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## 1 INTRODUCTION

### 1.1 Purpose

Pressure and temperature transmitters are examples of simple instruments that output ready-to-use readings, typically as a current or voltage. You can plug them into your control system and indicate the measured value as a number. For historical trending the details are of little importance so the sample rate can be low and it is OK to apply lossy compression on the data. Remote access directly to the instrument is normally not possible, nor of any use. The measurements are what they are – there is seldom a need to apply adjustments to the historical values.

Sand monitors are different. The output is not a sand rate; it is a raw value that requires post-processing. It is possible to use the raw value for trending, however to quantify the sand production additional information is required. SandQ™ sensors from ClampOn partially eliminate this requirement, however to optimize the system performance it is always useful to feed the data processing some information about the current flow conditions.

Sand production is erratic in nature – it can vary tremendously from second to second. Displaying the instantaneous value of such a reading on a numeric indicator is nearly pointless. For the operators to understand what is going on, the sand rate must be trended at a high sample rate and be presented together with trends of closely related parameters like choke settings, flow rates, pressures and temperatures.

The fact that the quantitative output is the result of a complex algorithm means that it is useful to be able to do recalculations based on the historical values and/or adjust the fixed parameters of the system. The instruments can also be used to do advanced signal analysis and self-tests to optimize their readings. This makes it advantageous to use software from ClampOn to do the calculations and to provide remote access to the system, especially for sand managers and corrosion-erosion specialists - and support engineers from ClampOn.

The purpose of this document is to describe these special aspects of sand monitoring and guide you through the decisions you need to

make to integrate the sand monitors into your process control system and optimize their performance.

The central questions in the design & integration of the sand monitors are:

1. Where do we do the sand calculations?
2. How do we interface with the sensors and/or calculation unit?
3. How do we optimize the accuracy of the system and make sure it is maintained?
4. Would remote access be required, and if so, how do we implement it, and who should have such access?

### 1.2 How sand monitoring works

When particles flow through a pipe bend their inertia will cause some or all of them to collide with the outer wall. ClampOn Particle Monitors are installed in the impact zone to measure the ultrasonic energy from these collisions. We refer to this measurement as the “Raw-Value”.

There will always be some ambient ultrasound, mainly emanating from the gas and liquid flow through choke valves and in the pipe. ClampOn Particle Monitors apply a series of filters to keep this background noise low and stable, however there will still be some of it left, and this “zero”-level will normally vary with the flow rates.

The presence of particles in the flow will rapidly increase the energy level. The amount of energy generated per unit of mass is linked to the velocity the particles have when they collide with the pipe wall. We call this conversion factor the “step”-value. To calculate the sand rate at any given time we use the step to convert whatever energy we have above the zero level, or - put in mathematical terms ( $v$  = fluid velocity):

