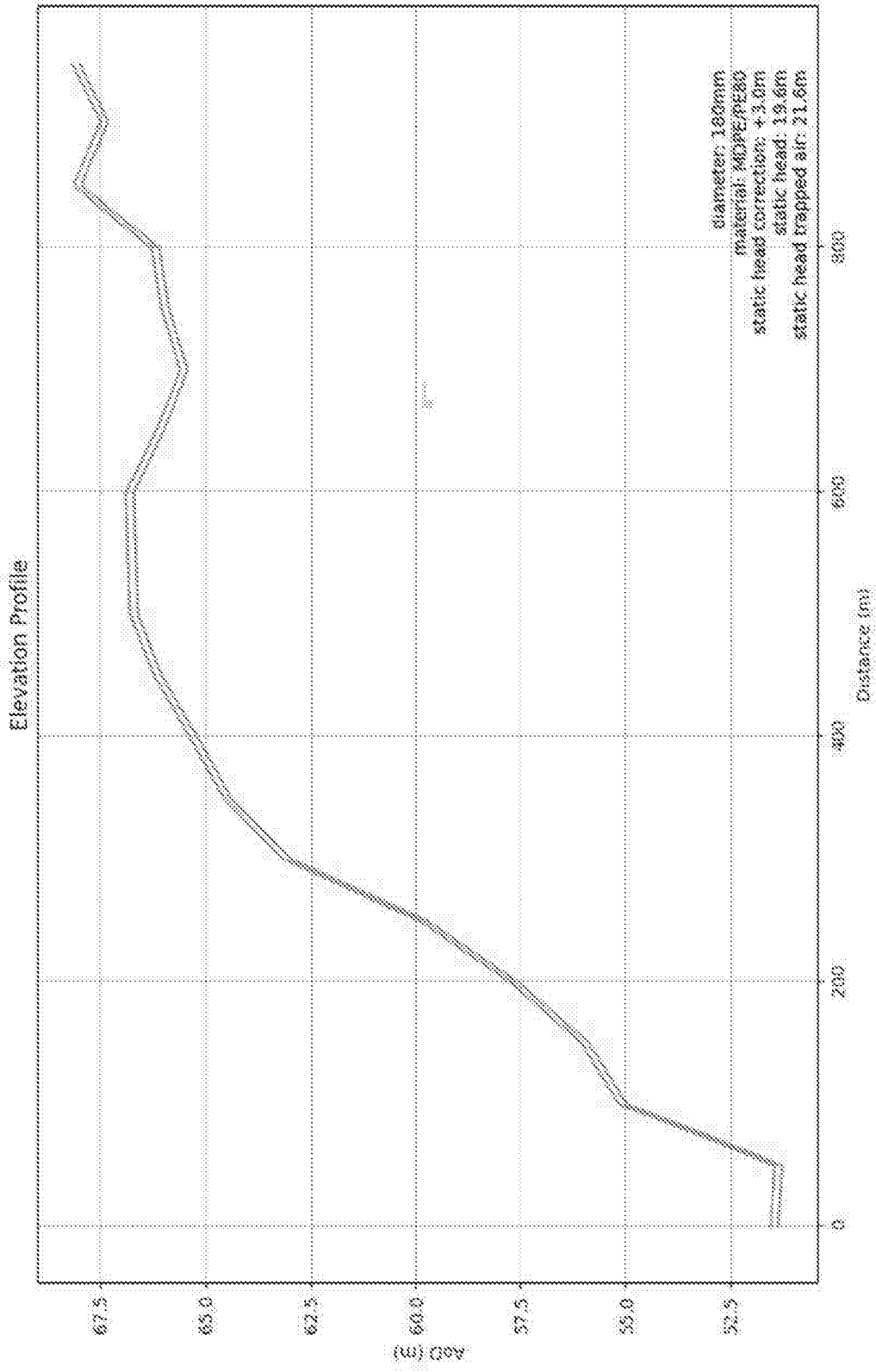


Fig. 2

