

The Myths and Realities of Gas & Multiphase Desanding

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1 INTRODUCTION

Wellhead or multiphase desanding has long been seen as the technology limit for removing solids from a process train. Removal of erosive sand from upstream of the first stage separator is in principle an attractive proposition but often the required design pressures and the limited available pressure drop can cause design and cost issues. In addition, some problems with regard to performance and mechanical integrity of the first generation systems have led to scepticism regarding reliability of multiphase desanding in some industry sectors.

This paper seeks to explain the “can’s and can not’s” of multiphase desanding. Given the uncertainty of the nature and level of solids production at the wellhead, the technology must be a flexible bulk solids removal, rather than a total solids “polishing” solution and one that is designed to remove solids that cause erosion and blockage problems in the downstream process train. Accepting this premise together with Cyclotech’s development of second generation multiphase desanding systems, where many of these early problems have been overcome, ensures the market availability of multiphase desanding solutions which are both technically and commercially robust.

In addition, the authors describe the important functions and design criteria when designing a multiphase desanding system to improve understanding of the critical data required when design evaluation is undertaken. As with any process system, correct process and design criteria are critical to ensure correct system sizing while achieving the required performance aspirations.

Case studies of two high pressure multiphase references are presented to illustrate this development. Design cases, photographs and field experience are detailed.

2 MULTIPHASE DESANDING BACKGROUND

2.1 Desanding Hydrocyclone Fundamentals



As with any cyclonic process, the wellhead or multiphase desanding cyclone is a device that utilises pressure energy to separate two phases of different density. In this case it is the separation of higher density solids from a primary gas phase. The feed fluid is fed tangentially into the cyclone insert at high velocity, causing the flow to spin in a confined swirling flow vortex pattern. This vortex creates an acceleration field (many ‘000s g) which forces the solid particles to migrate to the outer wall of the cyclone insert. Due to the differing pressure gradients, the desanded fluid at the radial centre travels axially upwards and through the cyclone overflow for further processing. The removed solids phase travels in the primary vortex and is routed downwards along the outer wall of the cyclone insert to be collected in the lower accumulator vessel.

Figure 1 to the left shows a typical wellhead desanding system set-up. The upper cyclone vessel has an outer pressure vessel containing a multiphase cyclonic insert. The lower vessel is the

Fig. 1 – Typical
WDC

accumulator vessel which collects the removed solids for onward disposal and / or cleaning.

Under a given acceleration field within the cyclone, a modified form of Stokes Law (shown below) describes the radial settling velocity achieved by a solid particle travelling towards the Hydrocyclone wall.

$$u_s = \frac{Gg\Delta\rho d^2}{18\mu} \quad (1)$$

Notation for the above equation (1) is contained at the end of the paper.

The faster this velocity (u_s), the greater the likelihood that the solid particle will reach the cyclonic insert wall (and therefore be separated) before being carried out with the fluids in the overflow. The effects of the various parameters on cyclone performance are discussed below.

2.1.1 Acceleration Field

The acceleration field increases with increasing throughput (and increasing pressure drop across the cyclone). Whilst the residence time decreases with increasing flow, the increase in acceleration field is more significant. Therefore, the cyclone separation efficiency increases with increasing flow.

Generally, acceleration field also increases with reducing cyclonic insert diameter. Therefore, smaller cyclone diameters generally provide higher separation efficiencies than larger cyclones. However care is required with gas desanding cyclones as turbulence levels within the cyclone also rise with increasing inlet velocity, which can cause particle re-entrainment and subsequent loss in performance. Gas desanding (where inlet GVF>95%) cyclones are particularly susceptible to this and the cyclone diameter which delivers optimum performance will increase significantly with increasing inlet GVF.

2.1.2 Density Difference

Increasing the density difference between the solids and continuous phases will improve the cyclone performance.

2.1.3 Sand Particle Size

The size of the sand particles has a significant effect on the Cyclone Separation efficiency. The actual cut size depends on the other parameters described in this section, but the separation behaviour trends are similar across most applications. Therefore, "small" particles below a certain size are unlikely to be removed, "large" particles above a certain size will all be removed and some particles in between these two critical sizes will be partly separated.