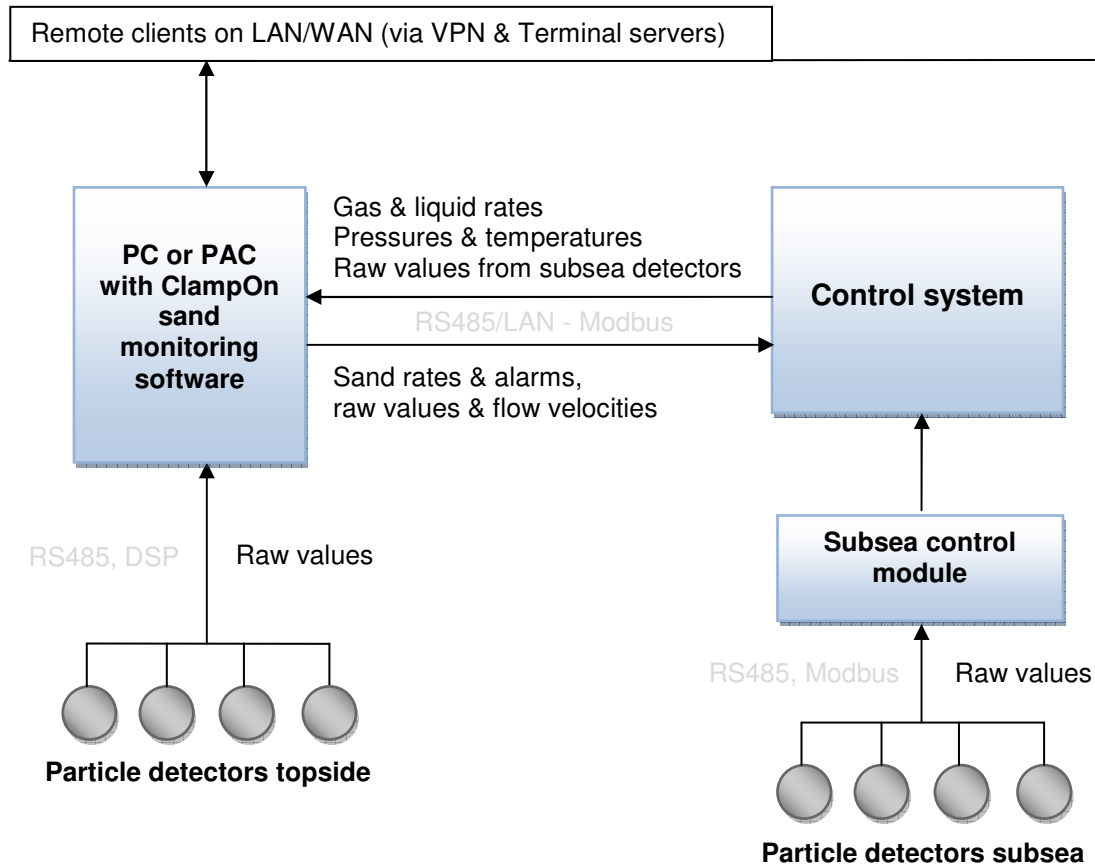
$$\text{Zero} = f(v), \quad \text{Step} = g(v)$$

If RawValue > Zero:  
Sand rate = ((RawValue-Zero)/Step)^Exp

Else:  
Sand rate = 0

Let us look at where and how this calculation should be done, and how to interface with the system:

## 2 SYSTEM DESIGN



### 2.1 The standard solution

The drawing above shows the tried and proven way of implementing a ClampOn sand monitoring system. Off the shelf sand monitoring software from ClampOn, running on a computer or a tiny automation controller, communicates directly (or via radio or network) with detectors topside. The processing unit is linked to the control system to receive measured or inferred flow rates, pressures and temperatures - and these parameters are used to calculate the sand rates. The results are sent back on the same link. Data from detectors subsea are either polled by the control module and routed topside for processing, or acquired by the processing unit itself using a separate, transparent, link (if such functionality exists). All communication with the sand monitoring system runs on industry standard hardware and protocols. Remote access and control is available by using the TCP/IP based client-server interface of the processing unit.

#### 2.1.1 Advantages

With the standard solution, project and installation time is kept at a minimum. There is little work required on the control system, and the sand calculation is maintained by ClampOn. The processing unit logs and displays current and historical data and has a client-server interface for remote access and control. Choosing a standard solution simplifies training and support, and opens up for value adding services like sand management.

For topside systems the standard solution removes the need to interface directly with the sensors. This means that you get access to all the advanced features of the native, proprietary protocol of the sensors (self testing, calibration, spectrum analysis, software download and more) without having to deal with the complexity of supporting it in the control system.

The sand monitoring software running on the PC or controller supports a wide range of industry standard protocols:

## 2.1.2 Interface options for the processing unit (PC/PAC)

Physical Interface	Protocol	In-built	Available as plug-in	Available as gateway	Two-way	No. of channels
LAN	Modbus TCP/IP	✓			✓	Unlimited
RS485/232	Modbus RTU/ASCII	✓			✓	Unlimited
LAN	OPC server & client			✓	✓	Unlimited
LAN	DDE server		✓		✗	Unlimited
LAN	PI Batch Files		✓		✗	Unlimited
4-20 mA	NA		✓		✓	Hardware dependant
Relay	NA		✓		✗	Hardware dependant

The sand monitoring software consists of a standard core which is used for all systems. Modbus support is built into the core and is always available; however the functionality of the software can be expanded by installing plug-ins or by running gateway software locally or on another computer on the network. The table above shows the protocols currently available, however alternatives are built on request (SQL, file-based IO, other hardware interfaces etc.). It is not in the scope of this document to describe the details of the different interface options, to receive such specific information please contact a ClampOn representative.