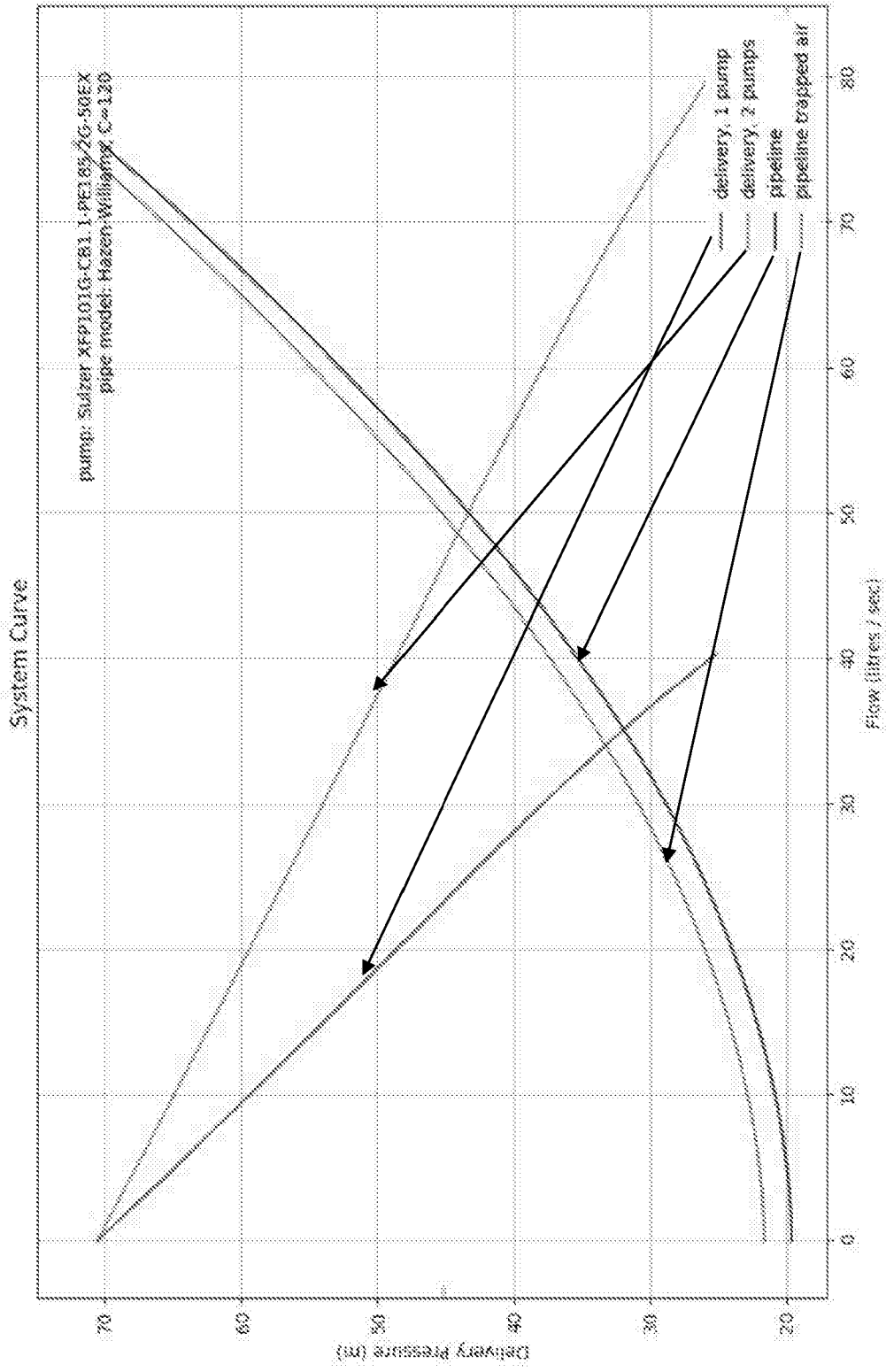


Fig. 3

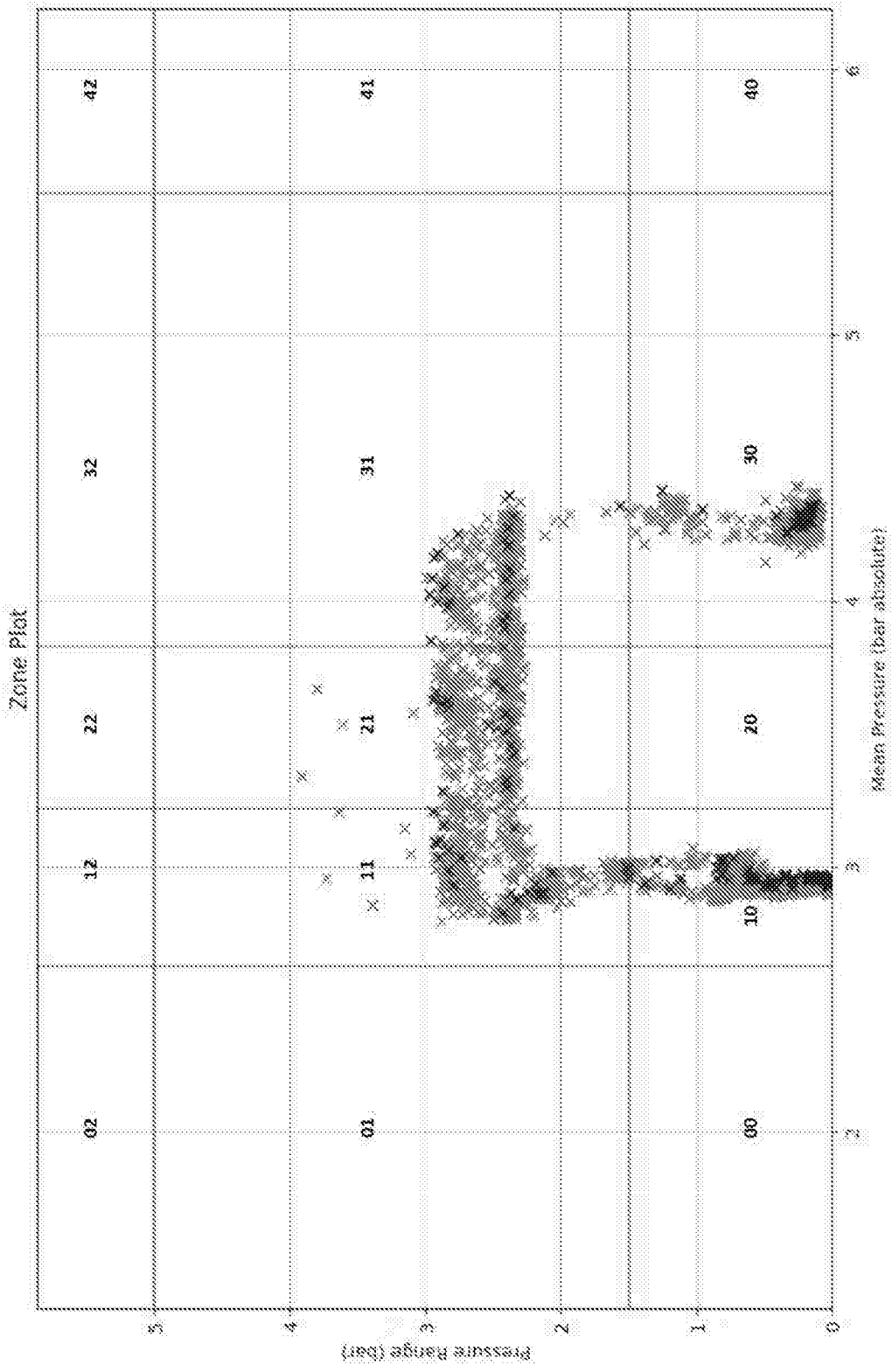
