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WAVEINJECTOR® TECHNOLOGY FOR USE IN REFINERY COKING APPLICATIONS

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1 ABSTRACT

Flow measurement of coker feed lines is a challenging task. The flow of these hot liquids (up to 450°C/840°F) can contain solids and when cool (during start-up and shutdown phases) can be highly viscous. In many refineries around the world, conventional flow meters for the different coker feed lines have been replaced without any plant shutdown with FLEXIM's high temperature non-intrusive WaveInjector®.

This paper will introduce the technology, the physical background and theory behind the WaveInjector®. The paper will also discuss the various considerations for coker feed flow measurement including the initial problems, typical challenges, installation, measurement and long term data including diagnostics and maintenance. Real world applications will be examined along with experience gathered from other sites where this technology is installed.

The paper will be prepared by flow meter experts/users with a background of more than 20 years in flow measurement in the downstream industry.

2 INTRODUCTION

Shifts in oil supply and demand are bringing the so called "bottom of the barrel" into focus. The "bottom of the barrel" has become more of a problem for refiners because heavier crude oils are processed and the market for heavy residual fuel oils has been decreasing. Historically, heavy residual fuel oils have been burned to produce electric power and to supply the energy needs of heavy industry, but more severe environmental restrictions have caused many of these users to switch to natural gas. Thus, when more heavy residuals are in the crude oil, it is more difficult to economically dispose of them. These complementary pressures affect the supply and demand work together to make it attractive to invest in processing heavier crude oils.

Coking units convert heavy feedstocks into a solid coke and lower boiling hydrocarbon products which are suitable as feedstocks to other refinery units for conversion into higher value transportation fuels. From a chemical reaction point of view, coking can be considered as a severe thermal cracking process in which one of the end products is carbon (i.e. coke). In fact, the coke formed contains some volatile matter or high-boiling hydrocarbons. In order to eliminate essentially all volatile matter from petroleum coke it must be calcined at approximately 1100 to 1250°C (2000 to 2300°F).

The delayed coking process was developed to minimise refinery yields of residual fuel oil by severe thermal cracking of stocks such as vacuum residuals, aromatic gas oils and thermal tars. In early refineries, severe thermal cracking of such stocks resulted in unwanted deposition of coke in the furnaces. As the process gradually evolved, it was discovered that furnaces could be designed to raise residual stock temperatures above the coking point without significant coke formation in the furnaces. This required high velocities (minimum retention time) in the furnaces, but it was found that the control of the hydraulic balance of the heater furnaces depended heavily on the correct inflow conditions. Providing an insulated surge drum on the furnace effluent allowed sufficient time for coking to take place before subsequent processing, hence the term "delayed coking".

Due to its practical advantages, external flow measurement with clamp-on ultrasonic transducers has become a standard measuring technique over the past twenty years. Experts are more than happy to resort to non-invasive technology when it comes to measuring the flow of complex media. The main challenges involved in reprocessing heavy crude oil fractions are high viscosity, solid bodies and high temperatures.

3 THE COKING PROCESS

Most coker plants in the world are based on the Foster Wheeler patented delayed coking method. The residue left over from crude oil distillation is led through a tube furnace under pressure at a high velocity and heated to temperatures of 925°F / 500°C. Due to the short length of time that the residue mixture stays in the furnace, there is no significant coke formation. This takes place in a "delayed" manner during devolatilisation in downstream coke drums.

Typically furnace outlet temperatures range from 480 to 500°C (900 to 930°F). The higher the outlet temperature, the greater the tendency to produce shot coke and the shorter the time before the furnace tubes have to be decoked. Hot fresh liquid feed is charged to the fractionator two to four trays above the bottom vapour zone. This accomplishes the following:

1. Hot vapours from the coke are quenched by the cooler feed liquid thereby preventing any significant amount of coke formation in the fractionator and simultaneously condensing a portion of the heavy ends which are recycled
2. Any remaining material lighter than the desired coke drum feed is stripped (vaporised) from the fresh liquid feed
3. The fresh feed liquid is further preheated making the process more energy efficient

3.1 Coke Formation and Removal

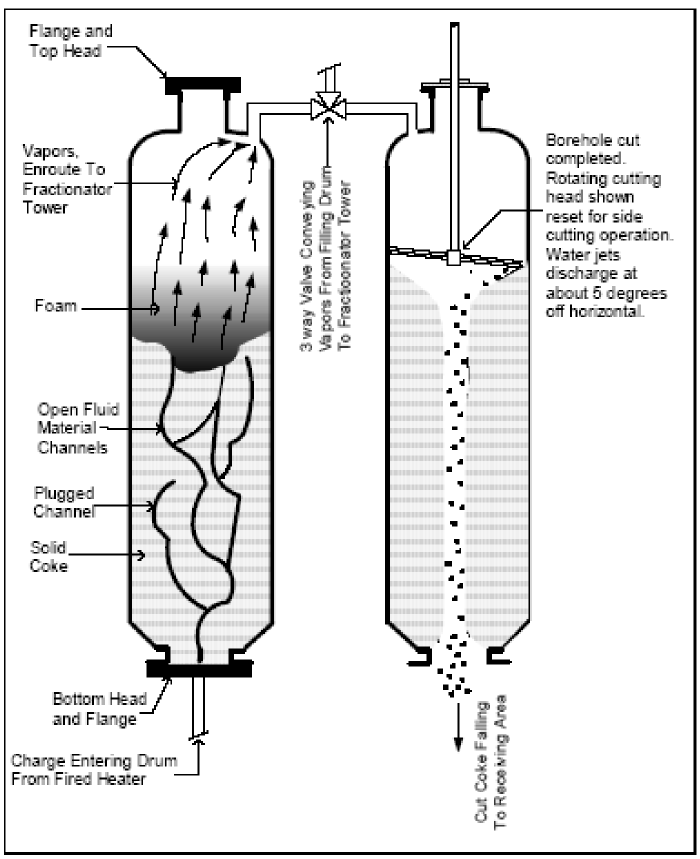

Fig. 1 : Alternating Filling and Removal from Two Coke Drums [3]

The heated residue is pumped from the furnace to the active coking drum. Due to the temperatures of around 925°F / 500°C and the pressure drop from 24 bar / 350 psi to approximately 4 to 6 bar / 60 to 90 psi, the hot feed cracks into two products, a gas vapour and a solid coke. The lighter fractions (gas, naphtha, gas oil) are separated and only solid coke remains in the drum.

When the coke drum in service is filled to a safe margin from the top, the furnace effluent is switched to the empty coke drum and the full drum is isolated, steamed to remove hydrocarbon vapours, cooled by filling with water, opened, drained and the coke removed.

Decoking is accomplished by a hydraulic system consisting of a number of high pressure (350 bar / 5000 psi) water jets.

As the coke drums are filled and emptied on a time cycle, the fractionation facilities are operated continuously and at least two coke drums are necessary for continuous batch processing. A typical processing time of one operation cycle is 20 hrs.

4 FLOW METERING REQUIREMENTS

From an engineering measurement perspective, this is the ability to measure the quantities of actual processes and physical components. As such, flow measuring instruments are used to measure the quantity of a flowing fluid at a certain point in a process. The fluid can be in an open or closed conduit and can be measured as an observed volumetric flow or a corrected mass flow.

For the coking process, which is not only extremely hot but can also contain toxic substances, the most important factor is safety. This safety is not only important for the operational and maintenance staff but also for the environment. Also, good process control and heater tube balance is essential in the running of the furnaces. To achieve this, the profile of an ideal flow meter should be built.