2.1.4 Viscosity

Decreasing the viscosity of the bulk phase increases the solids separation efficiency. As bulk phase viscosity is generally low for primarily gas systems (gas void fraction, GVF > 80% or more), this lends itself to efficient desanding for comparably larger diameter cyclonic inserts.

2.1 Early System Design and Experience

Cyclotech initiated a Joint Industry Project to develop, build and test Wellhead Desanding Cyclone technology in 1994. The project was supported by BP, Chevron, LASMO, Shell International and Statoil and the work lead to Cyclotech supplying what is commonly held to be the first installation of this type of equipment to Expro North Sea for use on the Shell Brent Delta platform.

These first generation multiphase desanding systems generally performed well but there were occasionally specific problems such as higher measured than predicted pressure drops.

These problems mainly relate to the early modelling used during the design phases of these projects. These early algorithms occasionally undersized the required cyclonic insert sizes. The result was efficient solids removal but higher than expected pressure drop values at design flowrates.

These higher than expected pressure drops not only limit potential throughput but also had a knock on effect of increasing erosion potential; reducing cyclonic insert life and potentially damaging WDC system integrity.

This experience led, in some instances, to some scepticism regarding wellhead and multiphase desanding.

3 CYCLOTECH MULTIPHASE DESANDING DEVELOPMENT

Cyclotech's Wellhead Desanding Cyclone technology has been developed to remove mid to coarse sized solid particles from multi-phase wellhead streams. This allows problematic solids to be removed from the wellstream upstream of the process train, and even upstream of the production choke. At the wellhead, it is more often than not the larger particles which cause significant erosion and potential blockage issues. For this reason it is important to target removal of these larger, potentially harmful particles. Smaller particles which may escape separation from a WDC system tend to have limited erosion potential and do not accumulate in the downstream process, preferring to pass through the system.

The key elements of the application of the technology centre around determining the range of volumetric flowrate and phase composition expected from the well or combination of wells in question. Once these ranges have been determined to a satisfactory level of confidence, the nature of the inlet multi-phase flow regime can be determined which in turn dictates the sizing basis for the Wellhead Desanding Cyclones – the inlet Gas Void Fraction is perhaps the key variable which influences the cyclone design. Other factors which influence cyclone design are the instantaneous sand concentrations in the fluids from the well and the particle size distribution of the produced sand.

Cyclotech has built all these factors into its Wellhead Desanding Cyclone design model to allow optimisation of Wellhead Desanding Hydrocyclones for the widest possible range of separation applications:

- Well Clean-Up
- Cold Well Start Up
- Under-balanced Drilling
- Production Systems

3.1 Current System Design

The Cyclotech WDC Multiphase Desanding Hydrocyclone vessel is generally a vertically mounted conical bottomed vessel accommodating the WDC cyclone. The sand will be separated from the multiphase gas stream and fall through the conical bottom into a separate sand accumulator vessel flooded with clean water.

Cyclotech's Wellhead Desanding range runs from WDC-100 100mm (4") diameter to WDC-1000 1000mm (40") diameter units comprising cyclone inserts located inside pressure housings providing the means to replace or re-size inserts easily. Separation performance in terms of specific particle size is dependent on fluid characteristics and composition.

Inserts are typically manufactured from hardened stainless steel, but can also be provided in duplex stainless steel and ceramic lined. For operation upstream of the choke, pressure housings up to API 5,000 psi are available as standard, although Cyclotech have constructed and supplied API 10,000 psi and API 15,000 designs. For operation downstream of the choke design pressures up to ANSI 2500# equivalent are standard.

The use of replaceable cyclone inserts allows a range of different inserts to be used for a single pressure vessel – increasing system turndown and maximising system flexibility; an important feature if the WDC is to be considered for multi-well applications.