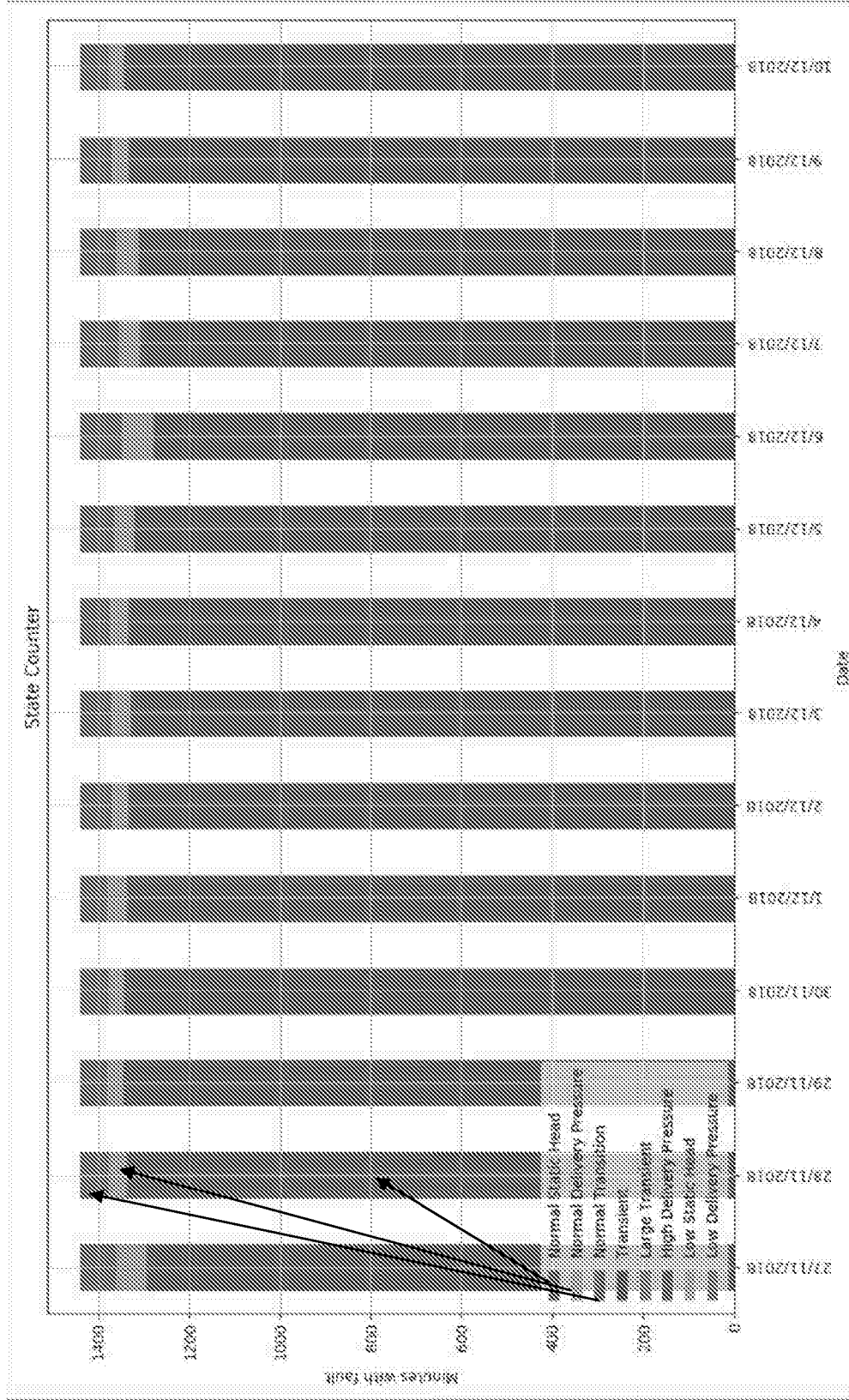