An ideal flow meter should have the following characteristics: -

1. Accurate and long term stability, even under changing process conditions

    - Suitable for the process conditions of high temperature, changing product in start-up and shut-down phases, changing viscosities and densities and solids and gasses in the liquid phase
    - High turndown
    - Fast response

2. Safe & Reliable

    - Self diagnostics to prove that not only is the reading valid, but also to warn of possible failures
    - Intrinsically safe not only in ATEX terms but also in operational and failure modes
    - There should be no possibility to vent or leak hazardous materials to the atmosphere during operation or maintenance
    - Long term reliability suitable for plant lifecycle
    - Resistive against wear, tear, scaling, chemical attack

3. Maintaining plant availability

    - Maintainable without plant shutdown
    - Pigable, have the ability to remain on the pipe during decoking, regardless of the method used

4. Reaction-free measurement

    - There should not be any reaction to the process caused by the flow meter

5. Economic - LTCO (Low Total Cost of Ownership)

    - Purchase price
    - Maintenance free
    - Energy usage / pressure drop

Currently, the typical differential pressure systems used do not fulfil many of the above requirements, but the closest ideal fit meter on the market is an ultrasonic meter. Ultrasonic meters by their very nature fulfil most of the above requirements and are proving to be a real benefit to many refineries around the world today.

For safety, these same flow metering instruments are independent of the process control system and are used to maintain a safe state as part of a Safety Instrumented System (SIS). The importance of these systems cannot be underestimated or brushed aside lightly. Process control allows for fully automated systems in which a small workforce can operate a complex process from a central control room.

For a SIS to operate, equipment must function correctly and quickly. These systems must be capable of detecting abnormal operating conditions. A logic solver system, which normally forms part of the SIS, receives input signals from all of the various sensors and makes appropriate decisions based on pre-defined limits. International standards IEC 61511 and IEC 61508 provide guidance to end-users on the application of Safety Instrumented Systems in the process industries.

We can therefore conclude that flow metering is a vital link in a very large process. The metering must be robust, accurate and reliable, for without these traits, it would not be possible to control and safely maintain a complex oil refining system.

5 CURRENT METERING TECHNOLOGIES

There are so many types of metering on the market today and they fall into various categories. These can be seen as mechanical (turbine, variable area, positive displacement, paddle etc), pressure based (orifice, venturi, pitot etc), electromagnetic / acoustic (magnetic, ultrasonic clamp-on, ultrasonic wetted etc), coriolis force based and other fringe systems such as optical and thermal mass systems.

With so many systems on offer, how does an end user decide which one is best fit for their process? [2] One thing is for sure, no one meter offers a panacea, but they each have their advantages and disadvantages. We will now explore for the more common systems seen in the modern refinery, these advantages and disadvantages.

5.1 Differential Pressure Meters

5.1.1 Orifice Plate

An orifice plate measures the flow of a liquid or gas by the difference in pressure from upstream to the downstream of the plate. This plate creates a restriction in a pipe that causes a difference in pressure between the two sides. A differential pressure transmitter then measures the difference in pressure across the orifice plate and converts this into a flow signal.

Fig. 2 : Typical Orifice Plate Hook-Up

Advantages:
- Can be used for liquids, gases, and steam
- Good for extreme process conditions (up to 400bar / 5800psi and 1000°C / 1800°F)
- Basic element is robust and entirely mechanical with no moving parts
- DP-transmitter isolatable for calibration
- Cheap installation cost

Disadvantages:
- Risk of clogging
- Pipe shut down for exchange of primary element
- Chance of leak (pressure tubing, valves)
- Limited turndown range
- Only 60 to 65 % of pressure drop is recovered
- Effected by changes in density, pressure and viscosity
- Pressure tubing needs trace heating
- slow response time due to cold liquid viscosity increase

5.1.2 Wedge

A wedge meter measures the flow of a liquid or gas in a similar manner to that of an orifice plate by the difference in pressure from upstream to the downstream of the wedge. This wedge creates a restriction in a pipe that causes a difference in pressure between the two sides. A differential pressure transmitter then measures the difference in pressure across the wedge and converts this into a flow signal.

Fig. 3 : Wedge Flow Meter on Coker Feed Using Three DP Transmitters with Diaphragms

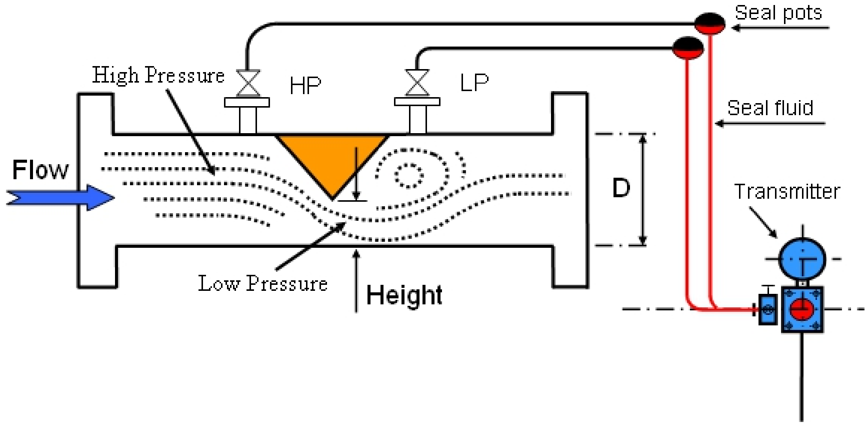

Fig. 4 : Wedge Flow Meter Cross Section Showing Pressure Restriction Wedge

Advantages:

- Small pressure drop
- Risk of clogging
- Can be used for liquids, gases, and steam
- Basic element is part of the assembly and is robust and entirely mechanical

Disadvantages:

- Limited turndown range
- Nominal sizes in the range of 150 to 600mm / 6 to 24inch
- Sensitive to variations in the velocity profile and turbulence
- Effected by changes in density, pressure and viscosity
- Pipe shut down for exchange of primary element
- Chance of leak (pressure tubing, valves)
- Pressure tubing needs trace heating
- Slow response time due to cold liquid viscosity increase

5.1.3 Common Differential Pressure Meter Problems

Purging

Impulse Lines - A common problem which occurs on orifice plate and wedge meters using impulse lines is blockages. To overcome this, when temperatures are lower than 315°C / 600°F it is common to purge the lines with glycol. When temperatures are over 315°C / 600°F, substances such as Krytox are used, which is not only expensive but when significantly above 300°C, the fumes are about as toxic as cyanide. This is a serious plant and personnel safety issue where a plant can no longer continue to run safely and the cleaning or purging procedures can be extremely dangerous to personnel.

Fig. 5 : DP Assembly Removed (Left) and Impulse Lines Blocked (Right)

The control of the hydraulic balance of the heater furnace depends heavily on the correct inflow. Therefore, as shown in Fig. 5, if impulse lines become blocked, the result is a meter which exhibits erratic readings as shown in Fig. 6. This is both an operational and a safety issue.

Fig. 6 : A Typical Eight Heater Feed Flows with One DP Blocked

Diaphragms

Chemical Seals - When using diaphragms seals, manufacturers have to employ special capillary liquids to cope with the extreme temperatures. They also tend to employ large area diaphragms to overcome blockages of the mounting nozzles. Overall measurement accuracy can drop if the chemical seal is small, its diaphragm is stiff, or if the capillary system is not temperature-compensated or not shielded from direct sunlight or other heat exposure.

Fig. 7 : Typical Diaphragm Seal DP Transmitter

Diaphragm seals always carry a concern over their fragility when exposed to such a hot and harsh service with clogging, build-up and often large particles and potentially lumps of coke running down the pipe.

Advantages:
- No blockage of pressure tubing
- Pressure transmitting fluid maintains low viscosity even at low temperatures

Disadvantages:
- Unequal heating of the filled capillaries leads to errors
- More complicated
- More costly maintenance
- No isolation and thus calibration of the DP transmitter is possible without process interruption

5.2 Vortex

Vortex meters cause a vortex-shedding phenomenon which can be observed as wind is shed from a flagpole (which acts as a bluff body). It is this vortex shedding effect which causes the regular rippling that can be seen in a flag.