Fig. 2 – WDC
Insert

To aid erosion monitoring, wear detection can be built in to the system – especially important for not normally manned installations. Monitoring of wear allows early warning of insert degradation and allows ample construction time for a spare insert; ensuring minimised downtime of the WDC system.

A vital part of WDC design is to develop an accurate model to simulate system performance, pressure drop and solids cut-size for a given insert size. In addition, the wellhead desanding geometry must be bespoke designed to accommodate the gas so that the presence of gas improves rather than depresses the separation performance when compared to a liquid/solid system.

For applications where the inlet GVF is typically above 80% (other factors do influence this), an in house developed gas desanding cyclone model is used as the start point which is then modified through correction algorithms to allow for the appropriate liquid fraction. The inputs to this correction include the inlet flow regime, the bulk properties of liquid phase and key cyclone geometry variables which include the inlet and gas outlet port dimensions. This is an iterative process which allows the geometry of the gas cyclone to be optimised for the specific range of design phase flowrates, operating pressures and temperatures etc.

Historically some suppliers have used a standard liquid/solid cyclone model which was modified to accommodate high gas rates. Cyclotech have determined that this is not appropriate as it is critical that the cyclone is designed to accommodate the gas flow otherwise it will depress rather than improve the particle separation performance. For GVFs below 80%, Cyclotech has had to develop more complex models. It is therefore not appropriate to use either standard geometries and/or solid/liquid cyclone geometries for a multiphase duty.

It is obviously impractical to test large diameter multiphase cyclones in the lab due to the very large gas and liquid flowrates involved. We have therefore verified our multiphase desanding cyclone models (~GVF>80% and ~GVF<80%) using real field data. The field experience detailed in Section 5 of this paper discusses how the design model compared to actual field performance.

Past experience of first generations WDC systems and design / modelling advancements discussed above have led Cyclotech to offer a second generation WDC system design which:

- Has high level of system flexibility;
- Offers a high solids separation efficiency over a wide operating envelope;
- Effectively accumulates, monitors, cleans (if necessary) and discharges removed solids;
- Can be fully automated and monitored;
- Can be fully modelled (in terms of system throughput, performance and operating pressure drop) at detailed design phase;
- Has high level of operator confidence.

The basic design now used incorporates a uni-cyclone design (ie pressure vessel containing a single WDC cyclonic insert) located above an accumulator vessel. Isolation (normally double block and bleed) is provided between these two vessels to allow normal operation while the accumulator vessel is off-line for solids extraction / cleaning and disposal. A nominal amount of solids hold-up at the bottom of the upper cyclone vessel allows the WDC cyclone to operate continuously without interruption during the accumulator purge procedure.

A typical second generation Cyclotech WDC is shown below.



Fig. 3 – Typical Cyclotech WDC System with upper cyclone vessel and lower accumulator vessel

3.2 The Argument for Single (Uni-Cyclone) Inserts

Cyclotech are able to supply either a single large diameter insert or a small diameter multi-cyclone design but for multiphase desanding applications, particularly when the gas void fraction is high, Cyclotech have always recommended the single insert design, as long as it meets the required separation performance, as it offers significant cost, weight and most importantly reliability benefits over the multi cyclone design. Figures 4 below shows the differences between uni (single) and multi-cyclone approaches.

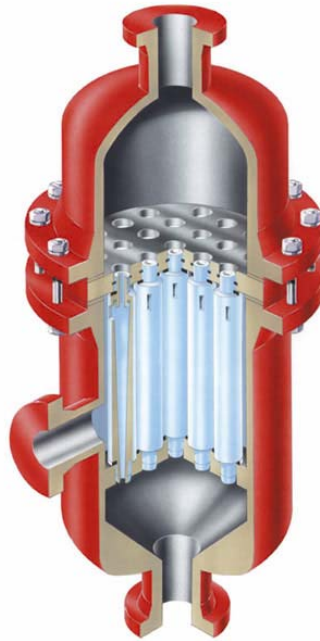


Fig. 4 – Uni-Cyclone (left) and Multi-Cyclone (right) designs

The argument for the use of the small diameter multi-cyclone design is that it provides better separation performance and better turndown. This is not always true, particularly for high GVF applications (as discussed in Section 2.1.1), and the following points should also be carefully considered :