Fig. 4



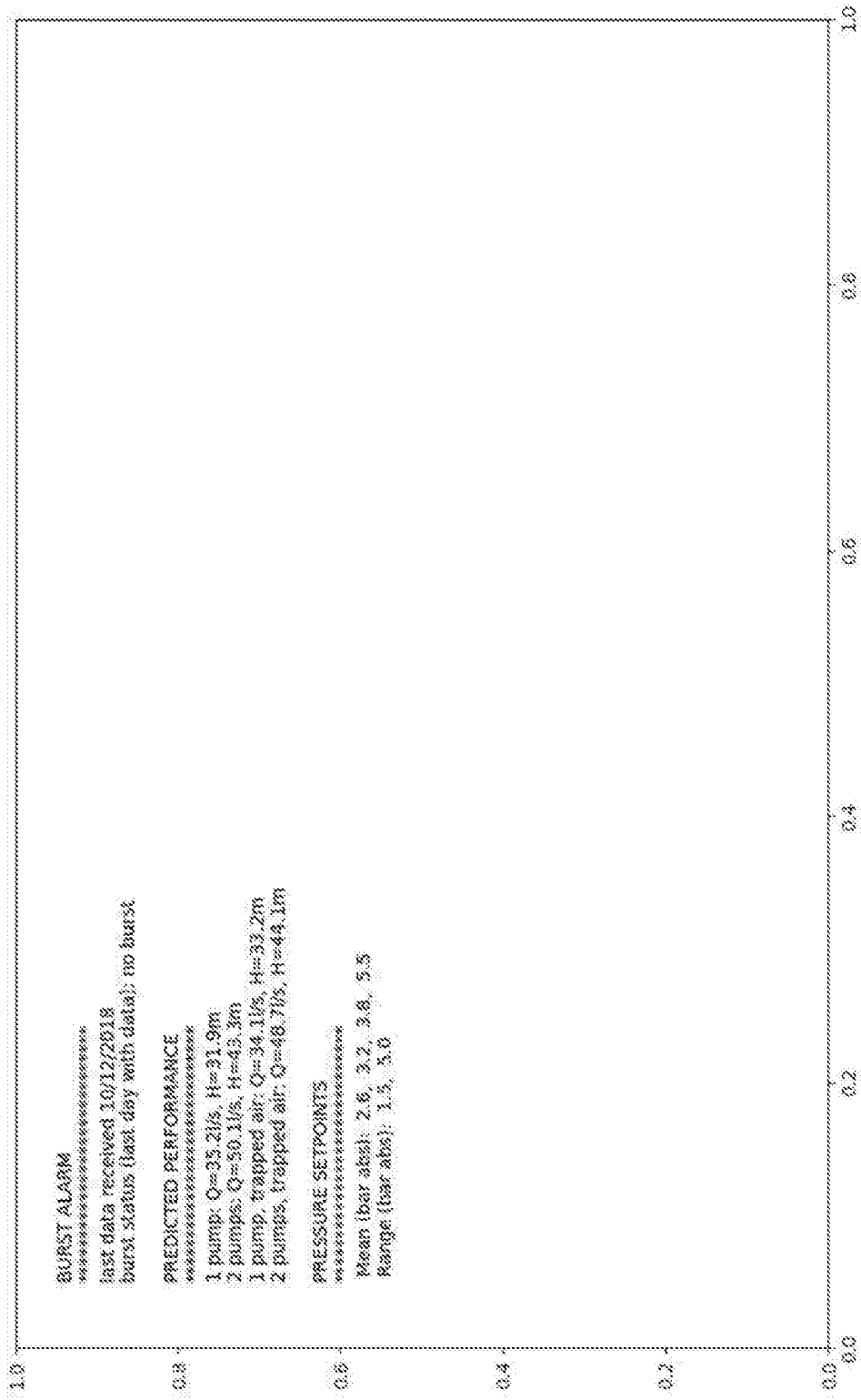


Fig. 6

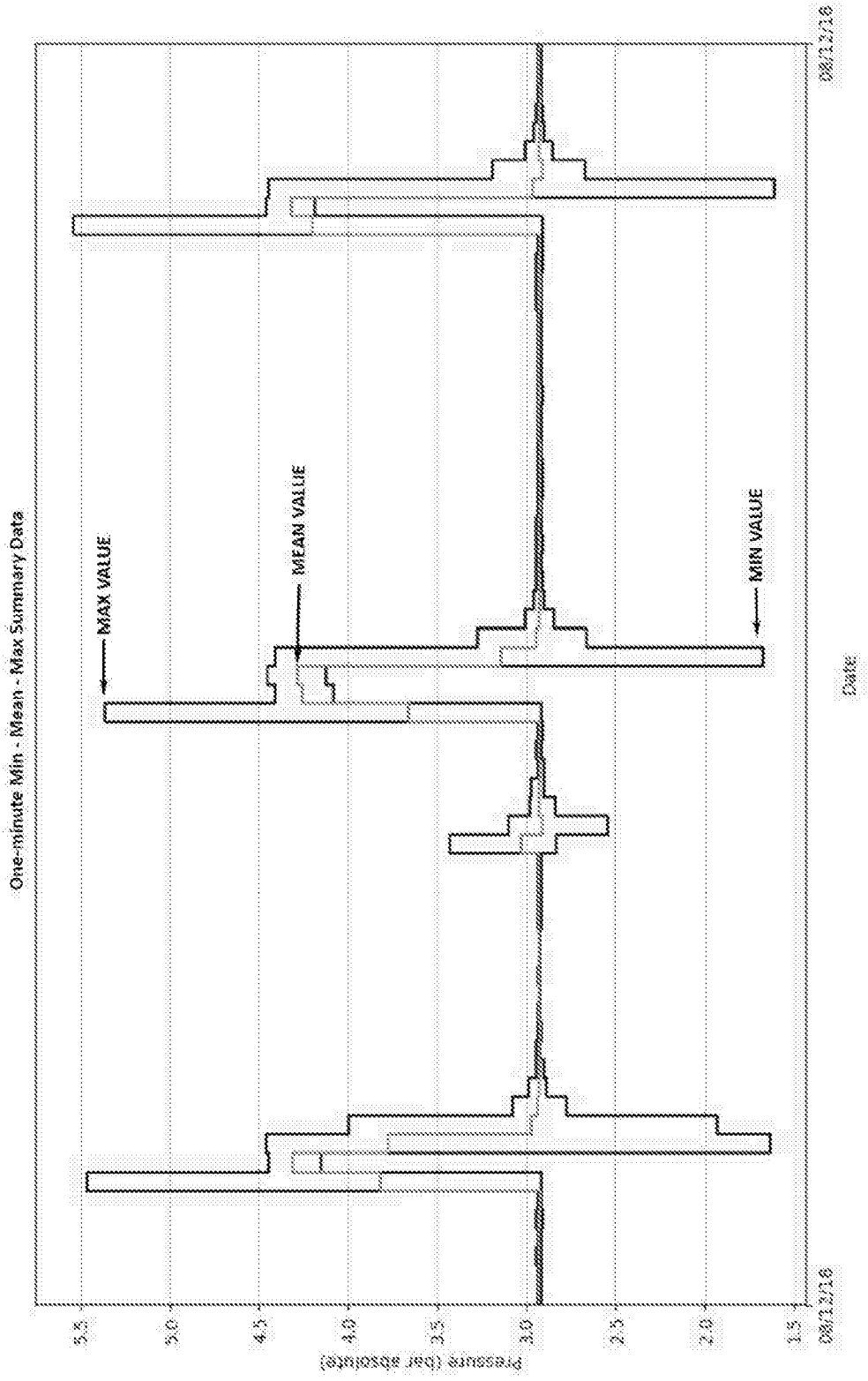


Fig. 7

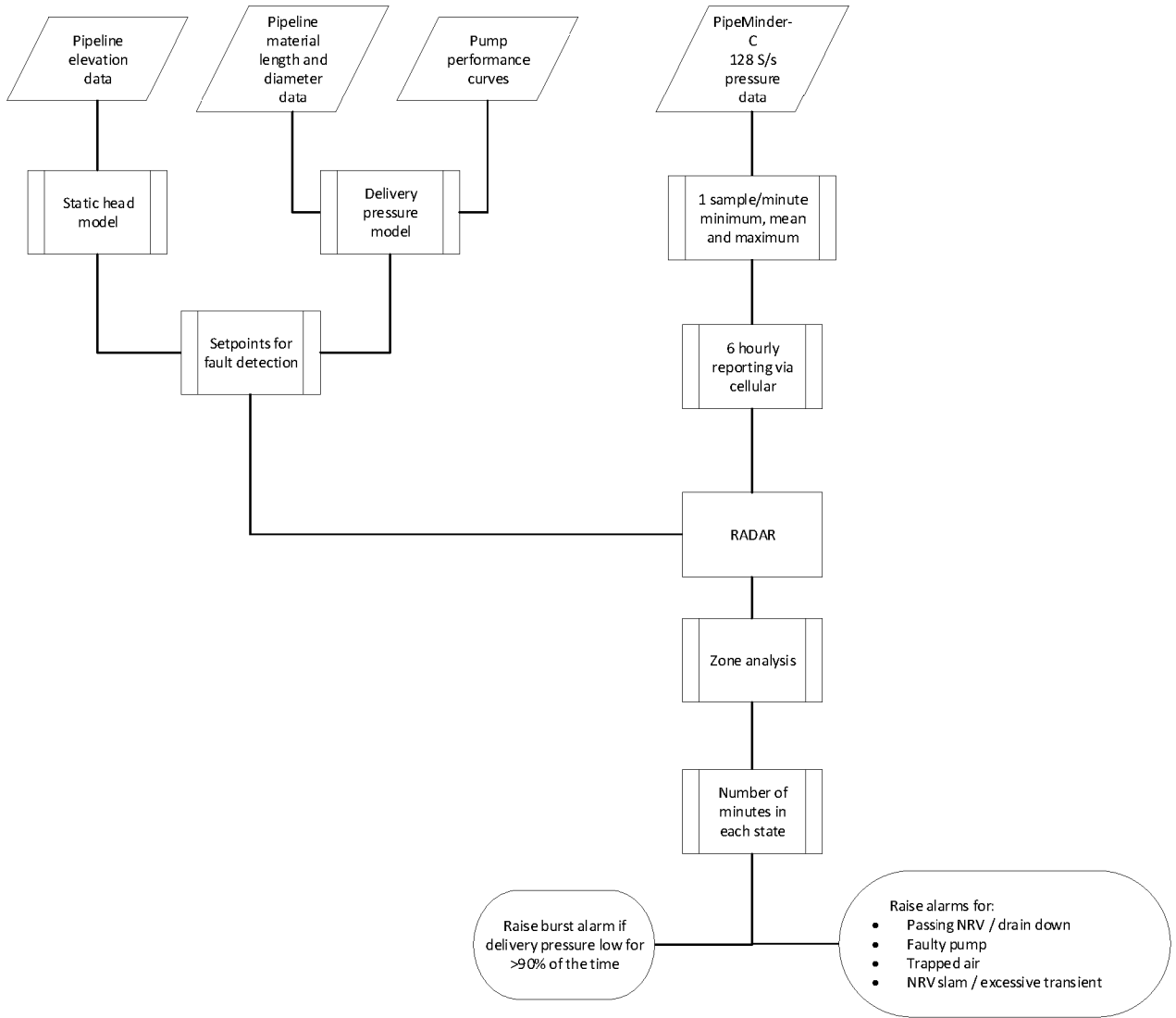


Fig. 8

22 12 20

Rising Main Pipeline Assessment System and Method

Field of the Invention

The present invention relates to a rising main pipeline assessment
5 system and method that are particularly applicable for automated
monitoring and alarm generation for rising main pipelines.

Background to the Invention

Pumped pipelines are used for many applications, although the
10 underlying characteristics of the pipelines differ substantially depending
on application, environment and on the fluid being transported. One
type of pumped pipeline that is particularly prevalent throughout the
world is what is known as a "rising main" or a "forced main". This is a
pumped pipeline carrying water. Rising mains are relatively simple
15 hydraulic systems, transporting waste water from a collection point (a
sump, for example) to either another collection point or to a treatment
facility or carrying potable water from a treatment facility to a storage
facility such a tower or reservoir.

20 Often, rising mains are installed at the time buildings are first erected
and are only interacted with if there is a problem such as a leak or
blockage. In cities and the like it is not unusual for buildings
themselves to be replaced or updated a number of times and still rely
on the rising mains installed to service the original buildings.

25

The most fundamental problem faced by pipeline operators of rising
mains and similar wastewater assets is that due to their age and
believed simplicity, there is very little instrumentation on these

pipelines and what there is, is of a very basic nature. Smart water technologies are conspicuously absent.