## 2.1.3 Sensor interface

The standard interface for the sand monitors is RS485 and their native “DSP” protocol. The DSP protocol is built into all ClampOn software and supports all the sensor functions, however only a few control systems have support for this proprietary protocol and then only for a subset of its functionality. This is not a problem if the communication is handled by a processing unit running ClampOn software, however if you do not wish to use such a unit and/or there is no transparent link available for subsea communication - there are a number of alternatives:

Physical Interface	Protocol	Sand rate	Multi-drop	Spectrum analysis	Repro-gramming	Self-test	Temperature and vibration	Contact verification
RS485/422	DSP [0]	✓	✓	✓	✓	✓	✓	✓
RS485/422	Modbus RTU	✓	✓	[1]	[1]	[1]	✗/✓	[1]
RS485/422	13B-MS [4]	✓	✓	[1]	✓	✓	✓/✗	✓
RS485/422	21B-MS [4]	✓	✗	[1]	✓	✓	✓/✗	✓
CAN [3]	CANOpen	✓	✓	[2]	[2]	[2]	[2]	[2]
Profibus [3]	Profibus DP	✓	✓	[2]	[2]	[2]	✓/✗	[2]
4-20 mA	NA	✓	✗	✗	✗	✗	✗	✗
Relay (alarm)	NA	✗	✗	✗	✗	✗	✗	✗

[0]: The native, proprietary protocol of the instrument.

[1]: Only in boot sector when it is running the DSP protocol for 10 or 30 seconds

[2]: Only in transparent mode.

[3]: Only available on subsea models.

[4]: Simple proprietary master-slave protocols

**Note that the sensors are built with a specific hardware interface (or a combination of multiple interfaces, e.g. RS485 and 4-20mA) so remember to decide the interface prior to ordering.**

## 2.1.4 System inputs

Choosing which process data to feed into the calculation of the sand rate is an important decision when designing the system. The recommended solution is to input continuously updated flow rates along with a pressure and a temperature representative to the location of the sensor. If measurements of the flow rates do not exist, the rates can normally be inferred using well performance data and a reference reading. It is advantageous to do the rate calculation on a unit that has access to such data directly, instead of having to depend on manual duplication. The table below shows some of the alternatives and their pros and cons:

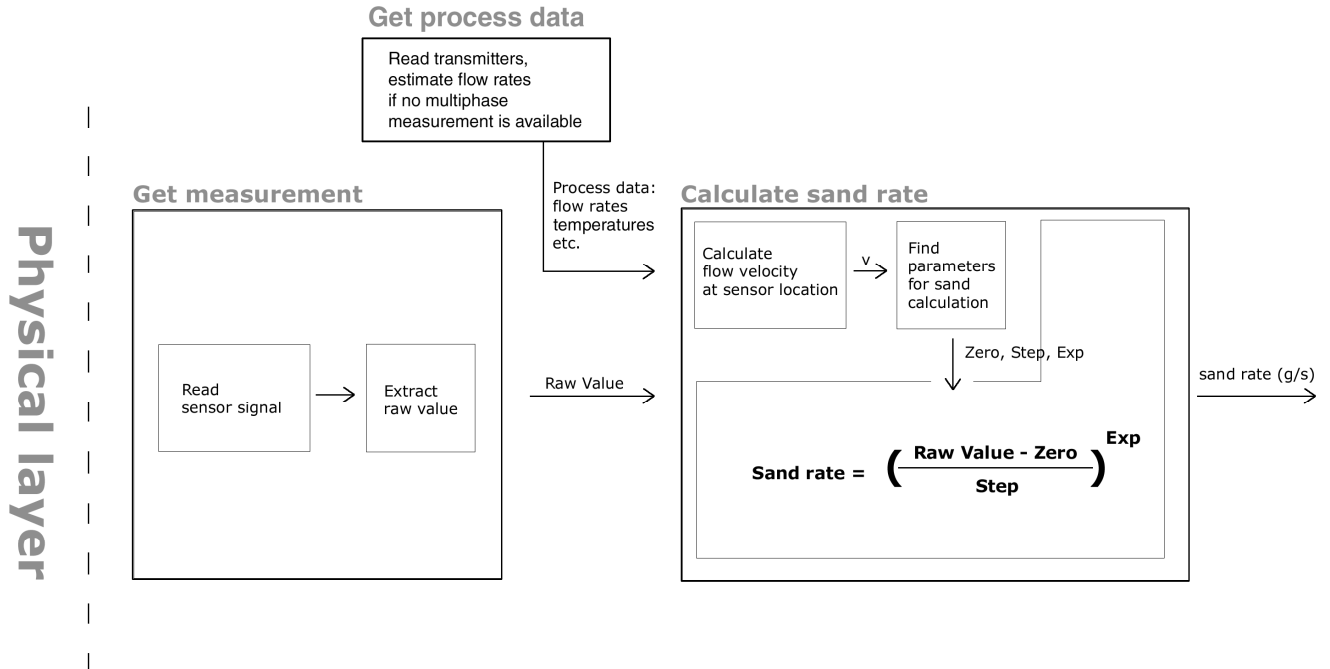
Live Input	Pros	Cons	Recommended
Standardized gas and liquid rates, pressure and temperature representative to sensor location.	Allows automatic adjustments of sand calculation parameters and provides valuable information for system maintenance.	If the flow rates are not measured, they must be estimated continuously based on well performance curves.	✓
Mix velocity	Allows automatic adjustments of sand calculation parameters and provides valuable information for system maintenance.	Unless the velocity is measured by a multiphase meter at the same line conditions as where the sand monitor is located the velocity must be calculated in the control system based on flow rates, pressure and temperature. Does not provide individual flow rate information for service personnel.	✓
WHP, THP or choke opening	Possible as long as the well performance is tested regularly.	Requires manual maintenance of performance tables in the ClampOn software. Instead of duplicating these tables they should be extracted automatically from the location where they are normally stored.	✗
Pressure differential across choke (or pressure up- and downstream)	Possible in most cases. Better than using fixed parameters.	Does not provide enough information for accurate sand rates, however it will normally be sufficient for automatic zero adjustment.	✗
Manual flow rates, pressure and temperature	Adjustments can be done from the control system.	Sand rate may become invalid if manual inputs are outdated. Zero and step tables must still be maintained in the Sand Monitor software.	✗
Manual zero and step	Adjustments can be done from the control system. No maintenance of parameters in Sand Monitoring software.	Sand rate may become invalid if the calculation parameters are not manually adjusted to flow conditions.	✗
None	No link required	Sand rate may become invalid if the calculation parameters are not manually adjusted to flow conditions.	✗

## 2.1.5 Presenting the measurements

The design of a user interface to present the outputs from the processing unit is discussed in section 2.2.6.

## 2.2 Alternative solution: Sand calculation in the control system

If for some reason you do not wish to use the standard solution or a variation of it, it is relatively simple to interface all the sensors directly with the control system and implement the sand rate calculation there.



The data flow of a typical sand rate calculation

### 2.2.1 Acquiring the measurement

The first part of implementing the sand calculation in the control system is to get the measurements from the sensors. From classic particle monitors this is the ultrasonic energy reading – the raw value. Sensors with SandQ™-technology can also output a measurement of the velocity. As the table in section 2.1.3 shows, the sensors have many industry-standard interface options, and support for the proprietary ones is also easy to implement or may already be implemented (depending on the type of control system).

On modbus e.g. the raw value can be read as a 16 bit input register, on CAN the raw value is a 24-bit PDO...Check with ClampOn to get the details on the different interface options.

#### 2.2.1.1 Scan rate

The sensors will always update their measurements every second, however if the control system is unable to handle such a rate you have several options:

- Averaging
- Average + Minimum and Maximum
- Buffering (only available on the DSP protocol)