- The cost of the vessel raw materials increases almost exponentially with diameter, particularly at high design pressures, and thus a key cost driver is always to minimise the diameter of the vessel. Indeed, as the required vessel inside diameter increases, the wall thickness will increase considerably which will significantly increase size and weight of the system. For a given design capacity, a single large diameter cyclone will always result in a smaller diameter vessel than a multi-cyclone alternative.
- One of the most important design requirements is to protect the pressure housing from the incoming sand laden high velocity flow. A single insert design, together with an inlet wear sleeve, will completely protect the housing from the incoming flow. A multi cyclone system will allow the incoming flow to impact directly on the pressure vessel wall and also directly on the multi-cyclone liner adjacent to the inlet nozzle.

- The larger inlet and outlet diameters associated with a single cyclone insert design will also be significantly more insensitive to blockage and high inlet sand concentrations increasing the system availability. Large solids could potentially block the smaller inlets of the small diameter liners. The multi-cyclone design also creates an additional chamber (inside the vessel but outside the liners) where solids could collect and eventually block the multi-cyclone liner inlet ports. For the single insert design, all the incoming flow is routed directly into the large inlet port.
- The turndown of the single insert WDC's is competitive and as the inlet GVF increases, the difference in separation performance between single insert and multi-cyclone design narrows markedly. Moreover, wells normally only produce sand at the higher end of the flowrate range, which implies that the system will deliver maximum performance when needed. At inlet GVFs >95%, a single insert geometry will generally outperform small diameter multi-cyclones due to their inherent lower turbulence levels.

3.3 Important Design Considerations

When considering a multiphase desanding system, it is vital that any prospective user supplies as much design / process information as possible in order to maximise effectiveness of the sizing model.

As a minimum, the information below is required:

- Design Pressure
- Total Flow Rate
- Water Cut (%)
- Oil Density
- Oil Viscosity
- Water Density
- Water Viscosity
- Total Gas Flowrate
- Gas Viscosity
- Gas Molecular Weight
- Z factor
- Operating Pressure
- Allowable Pressure Drop across Cyclonic Insert
- Temperature (°C)
- Materials of Construction
- Solids Production Rate
- Required Solids Removal Size

Assumptions can be made for missing data but maximising the quality of data supplied at the initial design phase allows the cyclonic insert size to be fixed. Once the cyclonic insert size is fixed, mechanical challenges (such as design of API 15,000 psi housings) can then be addressed to assess system feasibility.

It is also very important at the early design stage to build as much flexibility into the system as practically possible. This is mainly due to the uncertainty relating to well data provided at the design / enquiry stage.

4 MULTIPHASE DESANDING - THE "CAN'S" AND "CAN-NOT'S"

Given the modelling / design problems associated with the first generation of multiphase desanding systems in the North Sea and subsequent efficient performance of recent second generation systems, the following section is intended to show the prospective WDC user the expectations one can anticipate from an installed WDC system.

The aim is to show the reader the advancements in WDC technology with second generation systems and demonstrate that this is an extremely effective tool for solids management at the main flowline; either upstream or downstream of the production choke.

4.1 The WDC “Can’s”

The following are realistic expectations from Cyclotech second generation Wellhead Desanding Systems.

4.1.1 Realistic Performance Based on Design Model

As shown in the case studies described in Section 5, Cyclotech’s WDC design model is now an accurate, refined and useable tool for effective WDC design.

Field experience shows the actual solids removal cut-size is similar to that predicted in the model, for a given WDC insert’s size and available pressure drop. In some cases field experience is better than that predicted, showing the model errs slightly on the side of caution.