5 As these strategic assets age, the risk of failure increases which likewise increases the pressure on pipeline operators to manage their assets more effectively and react to problems more rapidly before they become major incidents. In recent years, agencies such as the UK Environment Agency have viewed pipeline failures of waste water mains as unacceptable and increasingly larger fines are being imposed.

10

One method known to be used in rising mains monitoring employs some form of device which enables a pressure pulse to be generated in the network. The effects of this pulse are then monitored and, dependent upon what is observed, conclusions about the pipeline's integrity or the condition of valves etc may be drawn.

15

Another method uses power monitoring of pumps. This can be used to infer the state or condition of the pump – the impeller is broken, for example

20

Another common technique is to use pump run-hours as an indication of pump performance (imbalance between the two) or pipeline blockage (pump time increases). Whilst this can be effective for assessing the pump performance, it tells little about the pipeline.

25

Assessment of this kind of pipeline is a very specialist field and therefore in any organisation running an estate of such pipelines, there may only be a handful of people who understand and can action the outputs of the techniques noted above.

Statement of Invention

- Embodiments of the present invention seek to provide systems and methods for condition assessment of a pipeline asset. In principle the
- 5 idea/technique is applicable to hydraulically simple pipeline comprising a pump (or pumps) that feeds a pipeline (that does not have additional inflows) leading to an outfall or tank at the end of the pipe, but for the purposes of explanation a "rising main" is used here.
- 10 The method described here, and forming part of one embodiment, uses the hydraulic signals generated as a consequence of the pipeline's operation as the raw data from which inference is drawn. No external device to generate a hydraulic event is needed.
- 15 Pump run hours provide no information on the static state of the pipeline which is a key issue for detecting leakage from the pipeline.

The embodiments discussed here makes monitoring of the condition of pipelines available to a much wider range of pipeline operators and

20 makes the action plan to mitigate the fault or risk very much easier.

Embodiments use a selected suite of data processing techniques that collectively highlight issues that a single one alone cannot. Preferred

embodiments use a very able data collector that, in combination with

25 the data processing techniques seeks to deliver a series of key benefits including:

1. Visualisation of the pipeline's pumped hydraulic operation allowing both automated (most important) and engineer driven alarms to be raised when the pipeline's operation is outside normal,

acceptable, parameters – the most urgent of which is a pipeline burst. The primary client for this information is the network operations team concerned with the integrity of the pipeline.

- 5 2. Examination of the pipeline’s longer-term hydraulic operation, highlighting issues such as (for example) drain down, which could indicate a leak or return valve improper operation. The primary client for this information is the hydraulic modelling and maintenance teams tasked with running assets efficiently and within the regulatory framework in place.
- 10 3. Highlighting the presence of air or gas pockets which are usually present through the non-operation or air release valves (“blow offs”) which, through maintenance neglect often do not function correctly. The original designers of the pipeline understood that not releasing air or gas from the pipeline can lead to serious
- 15 consequences for pipeline operation and hence returning the pipeline to an “as designed” condition is becoming more urgent as these assets age and the engineering redundancy incorporated into the design is eroded.

20 **Brief Description of the Drawings**

An embodiment of the present invention will now be described, by way of example only with reference to the accompanying drawings in which: Figure 1a is a schematic diagram of a rising main pipeline assessment system according to an embodiment;

- 25 Figure 1b is a schematic diagram of a pumped wastewater system with a measurement system of Figure 1;

Figure 2 is an elevation profile obtained for a pipeline and used in one embodiment;

Figure 3 is a visualisation of the delivery pressure model generated for the pipeline using the Hazen-Williams or similar modelling technique;

Figure 4 is a zone plot generated by an embodiment showing mean pressure and expected performance limits;

- 5 Figure 5 is a graphical representation of determined timings (counts of minutes or other timing sample periods in the state) for the pipeline in predetermined states;

Figure 6 is an example operating report that could be provided to a user or written to an event log;

- 10 Figure 7 is a graph illustrating a one minute data sample recorded by the monitoring system; and,

Figure 8 is a flow diagram illustrating a method according to one embodiment.

15 **Detailed Description**

Figure 1a is a schematic diagram of a rising main pipeline assessment system according to an embodiment

- The system 10 includes an analysis system 20, a monitoring system 30
20 and a processing hub 40.

- The analysis system 20 is configured to obtain data externally recorded on the pipeline and, from the externally recorded data 50 and generate a steady state hydraulic model for the pipeline, the model defining
25 expected performance zones for the pipeline under normal operating conditions and zone boundaries delineating normal and abnormal operating conditions for the pipeline. The analysis system being configured to record the model in a data repository 41 of the processing hub 40.

The monitoring system 30 includes a pressure transducer 31 that is connectable to the pipeline 100 (shown in more detail in Fig 1b) and configured to obtain measurements on the pipeline during operation of the pipeline. The transducer 31 and monitoring system 30 and generate, for each of a plurality of predetermined time periods, a data record including minimum, maximum and mean measurements obtained in the determined time period. The monitoring system 30 is configured to communicate the data record to the processing hub 40 (for example over a wired or wireless communication network 60, mesh network or the like).

The processing hub 40 is configured to classify each received data record measurements according to its measurements and the performance zones of the model, the processing hub being configured to monitor the classified data records for each performance zone and generate an alarm upon identifying a predetermined pattern of classified data records.

Figure 1b is a schematic diagram of a pumped wastewater system with an assessment system according to an embodiment.

A typical rising main which delivers waste water from a collection point to a treatment works is shown in figure 1. The diagram shows:

- a collection chamber 1
- two submersible pumps 2, 3 (alternatively could be dry pumps in a separate chamber of equal depth)
- the valve chamber 4 with non-return (reflux) valves and isolation valves
- the rising main 5 with elevation change due to ground level

- air valves 6 to expel air trapped in the system

a monitoring system 30 and pressure transducer 31, (? symbol on Figure 1). It is highly preferred that the monitoring system be capable of resolving, in time, the dynamic pressure changes which occur as the state of the pipeline changes from, for example, idle to pumping.