The design of a vortex meter relies on a bluff body or bodies placed within the fluid stream. Just behind the bluff body, a sensor picks up the high and low pressure and velocity fluctuations as the vortices move past the sensor Fig. 8. These fluctuations are linear, directly proportional to the flow rate and independent of fluid density, pressure, temperature and viscosity (within certain limits).

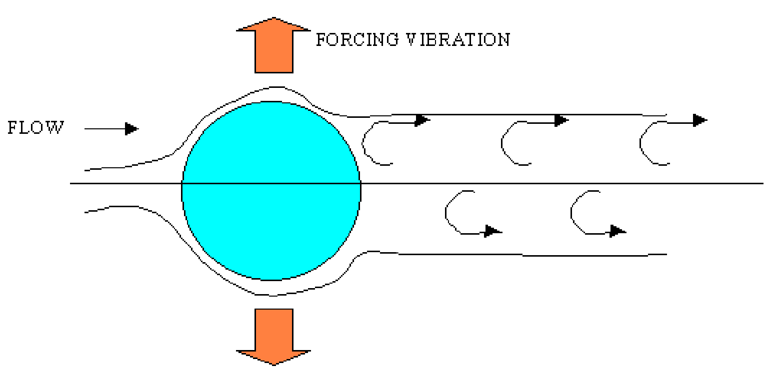

Fig. 8 : Vortex Flow Meter [4]

Advantages:
- No moving parts to wear
- No routine maintenance required
- Can be used for liquids, gases, and steam
- Stable long term accuracy and repeatability

Disadvantages:
- Cannot be used for very low fluid velocities
- Pulsating flow vortices adversely affect measurement accuracy
- Cannot be used on high viscosity fluids or slurries
- Not suitable for dirty fluids, coke builds on the bluff body causing heavy drift
- Frequent steaming necessary for cleaning (very costly maintenance)
- Susceptible to damage if larger 'chunks' can flow through a pipe
- Affected by pipe vibrations

5.3 Clamp-on Ultrasonic

A detailed clamp-on ultrasonic explanation will be covered in section 7.1. To be consistent, the following are the advantages and disadvantages of a clamp-on ultrasonic flow meter.

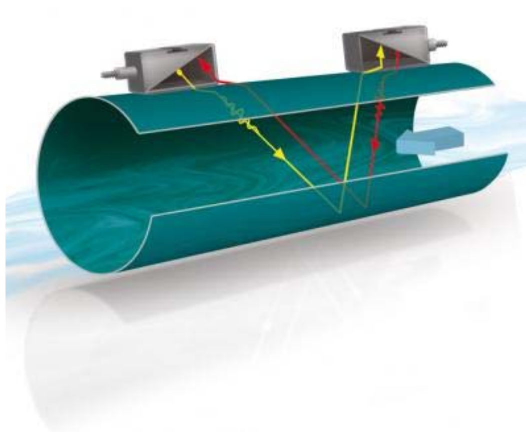

Fig. 9 : Clamp-On Ultrasonic Flow Meter

Advantages:
- Safe - No chance of leaks
- Safe - Self monitoring measuring principle with diagnostics
- Retrospective installation on running plant (full plant availability at all times)
- Non intrusive, no pressure drop, no risk of clogging and pigable
- Not in contact with fluid
- High turndown > 100:1
- Fast response time
- Can be used for liquids, slurries, solids, or gases

Disadvantages:
- High content of solids or gas in liquids can cause meter to fail
- Standard couplants will degrade over time
- Limited temperature range for transducers directly coupled to the pipe

6 FLOW METERING PARAMETERS

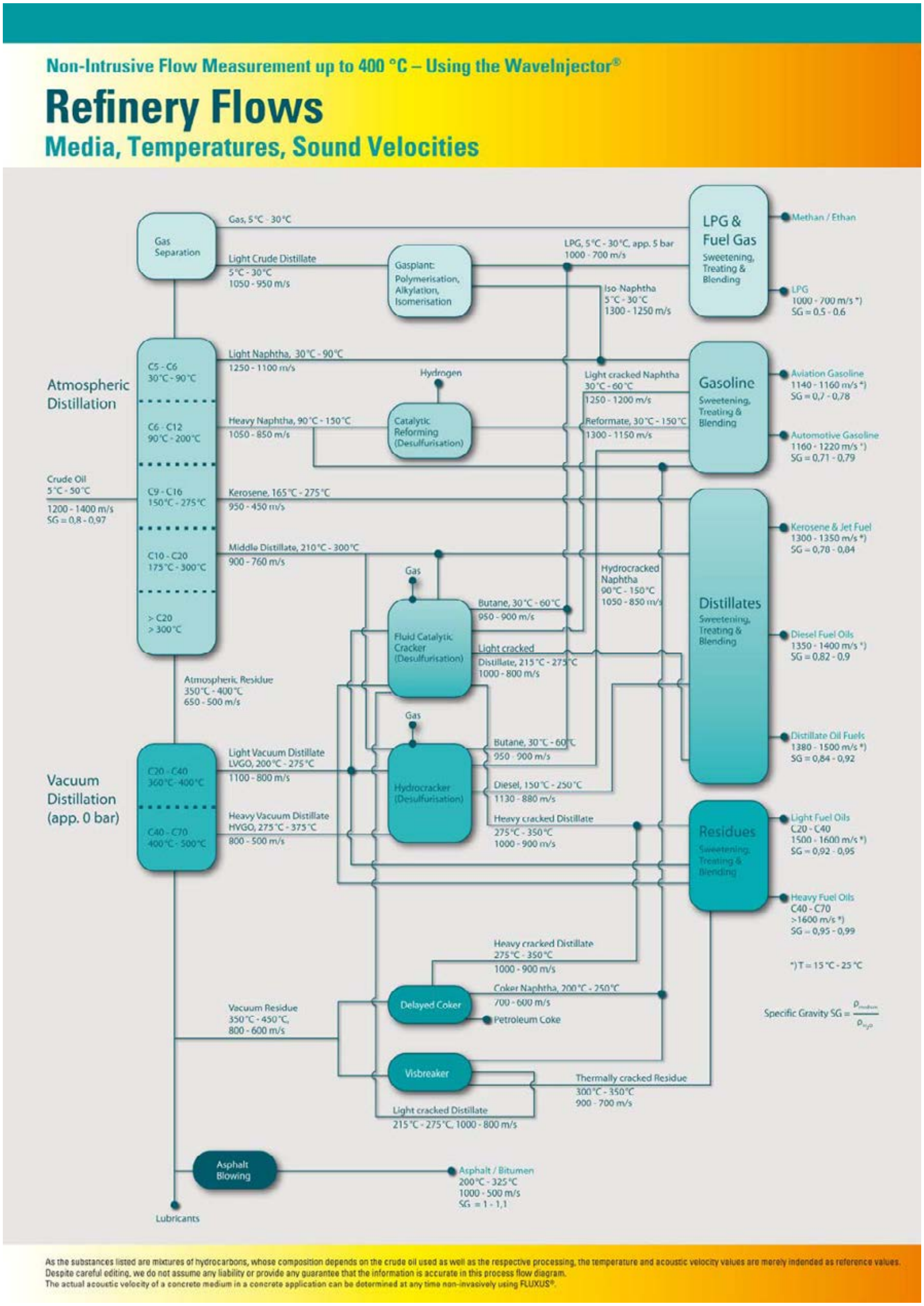

Fig. 10 : Refinery Flows Showing Typical Temperatures

7 THE WAVEINJECTOR®

Ultrasonic flow measurement at high temperatures was until now a troublesome business. Temperatures above the Curie Point [5] cause spontaneous polarization of the piezo crystal and the transducer ceases to 'sing'. Furthermore, high temperatures accelerate the aging of the ultrasonic transducer's piezo elements and thus limit their useful operating life. The gels or pads used for acoustic coupling between the transducers and the pipe have a limited temperature tolerance.