4.1.2 Effective Removal of Sand Particles

With correct design parameters, a uni-cyclone WDC insert will effectively remove sand particles significantly below 80 microns. Higher pressure drops can reduce this cut size even further but efficient solids removal below 80 microns can be achieved at sub 1 bar pressure drops. As the inlet GVF increases, the cut size will decrease. For inlet GVFs above 95%, cutsizes of ~10 to 20 μm are common for Cyclotech single large diameter cyclone inserts.

Not all WDC systems supplied are used for sand removal – some are used by well service companies for applications such as proppant flow-back after well intervention. As proppant tends to have larger mean particle diameter but still significant density compared to the gas phase, lower pressure drops can be tolerated.

4.1.3 Realistic Pressure Drop

As mentioned above, allowable pressure drops below 1 bar can be tolerated in a WDC system **as long as** this is allowed for at the design stage.

Normal design dp values of less than 2 bar are usually used if no other process data is available / specified. During design stage it is important to state that system sizing and performance (based on solids cut size) is based on minimum allowable dp. Therefore normal operations will result in better solids removal as the acceleration field within the WDC system will be greater. For gas desanding applications, pressure drops above 2 bar are not recommended due to high inlet velocities causing high turbulence levels and erosion rates.

4.1.4 Long Operational Life

Cyclotech’s normal material for WDC inserts is reaction bonded silicon carbide (RBSC). The RBSC insert is normally housed in a duplex stainless steel shroud for handling / installation proposes. This ceramic has a Vicker’s Hardness number twice that of tungsten carbide and ten times that of standard 22% duplex stainless steel. It is extremely erosion resistant and is ideal for solids removal applications such as multiphase desanding.

All high wear areas can be manufactured from RBSC to increase operational lifetime and, if desired, wear detection systems can be fitted to monitor ceramic lifetime.

4.1.5 Ease of Operation

Most WDC systems are easy to operate and can have variable levels of automation. Fixed installations can be fully automated (even solids discharge phases) and tied into platform

central control system / monitoring software. Cyclotech have supplied systems for Normally Unmanned Installations (NUIs) with complete automation of all removal / discharge sequences.

However well service companies may use a single WDC for varying purposes (well work-over, proppant flow-back, etc) and on varying installations. In such instances it is important to make system operation as simple as possible and usually with only manual control to improve WDC flexibility.

4.1.6 Discharge of Solids

The most reliable and effective method for monitoring solids level in the accumulator is with a nucleonic level detection system. When solids level set-point is reached, the discharge sequence can be initiated. Cyclotech's Sandscape sand ejector ensures solids are efficiently removed from the accumulator at a controlled rate and concentration. Solids can be routed to user's preferred destination; be that re-injection, further collection for onshore shipment or cleaning for overboard disposal.

For some wellhead applications, the separated sand is clean enough (ie less than 1 % ^{w/w} oil-on-solids) for discharge straight to sea, depending on local environmental constraints. The reason for this is reservoir sand is often water-wetted when it reaches topsides and if it can be removed quickly enough it does not have time to significantly oil wet.

4.1.7 Useable Turndown

For WDC systems with useable pressure drop up to 2 bar, a turndown of up to 3:1 to 5:1 can be expected. For fixed (usually single well) applications this is more than sufficient. If higher turndown is required, multiple vessel design can be considered.

For well service companies, a single WDC unit may be required for a number of different applications (ie well work-over, proppant flow-back, etc) and for such applications Cyclotech can provide a range of different WDC insert sizes for a given vessel. For example a 10" NB WDC vessel can be supplied with 8", 6" and 4" inserts to increase system turndown and equipment flexibility.

4.1.8 System Robustness

Robustness to sand erosion and sand concentration are two important factors to consider during the design phase. Erosion resistance was covered in section 4.1.4 but equally important is consideration of inlet sand concentration.

WDC systems often have to cope with solids slugs and have to be designed to deal with this. Cyclotech's WDC inserts have large inlet and solids underflow to deal with periodic high sand loading.

Valve selection is critical when designing an effective WDC system. Discussion between client and vendor is recommended to chose suitable valve types. In some instances, client valve selection for sandy service has not been suitable for the high solids loading and high levels of required automation sometimes required for WDC applications.