5

Pressure measurements at the rate at least of 100 samples per second have been found, empirically, to be most suited for the analysis process.

10 Variations on rising mains may include:

- consisting of more than one parallel pipe
- have a different number of air valves
- travel downhill or horizontally (i.e. have no height increase)
- have fewer or more pumps

15 A typical rising main system, because of the relatively small chamber size, will switch the pumps on and off multiple times per hour. Normally only one pump is run at a time, alternating between duty and standby pumps, but occasionally both are run when there is high inflow.

20 In embodiments of the present invention, the performance of the pipe-pump rising main system is predicted by an analysis system 20 prior to instrumentation or analysis by the monitoring system 30. The prediction uses, for example, pump performance curves, elevation and profile of the main, the length, size and material of the main - these are
 25 all combined into a steady state hydraulic model which produces the expected performance for the installation under consideration. The model is then recorded at a processing hub 40 in a central repository 41 for the particular rising main (or rising main segment). Although it is preferred that monitoring and processing is done centrally, it could be

done at the monitoring system 30 or at one or more of a number of distributed nodes (not shown).

The recorded model includes expected performance limits:

- 5 1. The static head (pump(s) off) is estimated from the elevation profile of the pipeline (figure 2). In this example it is 19.6m; this is the altitude change between the pump station (at 0m) and the high point.
- 10 2. The delivery pressure is estimated by modelling the flow head loss of the pipeline, preferably using the Hazen-Williams model or some similar method and overlaying with the pump performance curve. This is repeated for 2 pumps running and for a rising main with trapped air. See figure 3;
- 15 3. The static head with a small error band of approximately +/-5m (this band may vary depending on factors including the pipeline and local environment) is used to set the acceptable pump(s)-off static pressure range;
- 20 4. The predicted delivery pressure for one pump running less 5m is used to set the minimum delivery pressure and the predicted delivery pressure for two pumps running concurrently plus 5m is used to set the maximum delivery pressure.

The elevation profile may be obtained from, for example, an elevation survey, a geographic information system (GIS) or original design documents for the pipeline.

Once the model, including expected performance limits, has been created and stored, data can be processed from the monitoring system 30. Analysis of the pipeline's geographical height changes over the

course of its length, combined with performance curves of the pumps allows the regions of acceptable operation to be derived for each individual pipeline – which we refer to as a profile. This profile is crucial to correct interpretation of the data obtained from the in-service pipeline.

The monitoring system 30 communicates measurements on the pump and rising mains to the processing hub 40 which looks for performance points in the overall performance envelope which are unexpected when compared to the model including outliers or unexpected trends. This is determined with reference to the expected performance model in the repository 41.

Spotting when the measured performance varies from that expected can highlight pipelines that are restricted (blocked); emptying (burst); have trapped air or gas; the pump performance; non-return valve operation (slam shut or stuck open) and other failures that affect the pump delivery pressure or static head of the system. Causes are; pump running on when the sump is dry caused by a failure in the sump level detector; blocked inflow to the pump (blocked suction).

The monitoring system 30 provides data collected during pressure monitoring. This is reported, typically over a cellular or other data communications network 60 to the processing hub 40. The processing hub 40 analyses the data to determine the amount of time spent in the following operating modes:

- Zone 10: Normal static head: pumps off, check valves closed, static head of rising main observed at pressure monitoring point

- Zone 30: Normal delivery pressure: pump(s) on, flow stabilised, static + dynamic head observed at the pressure monitoring point
- Zones 11, 21, 31: Normal transition: during pump start or stop a larger range of pressures, due to hydraulic transient events, are seen at the pressure monitoring point.
- Zones 12, 22, 32: Large transient
- Zone 40: High delivery pressure: pump(s) on but delivery pressure higher than expected
- Zone 00: Low static head: pump(s) off but static head lower than expected
- Zone 20: Low delivery pressures: pump(s) on but delivery pressure lower than expected.

This is then compared to performance limits which in one embodiment include:

1. Monitoring system 30 collects 1-minute summary data of minimum, mean and maximum pressure from samples taken at 128 S/s.
2. Four times a day (could be more frequent) the 1-minute summary data is sent to a cloud analysis platform
3. At the hub 40, the data received is split into zones by plotting each 1-minute summary point on a mean vs range (max-min) graph (see figure 4). This plotting may not necessarily be on a paper or screen based graphical plot. It is more likely to be implemented as a computational process within the data processing hub to allow the swift automated processing of the data.

4. This can then optionally be output to a user. Data from a correctly performing pump station will appear as an upside-down U (\cap) with (referencing Figure 4):
- a. the lower left representing the static head with pumps off (low mean, low pressure range), shown as zone 10.
 - b. the lower right representing the delivery pressure (high mean, low pressure range), shown as zone 30.
 - c. the horizontal part representing the transitions back and forth between pump(s) on and off (high pressure range, increasing or decreasing mean), shown as zones 11, 21 and 31.
5. The vertical lines of the red limits shown on figure 4 are the expected performance limits
6. The horizontal lines of the red limits are empirically set to following an observation period of the system to ascertain the normal areas of operation for the system. The limits are then set to give sensitive positive alerts for abnormal behaviour by creating the fault zones (eg 20, 40, 00) to be as large as possible.
7. Figure 5 shows the number of minutes (or interval counts) spent in each zone during the day. It is important, to prevent false positives and incorrect interpretation of data points, that counts of the system's time in each zone are used rather than the instantaneous appearance of a single point in a zone. Making an alert decision on just one data point can lead to false positives
8. A burst is indicated when $(\text{Minutes Low Delivery Pressure} / (\text{Minutes Low Delivery Pressure} + \text{Minutes Normal Delivery Pressure})) > 0.9$ (i.e. 90% of the accumulated time).