To solve these issues, FLEXIM's unique WaveInjector® as shown in Fig. 11 has been specially engineered for high-temperature applications. Using patented technology, the WaveInjector® thermally separates the ultrasonic transducer from the hot pipe, allowing operation at process temperatures up to 450°C / 840°F.

Fig. 11 : FLEXIM's Unique WaveInjector®

The patented transducer mounting fixture realises a long-term stable clamp-on ultrasonic flow measurement with standard temperature transducers at temperatures as high as 450°C / 840°F. It offers all the well known advantages of the clamp-on ultrasonic technology, a non-intrusive measurement with a wide dynamic range and a high flexibility.

Since the WaveInjector® is a purely mechanical device, it can be used in explosion hazard areas without any further certifications.

7.1 PRINCIPLE OF MEASUREMENT

7.1.1 Meter Formula

The transit time ultrasonic flow meter measures the transit times t_{up} and t_{down} of an ultrasonic signal travelling upstream and downstream respectively. The difference Δt between the transit times is directly proportional to the mean flow velocity v_l on the sound path.

$$v_l = K_\alpha \frac{\Delta t}{2t_{fl}} \qquad (1)$$

K_α is the acoustical calibration factor and t_{fl} is the transit time within the fluid. The volume flow Q is the product of the average flow velocity v_A over the cross section of the pipe multiplied by the area A of the cross section.

$$Q = v_A \cdot A \qquad (2)$$

Fig. 12 : Ultrasonic Clamp-On Measurement

If the flow profile v is known, the area average v_A of the flow velocity can be calculated from the path velocity v_l measured by the flow meter. The meter calculates the fluid dynamical calibration factor K_{re}.

$$K_{re} = \frac{v_A}{v_l} \tag{3}$$

Thus the meter formula is

$$Q = K_{\mathrm{Re}} \cdot A \cdot K_\alpha \frac{\Delta t}{2t_{fl}} \tag{4}$$

In order to calculate the volume flow, a fully developed flow profile has to be presumed. This requires a sufficiently long distance of the measurement location from disturbances like bends and Tees. In that case the fluid dynamical calibration factor K_{re} depends on the kinematic viscosity of the fluid and the roughness of the pipe wall only.

If the flow profile can not be assumed to be fully developed, a deviation of the fluid mechanical calibration factor K_{re} has to be expected. Usually, this deviation is nearly independent of the flow velocity, as long as the Reynolds number is well above 10000. This permits accounting for such conditions by means of a constant correction factor if the magnitude of the influence is known. In some cases, empirical data can be used as many investigations have been carried out on 90° elbows for instance. The most reliable way of determining the necessary correction factor is to measure it on site by a calibration against a reference if such a reference is available. If neither method is available, a numerical simulation of the flow profile can help. This approach is described i.e. in [1].

7.1.2 Path Configurations

The fact that the flow profile is not always ideal is often addressed by using multiple sound paths. Fig. 13 shows a reflecting configuration in two planes. The advantage of a reflecting path is that non-axial flow components are compensated for. This is because the effect of the non-axial component (cross flow) on the two components of the reflecting path is the same in magnitude but opposite in sign. The use of sound paths in two planes reduces the impact of non-symmetry in the flow profiles caused by disturbances like bends or t-branches.

It is not always possible to use reflecting paths. In such cases the compensation for cross flow can be achieved by using two direct paths as shown in Fig. 14.

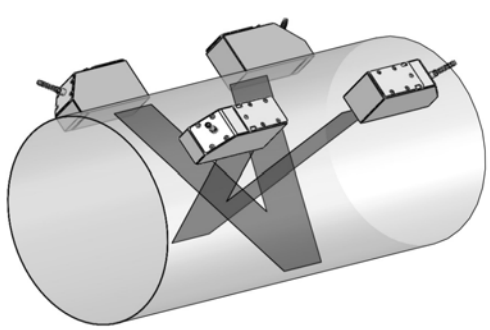

Fig. 13 : Reflecting Paths in Two Planes

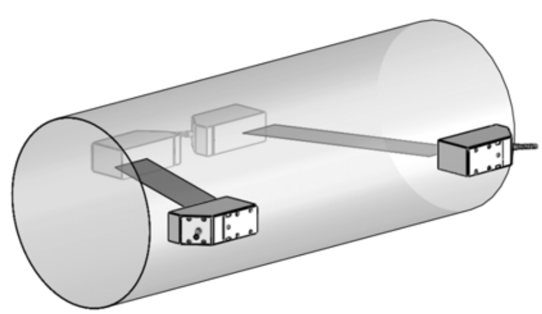

Fig. 14 : Two Direct Paths

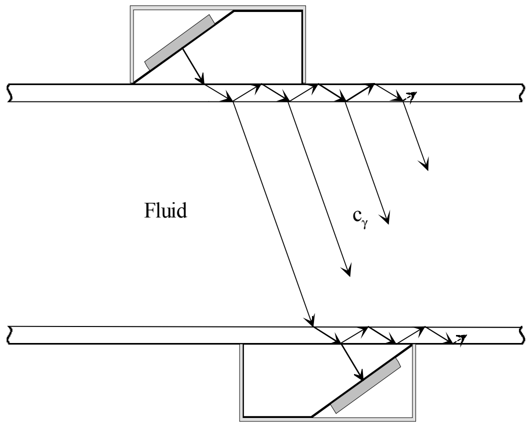

Fig. 15 : Shear Wave Transducers

7.1.3 Sound Transmission

The clamp on technology requires that a sufficient amount of the sound energy can be transmitted from the transducer on the outside via the pipe wall into the flowing fluid. The angles under which the sound waves propagate through the pipe wall and the fluid are given by Snell's law as expressed by formula (5).

$$\frac{\sin\alpha}{c_\alpha} = \frac{\sin\beta}{c_\beta} = \frac{\sin\gamma}{c_\gamma} \tag{5}$$

The propagation method used with clamp-on WaveInjector® measurements is the shear or transverse mode. Shear waves travel under an angle of approximately 45° through the pipe wall as shown in Fig. 15. The advantage of the shear waves is that the sound absorption within the pipe wall is negligible and nearly independent of the transducer frequency. So there is practically no upper limit in pipe wall thickness and the choice of the transducer frequency is not restricted by the pipe wall

8 WAVEINJECTOR® APPLICTIONS IN THE FIELD

FLEXIM's WaveInjector® was launched in 2004 and trials started instantly with many customers interested in the potential that this solution offered them. Amongst these customers were refinery engineers, who were amongst those looking for solutions to their high temperature flow metering problems.

The following two studies will look at instances where flow metering problems were faced by refinery engineers in the field, the parameters involved and the solutions provided. In each case the diagnostics will also be examined.

8.1 North American Refinery

A North American refinery expressed an interest in applying the Flexim Ultrasonic Flow Meters on high temperature fractionator tower bottoms in the delayed coker unit on the heater inlet. The Flexim ultrasonic flow meter was installed as follows: -

Pipe OD	-	101.6 mm / 4 inch (schedule XS - 4.5 inch / 114.3 mm OD)
Wall Thickness	-	8.1 mm / 0.319 inch (as measured by FLEXIM meter)
Pipe Material	-	9 Chrome 1 Molly Steel
Medium	-	Coker feed (short resid)
Operating Temperature	-	390°C / 730°F

Following pipe preparation, the 'WaveGuides' (see Fig. 16) were installed using silver coupling foils and a signal was immediately acquired.

A short data logging sequence was gathered to confirm the functionality of the meter (see Fig. 17)

BLUE	-	Volumetric flow (standard bbl/h)
RED	-	Signal amplitude (%)
GREEN	-	SCNR (dB)
BLACK	-	Sound speed as measured by flow meter (m/s)

The average flow rate recoded over this short period of time was 411 standard bbl/h. This was in line with the existing orifice plate meter. At this point it is important to point out that the standardisation of operation flow was carried out using the flow meters inbuilt specific gravity equation.

