A DET NORSKE VERITAS MODELED QUALIFICATION PROCESS FOR A TURBOCOMPRESSOR INCORPORATING A SEPARATOR KNOWN AS THE INTEGRATED COMPRESSION SYSTEM

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ABSTRACT

The Det Norske Veritas (DNV) Technology Qualification Process requires several steps to be completed before new technology can be qualified for service based on proven experience. This paper will present a brief overview of the DNV Qualification Process and how it was applied by an original equipment manufacturer (OEM) during the development of a new product that incorporates a separator into a centrifugal compressor.

The concept of incorporating a separator in the same casing as a centrifugal compressor is a novel approach that was not previously proven. The OEM created a demonstration rig to validate the concept of liquid separation and gas compression in a single case. The development process included the design of mechanical components based on previously existing rules, the creation of new design rules and analytical tools to accommodate new product specifications and requirements, as well as analysis of the resulting designs. In addition, extensive experimental testing of the new designs allowed the calibration of the analytical tools and subsequent optimization of the components. This development and design process resulted in the creation of a virtual design/development/test laboratory. The economic and technical value of this virtual design and test process will also be discussed.

INTRODUCTION

Traditional compression modules are typically large, heavy, and expensive structures that require a lengthy time to produce. In the case of floating offshore applications, such as the ones shown in Figure 1, the weight and size available for the equipment at the platform are limited. For this reason, weight and size of compression modules play an important role in sizing the platform or vessel that will support them. For onshore applications, a reduction in the size of the compression package will also benefit the end user because the overall installation size can either be smaller or more compression capacity can be fit into a fixed footprint.

Figure 1. Traditional Offshore Floating Oil and Gas Production Facilities.

From the systems integrator and end-user’s point of view, solutions that can reduce the size and weight of the compression package and its associated auxiliary and support systems are very attractive because they allow the optimization of future offshore platform designs to much smaller, lighter, and more cost-effective installations. On the other hand, in the case of existing platforms, the use of compact compression systems allows the end user to debottleneck the existing capacity of older platforms in which additional space is not readily available.

Another aspect that is very important to the end user is the reduction of the life-cycle cost of the compression equipment, which includes the operation and maintenance costs. This cost can be reduced when the compression equipment uses reliable and high-efficiency, state-of-the-art technology and eliminates the systems that require the use of consumable materials and fluids that require periodic replacement such as lube oil systems.

Finally, a third aspect that directly affects the time to revenue is the total project cycle time. The use of compression modules that could be tested as a whole at the original equipment manufacturer’s (OEM’s) facility during the factory acceptance test under actual wet gas conditions would significantly reduce the installation, commissioning, and startup time, providing the end user with a shorter time to generate revenue.

The integrated compression system (ICS) has been developed following an innovative approach to address these issues and uses breakthrough technology to provide a truly unique solution. By using a building block approach, the system maximizes the application of technology and components with a proven track record in the field. This approach reduces the overall risk associated with the use of the system and also reduces the time required to introduce the product line to the marketplace.

TECHNICAL QUALIFICATION

The centrifugal compressor and the separator have a proven track record in the field. However, the OEM’s objective to minimize the weight and footprint of the compression system was best achieved by creating a new technology that integrated the gas/liquid separator with the compressor in a single casing. Benefits of this new technology included increases in overall system reliability, and a reduced number of bearings in the system. As will be evident throughout this paper, the system reliability is increased by the elimination of several traditional compression train components, such as the lubrication oil system and the speed-increasing gearbox between the motor and the compressor. The gas/liquid separation also enhances reliability and extends the life of the compressor by avoiding the ingress of liquids into the compression flowpath. Application of the new technology required the development of unique algorithms for process stream separation and new mechanical designs. The designs needed to accommodate a new flowpath for the centrifugal separator, mechanical considerations for sharing a common bearing system, and techniques that consider the separator and compressor rotating at the same speed.

The integration of the separator and compressor components are considered to be a new technology and, therefore, required to be qualified before the system was put into service. This paper will focus on the process that was used to support the qualification of this technology for applications that require the compression of wet gas streams.

Following is a description of the ICS and the value associated with the use of this technology. A following section will present a brief introduction to the Det Norske Veritas (DNV) recommended practice DNV RP-A203 (2001), which is a document that provides procedures that can be used by OEMs, system integrators, and/or end-users for the qualification of equipment that is considered to be new technology. Finally, the remainder of the paper will provide insights into the development program that the OEM followed to qualify the technology required for integration of to liquid separation and gas compression into a single casing.