Alarm conditions, as illustrated in Figure 8, may include:

A burst is indicated by:

- Low delivery pressure: $(\text{zone 20 count} / (\text{zone 20 count} + \text{zone 30 count})) > 0.9$
- Points in zone 00 after pump stop (drain down of rising main back into reservoir)

5 A passing NRV is indicated by:

- Points in zone 00 after pump stop (drain down of rising main back into reservoir)
- Points in zones 20 and 30 (i.e. when the pump with the good NRV runs the flow goes back into the sump via the failed NRV / pump)

- 10 • Much longer run times for the pump whose delivery pressure is in zone 20, due to recirculation back to reservoir. This feature discriminates between a burst and a failed NRV.

Faulty Pump

- 50% of delivery pressures in zone 20 and 50% in zone 30 (i.e. when the pump with the good NRV runs the flow goes back into the sump via the failed NRV / pump)
- No points in zone 00 (i.e. no drain down)

Trapped Air

- Changes to the transient response (pump stop / starts), possibly points in 32, 22, 12
- Increased delivery pressure (points in zone 40)

NRV slam/excessive transient

- Points in zone 32, 22, 12

- 25 Preferably, the monitoring system 10 includes a pressure sensing device such as a pressure transducer. In one embodiment, the pressure transducer includes a diaphragm and a strain gauge and is configured to deliver long-term stable data measurements at a sufficiently fast rate. In one embodiment, 128 samples-per-second is processed down

to a rate suitable to the analysis method presented here. This lower rate may be, for example, one sample per minute, although the rate may vary on implementation and also depending on pipeline structure. The system is preferably configured such that the summary min-mean-
5 max is derived from a high sample rate to retain the dynamic range in the summary data point.

It is to be appreciated that certain embodiments of the invention as discussed below may be incorporated as code (e.g., a software
10 algorithm or program) residing in firmware and/or on computer useable medium having control logic for enabling execution on a computer system having a computer processor. Such a computer system typically includes memory storage configured to provide output from execution of the code which configures a processor in accordance with the
15 execution. The code can be arranged as firmware or software and can be organized as a set of modules such as discrete code modules, function calls, procedure calls or objects in an object-oriented programming environment. If implemented using modules, the code can comprise a single module or a plurality of modules that operate in
20 cooperation with one another.

Optional embodiments of the invention can be understood as including the parts, elements and features referred to or indicated herein, individually or collectively, in any or all combinations of two or more of the parts, elements or features, and wherein specific integers
25 are mentioned herein which have known equivalents in the art to which the invention relates, such known equivalents are deemed to be incorporated herein as if individually set forth.

Although illustrated embodiments of the present invention have been described, it should be understood that various changes,

substitutions, and alterations can be made by one of ordinary skill in the art without departing from the present invention which is defined by the recitations in the claims and equivalents thereof.

Claims

1. A rising main pipeline assessment system comprising:
an analysis system, a monitoring system and a processing hub,
5 the analysis system being configured to obtain data externally recorded on the pipeline and, from the externally recorded data, generate a steady state hydraulic model for the pipeline, the model defining expected performance zones for the pipeline under normal operating conditions and zone boundaries delineating normal and abnormal
10 operating conditions for the pipeline, the analysis system being configured to record the model in a data repository of the processing hub;
the monitoring system including a pressure transducer that is connectable to the pipeline and configured to obtain measurements on
15 the pipeline during operation of the pipeline and generate, for each of a plurality of predetermined time periods, a data record including minimum, maximum and mean measurements obtained in the determined time period, the monitoring system being configured to communicate the data record to the processing hub;
20 the processing hub being configured to classify each received data record measurements according to its measurements and the performance zones of the model, the processing hub being configured to monitor the classified data records for each performance zone and generate an alarm upon identifying a predetermined pattern of
25 classified data records.
2. The system of claim 1, wherein the processing hub is configured to split data received into zones by plotting each data record on a mean vs

range (max-min) graph or plot, the processing hub being configured to apply the performance zones to the graph to classify the data records.

3. The system of claim 2, wherein the processing hub is configured to
5 classify data records as falling inside or outside the respective performance zone.
4. The system of claim 2 or 3, wherein the system includes a
10 performance zone for normal static head of the pipeline in which the pump or pumps of the pipeline are off, check valves closed, and static head of rising main is measured by the monitoring system.
5. The system of claim 2 or 4, wherein the system includes a
15 performance zone for normal delivery pressure in which the pump or pumps of the pipeline are on, flow has been determined to be substantially stabilised by the monitoring system and static + dynamic head is measured by the monitoring system.
6. The system of any preceding claim, wherein the processing hub is
20 configured to recognise a pattern as a normal transition event during pump start or stop in which a larger than normal range of pressures, due to hydraulic transient events, are measured by the monitoring system.
- 25 7. The system of any preceding claim, wherein the processing hub is configured to recognise a pattern as a transient event upon matching the data records to a transient pattern.

8. The system of any preceding claim, wherein the processing hub is configured to recognise a pattern as a high delivery pressure event upon the data records indicating that the pipeline's pump or pumps are on but delivery pressure is higher than the respective performance zone.
- 5
9. The system of any preceding claim, wherein the processing hub is configured to recognise a pattern as a low static head event upon the data records indicating that the pipeline's pump or pumps are off but static head is lower than the respective performance zone.
- 10
10. The system of any preceding claim, wherein the processing hub is configured to recognise a pattern as a low delivery pressure event upon the data records indicating that the pipeline's pump or pumps are on but delivery pressure lower than the respective performance zone.
- 15