In order to standardize the volumetric flow down to base conditions a calibration factor, equal to the ratio of S.G. at flow conditions over S.G. at base conditions, was entered into the meter: -

S.G. at flow	=	0.76
S.G. at base	=	1.0
Calibration Factor	=	0.76

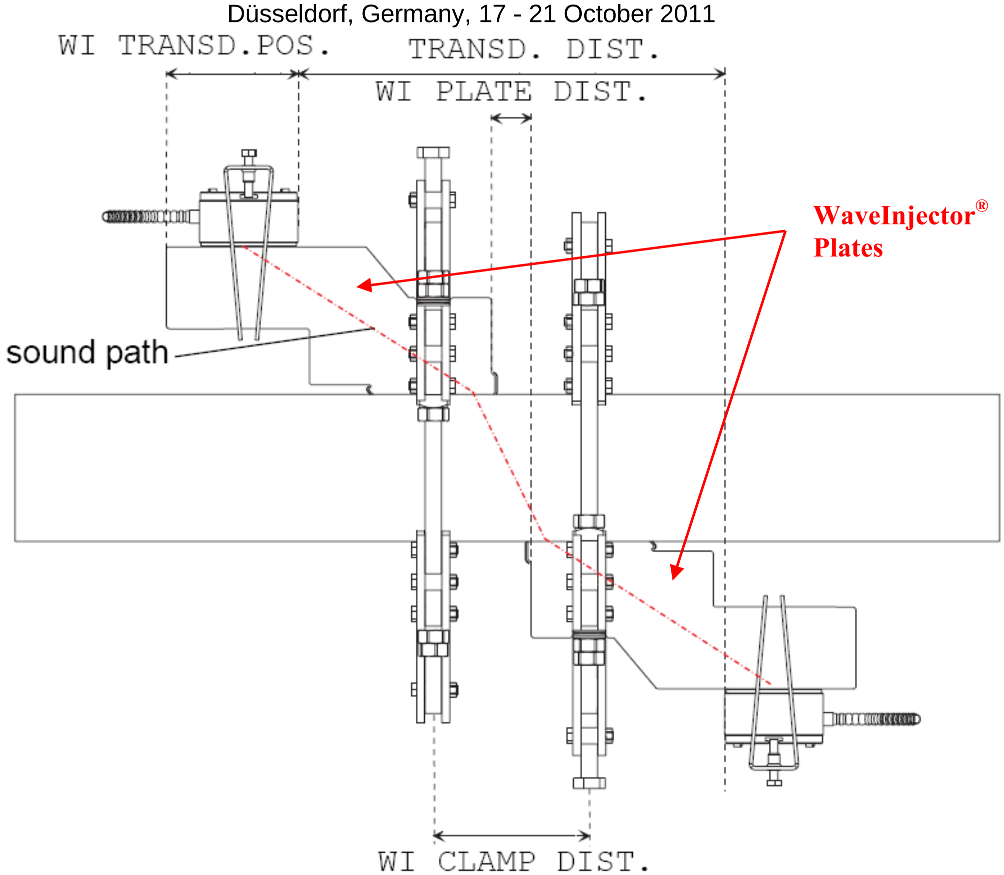

Fig. 16 : Typical WaveInjector® Installation Showing WaveInjector® Plates

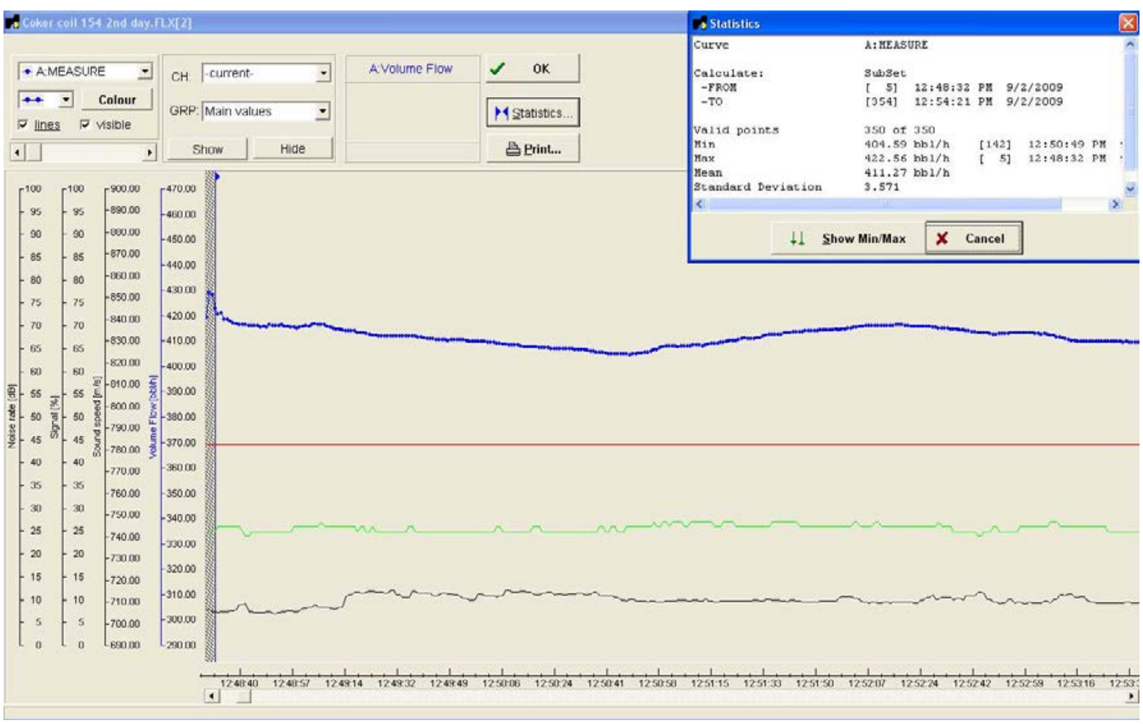

Fig. 17 : Data Logging Sequence

The Signal amplitude is well within specifications and held very steady throughout the test. The SCNR or signal to correlated noise ratio (see Section 12), which is considered to be the most important diagnostic tool is also within specifications at about 26dB and held very steady. Variations in any of the diagnostics would point to a marginal installation. The trend also shows the sound speed of the medium as measured by the meter in real-time. This quite consistent at an average of 711 m/s (this being a typical sound speed for coker feed short resid).

The final installation is lagged, leaving just the transducers in free air for cooling purposes (see Fig. 18). The result was a flow meter working on a coker short resid feed line at 390^{o}C / 730^{o}F, which compares with the troublesome in-line orifice plate. The whole procedure was carried out without shutting the line down or stopping production in any way.