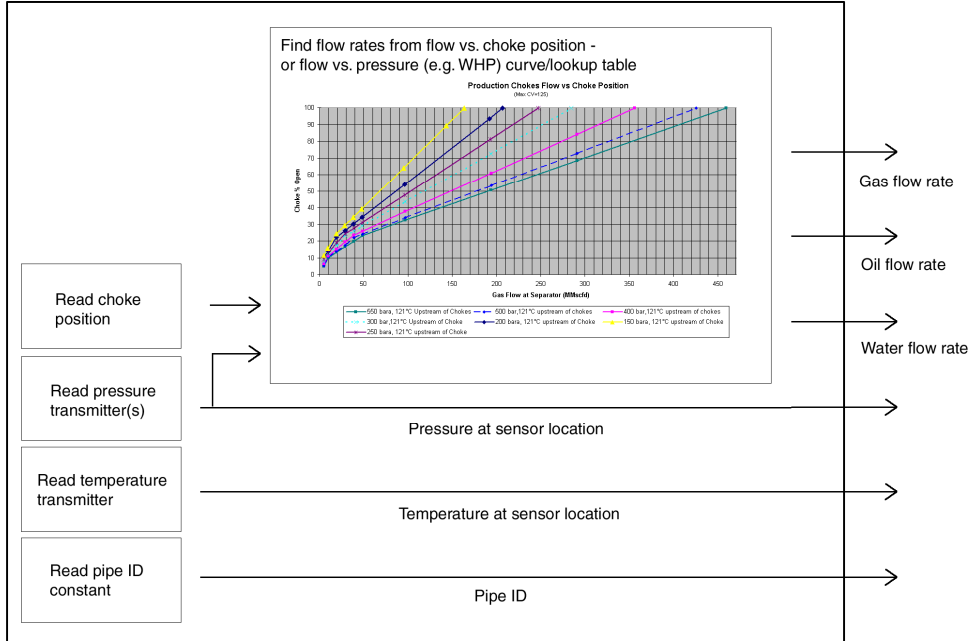
If you choose alternative a) or b) you should decide on a scan rate and ask ClampOn to configure the sensors with a corresponding averaging window.

### 2.2.2 Required process data

As mentioned in the introduction of this document a zero level must be subtracted from the raw value to isolate the particle impact signal. This signal must then be converted into a mass flow rate using a conversion factor called the "step". To decide these parameters we normally use the mix velocity at the sensor location. The velocity is used to look up which zero and step value we should use to get the correct sand rate at the current flow conditions. If the system will be based on sensors with SandQ™-technology the sensors will be able to provide a velocity measurement that you can use, with classic particle monitors you will have to implement a calculation in the control system.

The alternative approaches to this were described in the system input table in section 2.1.4. The figure below illustrates how an approach that involves well performance curves to find the flow rates can work:

### Get process data



### 2.2.3 Calculating the velocity

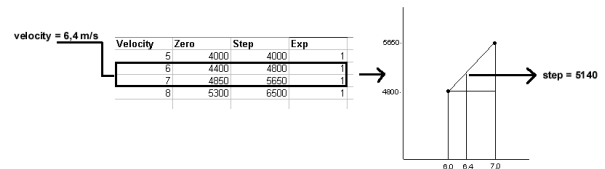
The flow velocity (mix) can be found by adding up all the flow rates and divide the result by the area of the pipe cross section. Measured or inferred flow rates are typically given for standard conditions so we use measurements of the pressure and temperature to find the actual volume that flows through the line at the sensor location. We then divide that volume by the pipe area to get the flow velocity. In mathematical terms the calculation for this in metric units is as follows:

$$\text{Mix velocity (m/s)} = (G' + O + W) / ((24 * 3600) * A)$$

Where:

- A =  $\pi * (D * D) / (4 * 1000000)$
- D = Internal Diameter of the flow line (mm)
- G' =  $G * ((273 + T) * 1.01325) / ((273 + 15) * (P + 1.013))$
- G = Gas Rate (Std. m3/day)
- O = Oil Rate (Std. m3/day)
- W = Water Rate (Std. m3/day)
- T = Flow line Temperature (deg. C).
- P = Flow line Pressure (bar.g)

### 2.2.4 Selecting the calculation parameters



Based on the mix velocity we just calculated we can find the zero, step and exp values to put into our sand calculation.

As mentioned early in this document the level of background noise will typically vary with the flow conditions and this variation must be observed in the field to generate a look-up table we then can use to automatically adjust to the current conditions. In addition to the floating zero level there is a conversion factor used to go from raw signal to sand rate. The step is linked to the velocity as well and here we can either use standard look-up tables from ClampOn, or generate optimized, site specific tables by doing sand injections at different flow velocities.

**Example table:**

Mix velocity m/s	Zero	Step
1	4052	525
2	4150	1500
4	4320	3200
6	4480	4800
8	4650	6500
10	4850	8500
15	5805	18050
20	7150	31500
25	8824	48240
30	10498	64980

(The step values in this table are typical for a gas well.)