4.1.9 System Flexibility

Especially for well service companies, system flexibility is an important issue. During design it is important to consider all flowrate and available pressure drops expected for the system. For these conditions the WDC should be designed under "worst case" scenarios with high flowrate and low allowable dp to ensure efficient operation.

Again, a range of different WDC insert sizes can be provided for a single vessel to increase system flexibility.

4.1.10 High Design Pressures

High design pressures were a concern when designing the first generation of WDC systems. However Cyclotech have supplied second generation WDC vessels with design ratings of API 5,000, 10,000 and 15,000 psi. The mechanical design of these systems is complex and through experience and considerable investment, Cyclotech can offer an optimised and efficient WDC design (in terms of weight, reliability and cost) for these high pressure applications.

4.2 The WDC “Can-Not’s”

As with any technology, there are limitations with WDC systems. It is hoped the following points highlight these technology limitations and help increase technology understanding.

4.2.1 WDC Systems cannot handle limitless sand concentrations

For periodic sand slugs (ie more than 70% v_v solids), most well designed, single insert WDC systems can cope for short periods of time. However to deal with prolonged solids slugging requires a slightly different design approach and it is important this is brought to attention at the design phase – if such information is known. Multi-cyclone designs tend to have a much lower tolerance to high inlet sand loadings due to smaller inlet ports and the presence of an “inlet chamber” within the vessel.

High sand loading can also lead to increased accumulator emptying frequency and this can be designed-out with a larger accumulator if known up front. However balance has to be struck between accumulator size (and cost) and desired discharge frequency / destination.

4.2.2 WDC Systems cannot remove reservoir fines as well as large particles

Most WDC systems are designed to remove relatively large (greater than 50 microns) particles at relatively low (sub 2 bar) pressure drop values.

This indicates WDC is an effective mid to coarse solids removal tool intended for:

- erosion protection;
- flowline assurance;
- minimising downstream solids build-up.

Due to the coarse solids removal design conditions (and relatively large cyclone diameter compared to fine sand/liquid cyclones) few fine particles will be removed. The exception here is gas desanding where many fine particles will be removed. However reservoir fines do not have the associated erosion and cumulative effect of larger particles.

4.2.3 WDC Systems require pressure drop

It is an important fact to remember that any WDC system will require a certain amount of pressure drop to operate effectively.

For low pressure drops (less than 0.5 bar) applications, the WDC insert diameter becomes larger to deal with the necessary flowrates. Again a balance has to be struck between WDC insert diameter (and associated cost) and available pressure drop.

4.2.4 WDC systems cannot be installed anywhere

A fully automated, double block and bleed valved WDC system can be large and up to 10m high in some cases. Obviously this will not fit all applications and, as well as process conditions, size, weight and footprint, this also needs careful evaluation.

5 CASE STUDIES

To demonstrate the comparison between design model and supplied systems, two case studies are now briefly discussed.

These are Shell Leman Delta in the Southern sector of the North Sea and Shell Todd Mangahewa in New Zealand.

5.1 Shell Leman Delta

To our knowledge this is still the largest wellhead desanding system in the world, supplied at the start of January 2002. Design conditions are listed below:

Cyclone	Liquid Flow	Gas Flow	Design Rating
WDC-600 (24")	10 m ³ /h	360,000 sm ³ /d	600#

Photographs of the system supplied are shown below in Figures 4 and 5.