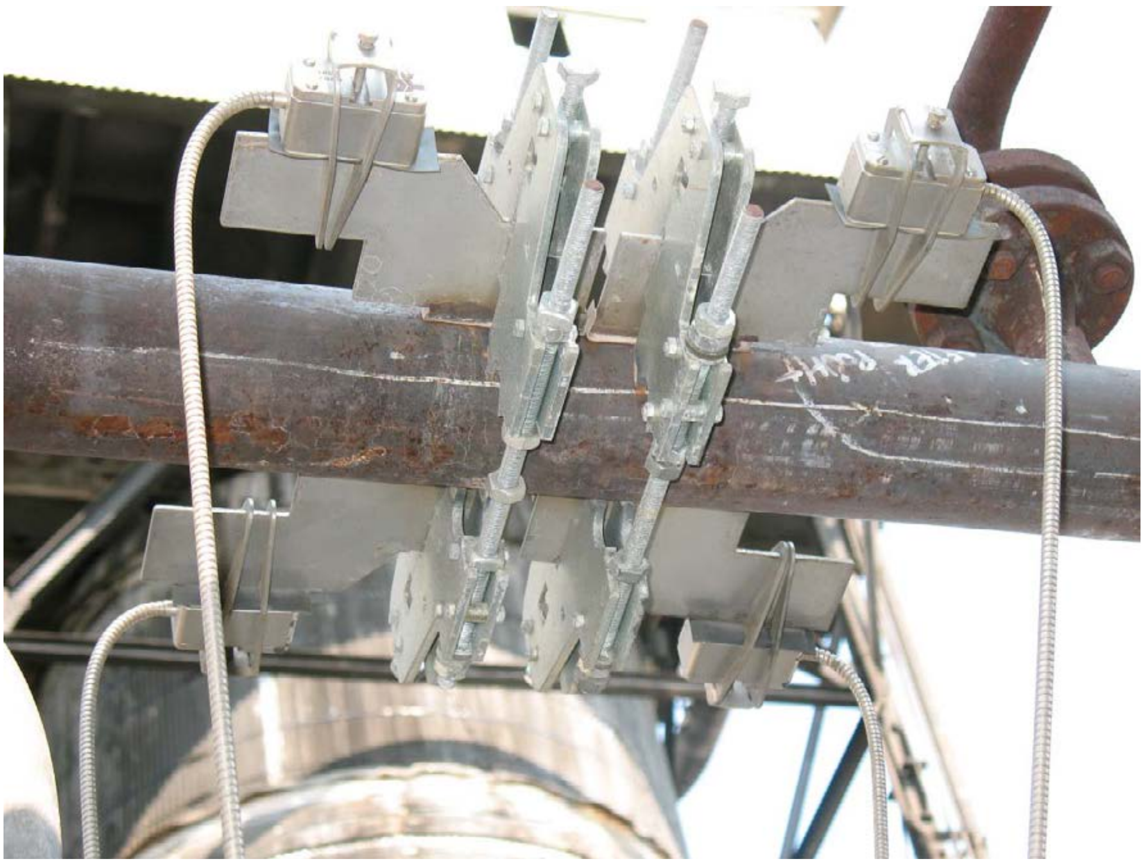

Fig. 18 : Final Installation Prior to Lagging

8.2 European Refinery

In a European refinery, a problem existed with a orifice plates where high maintenance was being caused by the impulse lines blocking on an almost weekly basis. This was unsatisfactory for the maintenance team and a solution was sought, but it had to fulfil some requirements.

The cleaning intervals of the pipes vary between six months and five years. On average, a standard cleaning interval of five years is anticipated. During this five year period, it should not be necessary to shut down any part of the plant. The highest possible reliability of the applied measurement technique had to be found. Performance and durability of the furnace depend particularly on the exact balancing of the coker feed between the furnace zones, therefore the highest possible accuracy of measurement had to be installed.

Test measurements began and at this time, the pipes had not been cleaned for about two years. The test required the installation of a WaveInjector® WI400 Q with silver coupling foils. The measured values were compared with those of the orifice plates and automatic coker control was based on these Δp measurements. The test period was scheduled for six months and in addition, the plant was to be shut down during this period.

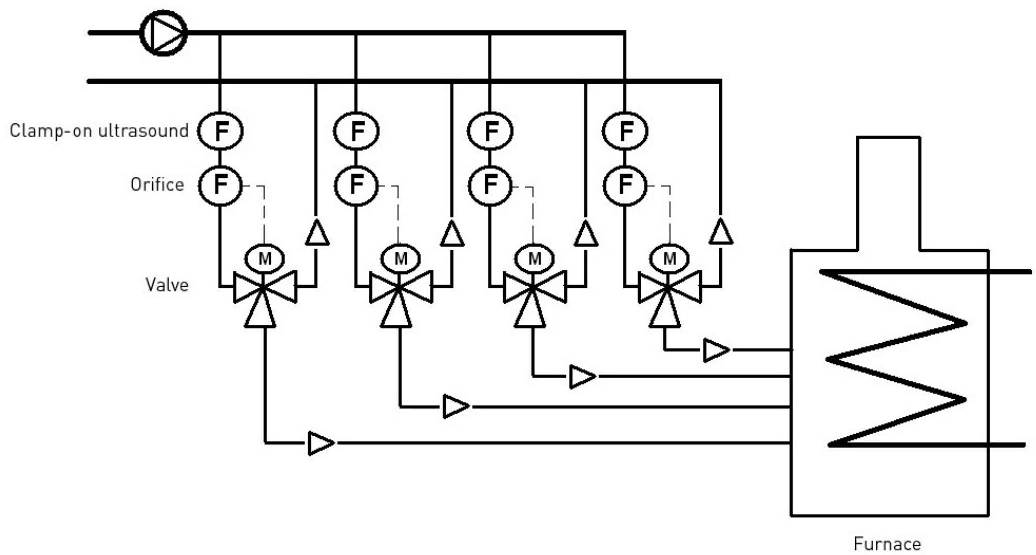

Fig. 19 : Piping and Instrumentation Diagram

The residue is fed over 3-way valves to the furnace and it is essential to install the clamp-on flow measurements at the inlet of the valves and the orifices as shown in Fig. 19. Failure to do so may result in measurement failure as due to the pressure drop at the outlet of the orifices and armatures, gas bubbles might occur. These gas bubbles can interrupt the ultrasonic metering paths resulting in instability and in severe cases meter failure.

The Flexim ultrasonic flow meter was installed as follows: -

Outer Diameter	-	114.3 mm / 4 inches
Wall Thickness	-	8.6 mm / 0.339 inch (4 inch schedule 80)
Pipe Material	-	Stainless steel ASTM 335 P5
Temperature	-	380 °C / 715°F

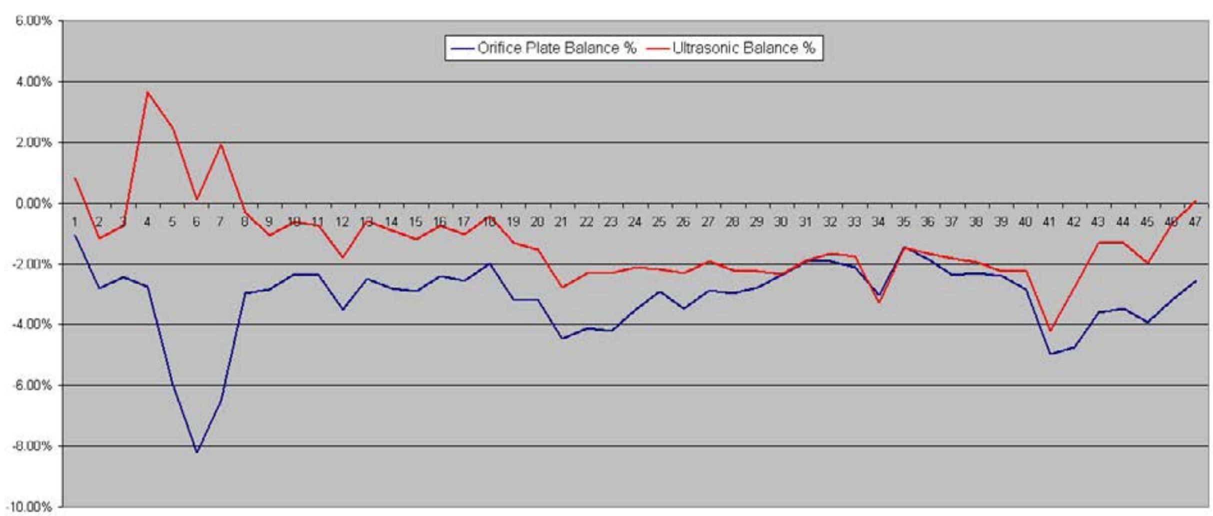

Fig. 20 : Orifice Plate and Ultrasonic Inflow Balance Tests

Tests were carried out to check the ultrasonic measurement accuracy against the installed orifice plates. To accommodate this inflow check, periphery flows into the furnaces had to be taken into account. Tests were carried out over an extended period (the 'X' axis shows days of testing) and the results showed that the highly dynamic flow measurement using the FLUXUS® ultrasonic systems allowed for better balancing of the inflows, as shown in Fig. 20.