You normally just need about 10 rows in the tables to cover the range of possible flow conditions, and then just use linear interpolation to increase the accuracy: Find the two closest entries in the table(s), the one just below and the one just above the calculated flow velocity, and interpolate between these to find the exact value to use. Based on the table above the step for a velocity of 6,4 m/s would be calculated like this:  $step(6,4) = 4800 + (6,4 - 6,0) * ((6500 - 4800) / (8,0 - 6,0)) = 5140$ . Do the same for the zero and exp values, and you have the parameters you need to use in the final stage of the sand rate calculation.

Important: For velocities outside the range of your lookup table you can extrapolate, however it is important not to extrapolate at the lower end: If the first entry is:  $v = 0,5 \rightarrow zero = 2300, step = 200$  e.g. then those values should be used even if the velocity drops below 0,5 m/s – otherwise the zero would drop below the sensor's own noise level and the step value would go to zero or negative - making the sand rate invalid.

**2.2.5 Calculating the sand rate**

With all the inputs for the sand rate formula in place – all that is left is to calculate the result:

If Raw Value > Zero:

$$SandRate = \left( \frac{RawValue - Zero}{Step} \right)^{Exp}$$

Else: Sand Rate = 0.

**Example:**

If the raw value is 39500 e.g. and we use the zero and step values we found using interpolation on the illustrated lookup table the sand rate would be:

$$Sand\ rate = ((39500 - 4580) / 5140) ^1 = 6,79\ g/s$$

If the raw value was 4000 it would be below the zero level and sand rate would be zero.

Now all you need to do is to run this process for each individual sensor you have (depending on the way your control system is programmed this might e.g. be a matter of building a set of input and output arrays to and from one single looping function).

**2.2.6 User Interface**

**2.2.6.1 Presentation**

The sand rate will change from second to second so if you want to show the sand production on a numeric indicator make sure to average the number over a minute or more. It may sometimes be necessary to react rapidly to a change in the sand rate though so make sure you have alarms and/or trends that give a more instantaneous response.

The best way to view and evaluate the sand production is to trend it together with relevant process data like the flow rates, the choke setting, pressures and temperatures. Trend the raw value as well, it will work as a backup if the sand calculation is faulty (due e.g. to an invalid process parameter). A good default time period to show is 1-3 hours (or two bottoms up periods).

If possible, put icons of the detectors on the process overview screens and link the icons to the predefined trends.

## 2.2.6.2 Alarms

Due to the erratic nature of the sand production putting a simple limit on the instantaneous reading is bound to produce spurious alarms. You still want the operators to react fairly quickly to an increase in sand production though, so do not solve this by averaging or accumulation – but by delaying the triggering. ClampOn solves this by having two different alarms: There is one “HiHi” limit that is triggered if the sand rate has exceeded it for just a few seconds (5 g/s e.g.), and then there is a lower “Hi” alarm (0,5 g/s e.g.) with a longer delay time. To prevent drops to zero from resetting the counters we also have a “reset”-delay.

Many users want to trigger the sand alarms at a sand rate they have calculated based on the erosion tolerance of a choke or other process equipment. Such limits are typically based on the assumption that you will have a constant production at that level and this makes them too low to be used for rapidly responding alarms.

## 2.2.6.3 Easy access to lookup tables

A reoccurring problem with many control system implementations is the lack of ownership and the consequent lack of maintenance. The programmers behind the implementation have no invested interest in the system once it has been delivered and this means that it is crucial that any part of the system that needs maintenance must be known and simple to access for the end users. Zero levels and step values will change as the properties of the produced fluids change so make sure the lookup tables are visible and possible to edit without any extraordinary skills or downtime. Preferably it should also be possible to do such editing by remote, this way expert users can adjust the system without having to travel to the installation site.

## 2.3 Alternative solution: Hosted Monitoring

A third alternative, and the last we will cover in this document, is to have the sand monitoring hosted by ClampOn. This means that instead of having any advanced equipment or algorithms on-site the readings from the sand monitors are simply forwarded for processing on servers maintained by ClampOn. The advantage of this is that the system is continuously maintained by expert users - without any travel expenses or the security issues of granting remote access.

The operators can focus on the readings, while ClampOn can provide boosting and sand management services from onshore. The sand rates can be routed back to the main process monitoring system, and/or be accessed directly from the ClampOn servers using a web client.

## 3 SUPPORT

For help in the design and integration of sand monitors from ClampOn, please call us to talk to one of our support or project engineers.

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