Fig. 5 – Shell Leman Delta
WDC insert being installed

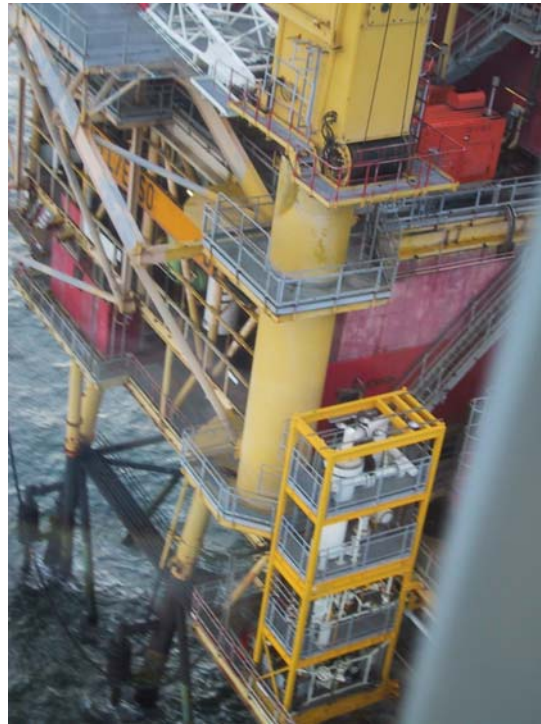


Fig. 6 – Shell Leman Delta
WDC skid installed

The Shell Leman platform is not normally manned and all WDC operations (including solids monitoring and discharge) are automated and remotely monitored and logged.

It is always difficult to obtain field data from operating systems and unfortunately the Leman operations personnel have not deemed it necessary to analyse the separated sand for particle size but what we do know is that the system separates all incoming sand (the only problems have been confined to the valve selection and not the process performance of the desanding insert itself). This is confirmed by sand monitors on the inlet and outlet pipework. We also have an inlet sand particle size distribution determined from a sample taken prior to the desanding system being installed. Given that we know that no sand has been discovered in the downstream pipework which has emanated from the desanding cyclone outlet, it suggests that the D98 (ie size at which 98% of all particles larger will be removed) cutsize is at least 40 microns but likely to be lower at 15 microns but this can not be conclusively proven given that the sand particle size distribution is reasonably coarse resulting in little sand existing below 40 mm. Pressure drop prediction was correct at 0.3 bar.

5.2 Shell Mangahewa

This system had a significantly higher design pressure (API 5,000 psi rating) than Leman Delta. Design conditions are listed below:

Cyclone	Liquid Flow	Gas Flow	Design Rating
WDC-300 (12")	4 m ³ /h	567,000 sm ³ /d	API 5,000 psi.

Photographs of the system supplied are shown below in Figures 6 and 7.



Fig. 7 – Shell Mangahewa
5,000 psi WDC Insert



Fig. 8 – Shell Mangahewa
5,000 psi WDC System

Again the operator has not found it necessary to analyse the separated sand as they are satisfied that the unit removes all the sand and the downstream process is now clear of sand. The required cutsize was a D98 of 50 µm. Pressure drop prediction of 1 bar was again verified.

6 CONCLUSIONS

From the information discussed in this paper, the following conclusions can be drawn:

- Multiphase or wellhead desanding is an effective method of coarse solids removal from high GVF streams;
- WDC systems can significantly reduce downstream erosion and solids build-up in multiphase systems;
- Effective solids removal can be achieved at relatively low (less than 2 bar) differential pressures;
- Careful design and modelling is required at an early stage to determine required WDC insert size for a given application and accurately estimate expected performance;
- Correctly designed, significant flexibility and turndown can be built-in to a given system;
- Correct system design allows for easy operation with minimal operator intervention;
- First generation WDC system models tended to undersize the required cyclone size, resulting in increased dp at design flowrates;
- Current Cyclotech WDC model is an effective design tool and accurate performance prediction has been verified by operational feedback.
- Multi-cyclone designs are non preferred due to their increased blocking and erosion potential. This is particularly true for systems which utilise standard solid / liquid cyclone geometries which are not designed to handle the gas phase and will produce inferior performance.

7 NOTATIONS

Notation for this paper is as follows:

u_s	Solid particle radial settling velocity
Gg	The acceleration field created by the vortex flow
$\Delta\rho$	The phase density difference
d	The solid particle diameter
μ	the continuous phase viscosity
GVF	Gas void fraction
WDC	Wellhead desanding cyclone
NUI	Normally Unmanned Installation