Since installation and testing, the ultrasonic meters have never been removed, never cleaned, never serviced and are still running without interruption. The outcome is that the meters fulfilled the primary concern of the refinery, that of mass balance (control of the hydraulic balance of the furnace) and safety.

Within the first six month test period, a planned shutdown of the plant also took place. During the shutdown and subsequent start-up, there are important changes in the fluid characteristics; composition of the fluid, temperature, pressure and viscosity. Correspondingly, the FLEXIM FLUXUS® flow meter recorded significant changes in the sound velocity, from 550 m/s up to 1300 m/s.

Shutdown: -

- With decreasing temperature, the gas oil portion increases to 100%
- The pure gas oil is circulated at approximately 125°C to 150°C (250°F to 300°F)
- Viscosity increases as temperature decreases
- Risk of formation of oil sludge's on the inner pipe wall
- Rapid pressure changes may cause the formation of gas bubbles

Start-up: -

- With increasing temperatures, the gas oil portion decreases to 0%

As the fluid temperature at the measuring point comes close to the fluid's cracking temperature, a varying amount of solid coke particles is constantly carried in the stream, particularly after pressure drops.

Following the testing phase, which took six months, the refinery equipped all eight coker furnace feed lines with WaveInjector® WI400's. At this point, coker control still relied on the existing Δp measurements.

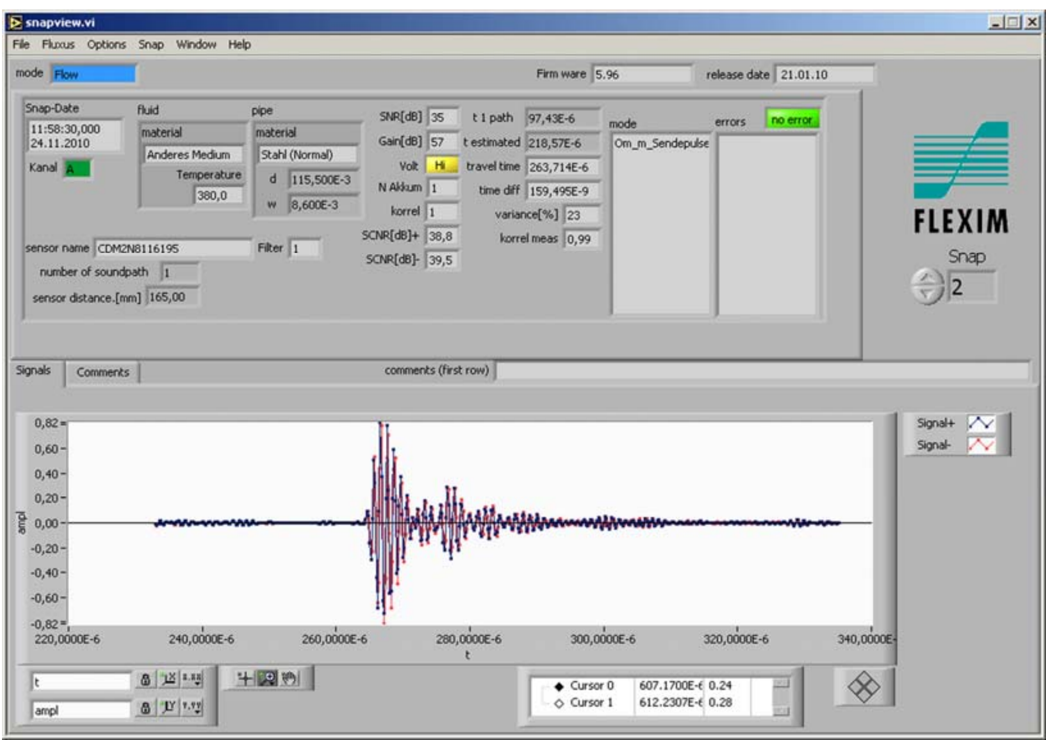

Fig. 21 : Snapshot of Channel A, 1 MHz 'M' Transducers in Diagonal Mode

Direct comparison between the control behaviour of the Δp and the ultrasonic measurement clearly demonstrates the superior dynamics of non-invasive technology. The screenshots shown in XXX taken from the process control system show measured mass flow rates after having set the required rate to + 3 t/h.

Fig. 22 : Comparison of the Control Behaviour of the Δp Flow Measurement

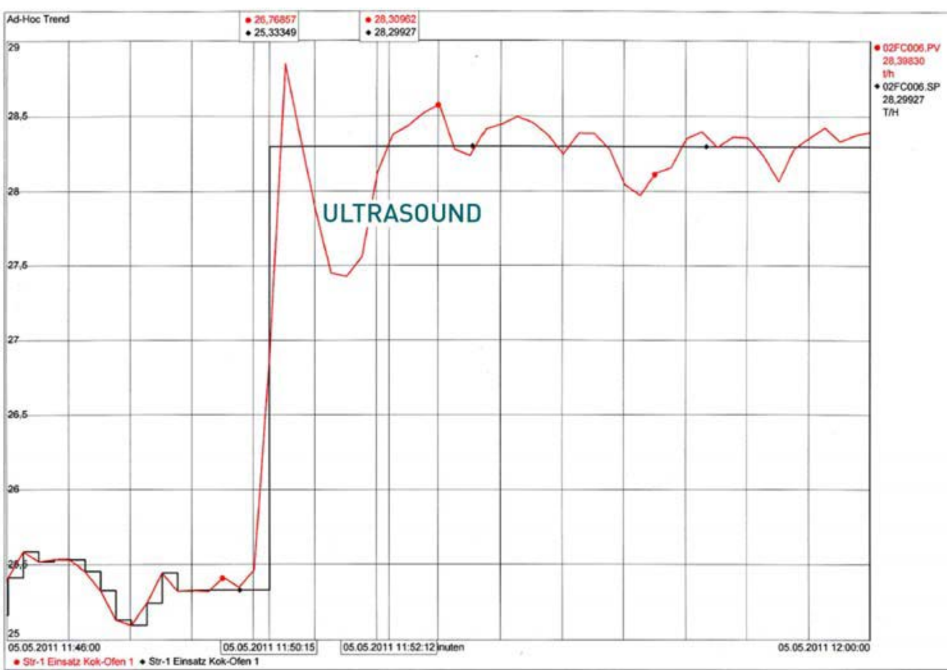

Fig. 23 : Comparison of the Control Behaviour of the Ultrasonic Flow Measurement

The installation has proved very successful, with the ultrasonic systems controlling the coker feed, with the following outcome: -

- Safe - diagnostics shows information about the health and quality of the measurement
- Precise, wear-free flow measurement without drift
- Unlimited plant availability due to non-invasive measurement method
- No wear and tear by solid particles carried in the liquid flow
- No blocking of impulse lines and no risk of leakage
- Detection of entire operational range including start-up and shutdown
- Effective reduction of maintenance costs

To finally achieve the above control of the coker feed, it was necessary to have redundant systems utilising different transducers and installation techniques (see Fig. 24). The control was only possible because these different systems work together to cover all of the possible flow conditions, and the result was that one system was always working regardless of the process variables.

One system utilised higher frequency transducers mounted in a reflect mode (see Fig. 13) whilst the other installation used lower frequency transducers in a direct mounting mode (see Fig. 14).

Together, utilising a conditioned output, the control system is configured to use both of them when the process is working well and either one of them should the plant experience some changes.

Fig. 24 : WaveInjectors® Insulated at the Feed Lines of the Coker Furnace

9 DECOKING [6]

An established fact is that the most critical measuring point in the coking process is the flow meters for the different heater passes (coils). Due to the high asphaltene containing feed in North American refineries, the different heater coils tend to scale up with coke due to the unbalanced flow in the different pipes. Low flow leads to higher temperatures, which leads to faster coke build-up. This problem becomes self perpetuating creating more and more build-up as time progresses. The best way to slow down this build-up is to have good metering and hence good balancing of the heater coils, but coke build-up is still going to occur. To overcome this issue, various methods of decoking are employed.

There are three methods of decoking a heater; steam air, mechanical (pigging) and online spalling. Steam air decoking is the oldest of these three methods and is currently being replaced by the other two methods. Steam air decoking can be rough on the heater tubes, labour intensive and requires a heater and unit shutdown. Some facilities have moved away from this method because the environmental problems caused when burning the coke out of the tubes.

Online spalling has become the best method of decoking, but is not always possible depending on the heater mechanical arrangement and the size of the coker. A small delayed coker with few tubes passes will find this method more difficult than a large coker with multiple drums and heaters. This process is very attractive as the unit does not require a shutdown and loss of throughput and reliability problems are kept at a minimum.

Finally, mechanical decoking or pigging has become a popular practice for delayed coking. The mechanical decoking does require a heater shut down, but some facilities have developed isolation procedures where individual heater boxes can be isolated and the heater passes decoked without a complete shutdown. The time required to mechanically decoke a heater is approximately the same as online spalling of a heater. Since pigging is relatively easy, many facilities have elected to only mechanically clean their coker heaters. This method of decoking can remove difficult inorganic solid foulant from solids in the coker feed. Inorganic solids generally foul in the upper radiant section or even the convection section of the heater. Spalling coke in the upper section of the heater is very difficult if not impossible, which is why a method of pigging the delayed coker heater was developed.

Fig. 25 : Before and After Decoking by Pigging [7]

Fig. 26 : APRO-PIG® Decoking Pigs [7]

The WaveInjector® is ideally suited to any kind of decoking process as it is non intrusive, has no pockets for coke to build up in, does not restrict the line, is not damaged by any of the processes above and can be left in-situ during the whole process.

10 THE FUTURE - OVER 5 YEARS AND COUNTING

Currently, the FLEXIM WaveInjector® has an installed base of over 1000 systems across the globe. These systems range from high to low temperature, from refineries to liquid LNG. Other common flow measurements for the WaveInjector® include heat transfer oils, bitumen, pitch/tar, crude oils/synthetic crude, gas oils, refined petroleum products and other hot and toxic substances.

The limits are still being explored by our customers with recent work in thermosolar applications where molten salts can reach temperatures in excess of 600°C / 1100°F.

The WaveInjector® continues to be popular and further developments are underway within the FLEXIM Research & Development group to push the boundaries even further.

11 CONCLUSIONS

Flow measurement in the coker section of a refinery is a challenging task with high process temperatures, coke formation, changes in feedstock qualities and fluid properties.

Critical for the reliable and efficient operation of the furnace is a balanced feed of the different heater passes for the coker feed. There is no ideal flow meter for this application and measurements were made by classical orifice plates. The replacement of these orifice plates by wedge flow meters in combination with diaphragms improved the situation but brought their own new problems with them. A question which is always asked is do the meter readings really represent the flow rate inside the pipe? Ultrasonic flow meters seem to be the best solution currently available, since they bring with them diagnostic capabilities. With the invention of the WaveInjector®, a non intrusive solution is now available with additional safety in operation and flow measurement.

This WaveInjector® offers a reliable and non-intrusive solution for Coker/Heavy Oil applications with reliable measurement to 450°C / 840°F. The metering systems offer easy set-up with no process interruption or upset during installation.

Some of the major benefits offered with this flow measurement technique are no pressure drops, no potential leaky connections, no more plugging of the meter or capillary lines, cost effective with low cost of ownership and virtually maintenance free. In addition, the meter can be installed with no intervention or loss of production and once completed can immediately be called into service.

Should any maintenance be required, the meter can be worked on safely and without the maintenance personnel being exposed to any part of the process.

FLEXIM's transit-time technology has a response time of <1 second, resulting in a SIS system in which the alarm will be activated as soon as flow reaches a preset limit. Differential pressure systems include mechanical damping that introduces a longer response time, which is not what a SIS system should be relying upon.

Finally, we should return to our ideal flow meter and consider each of the requirements and ask if the WaveInjector® system fulfils some or all of the requirements.

An ideal flow meter should have the following characteristics: -

1. Accurate and long term stability, even under changing process conditions
2. Safe & Reliable
3. Maintaining plant availability
4. Reaction-free measurement
5. Economic - LTCO (Low Total Cost of Ownership)

Now we should consider how the WaveInjector® system compares to the questions asked: -

1. The WaveInjector® system is currently suitable for process temperatures of up to 450°C, full line pressure, can work with varying temperatures, viscosities and densities. The meter is largely unaffected by solids and gasses in the liquid phase but does have an upper limit where the meter will stop working

   The meter has a turndown of greater than 100:1 and has a response time of <1 second

2. The system contains full internal diagnostics where a live sonic velocity shows that the reading is valid and other diagnostics parameters show the health of the system. All of this is available on a HART link and can directly link into an AMS system

   These systems are available as ATEX certified, but of more importance, if the meter is not working it is not because an impulse line is blocked or conditions have changed significantly but that something more significant has occurred and the diagnostics will tell you why

   The system is non-intrusive so no leak paths are possible even during installation, commissioning and maintenance. The pipe always remains at full integrity, therefore the meter is fully resistive against any wear, tear, scaling or chemical attack

3. Regardless of the decoking techniques employed (steam air, mechanical (pigging) and online spalling) the meter stays on the pipe. The meter will suffer no ill effects from any of these methods and can remain on the pipe almost indefinitely throughout the entire flow cycle of the coking process including start-up, shut-down, cleaning, maintenance and normal running

4. The system is non-intrusive, therefore not only does the meter have no possible leak paths, but has no pockets or interaction with the process and therefore does not react with the process in any way

5. The WaveInjector® system has been installed and working for a number of years now and with over 1000 systems installed globally has shown its long term viability and reliability

   Due to it's fully non-contact clamp-on nature, the meter is installable and maintainable during normal process operations, develops no pressure drop, has no crevices or lines to block. This results in a meter which is easily installed, is virtually maintenance free and presents no pressure restriction to the fluid

So, we can see that although the WaveInjector® flow meter does not fulfil all of the requirements of an ideal meter, it is the best fit on the market today.

12 GLOSSARY

12.1 Gain (dB)

The gain is the amount of amplification required by the raw signal and is measured in decibels. The amplifier can run up to 108 dB.

12.2 SNR (dB) - Signal to Noise Ratio

The noise in this context is random with respect to the signal. It can be filtered and further reduced by signal processing (as long as the remaining noise is not so strong that the signal cannot be detected) and does not affect the long term average of the measurement result. The only effect is an increased standard deviation. Potential random noise sources are electrical sources like variable frequency drives and acoustical sources like regulating valves.

12.3 SCNR (dB) - Signal to Correlated Noise Ratio

This is a FLEXIM specific term and the noise here (the pipe signal) is correlated to the signal because both signal and noise are generated by the same source. This noise cannot be filtered and can only be reduced by acoustical means. The use of damping materials and transducer design are used to reduce this noise including matching the transducers to the pipe (selecting the right transducers).

12.4 USFM - Ultra Sonic Flow Meter

The term USFM is applied to any ultrasonic flow meter, regardless of its technology, physical arrangements or flow analysis technique. The term can be applied to clamp-on time of light, correlated signal as well as Doppler. The term also applies to in-line ultrasonic meters from the basic right up to the fully fiscal multi chord systems.

13 LITERATURE

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