Integrated Compression System

The integrated compression system developed by the OEM is engineered to provide an efficient, compact wet gas compression system in a single lift module. The ICS uses the OEM’s centrifugal compressor technology driven by a high-speed, close-coupled closed loop gas-cooled motor with an integrated gas-liquid separator, packaged with process piping, process control valves, and gas coolers into a single module. Design attributes also include the use of magnetic bearings and a pressurized and sealed separator/compressor/motor unit, which results in a zero emissions system without the use of dry gas seals. It provides a complete compression system that can be applied to all markets—upstream, midstream, and downstream. A typical arrangement of an ICS unit is shown in Figure 2. The system components are arranged in such a way that allows sufficient access for maintenance and inspection of the main components.

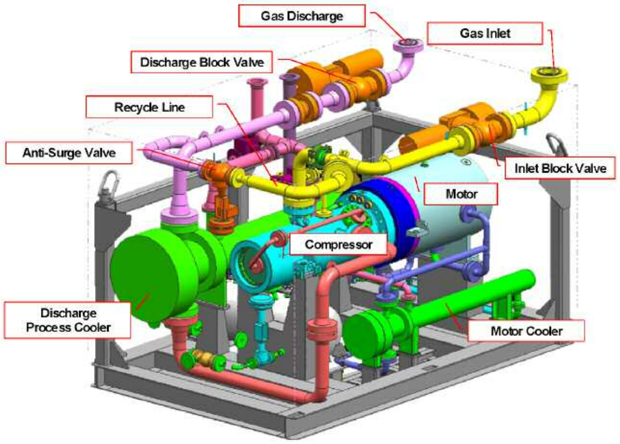

Figure 2. Example of a Single Section ICS Unit Arrangement.

Compared to a conventional compression module, in which the equipment is arranged in multiple decks, the ICS has the potential to reduce the size and the weight of the package by approximately 50 percent. This is a direct result of the compact packaging of the compression module components and the elimination of the gravity-based scrubbers, lube oil system and the speed increasing gear (a consequence of the use of a high-speed motor). The performance of the ICS, which incorporates centrifugal compressor and gas/liquid separation technologies, is competitive with the overall performance of traditional systems when the suction scrubber and inlet piping losses are taken into account. The result is a cost-effective solution that can add real value to capital projects and operations throughout the life of the equipment.

Another important feature of the integrated compression system is the ability of the OEM to completely test the whole compression module, with all of the contract auxiliary systems as a single unit during the factory acceptance testing. This allows a significant reduction in the installation, commissioning, and startup times to put the module into service once it arrives in the field. As a consequence the platform can generate revenue in a shorter time when compared with a traditional compression solution approach.

The OEM’s line of centrifugal compressors has set the standard for modular design and best-in-class performance. These units have improved the serviceability of centrifugal compressors, resulting in reduced downtime and lower overall life-cycle costs. Driving this compressor line with a high-speed, close-coupled motor ensures a compact design that is environmentally friendly and cost-effective.

Completely Integrated Separator Technology

The ICS’ ability to effectively handle any dry or wet gas application is made possible by the integration of the OEM’s proprietary separation technology, advanced impeller metallurgy, and efficient compression technology in a common case. The separator in the ICS makes use of centrifugal forces to separate liquids and solids from the gas stream, allowing the development of more compact units that can achieve equal or better efficiencies than conventional systems.

As mentioned above, the use of this technology allows oil and gas producers to effectively reduce the overall size of production facilities, platforms, and subsea modules. Furthermore, downtime and potential production losses are reduced because the separators protect the equipment from liquids and particles in the pipelines.

The ICS is uniquely suited for the developing subsea applications, where the reduced weight and smaller footprint make it very attractive when compared to traditional pump-only or compressor-only technologies. In addition, it is easier to transport, install, and retrieve. As opportunities for subsea compression emerge, a “marinized” ICS system is expected to offer the best solutions and provide real value to the clients who have seabed operations. Additionally, the option for the combined functionality of a pump-separator-compressor with a reduced number of bearings and the flexibility of operating conditions (including large variations in process stream composition) offer another unique alternative to traditional systems.

THE DNV QUALIFICATION PROCEDURE

The companies involved in the exploitation and production of oil and gas fields around the world require the constant development of new and improved technologies that can support their current and future needs. These new technologies help them become more competitive in the markets they serve by improving the performance and reliability of the assets used in their oil and gas operations. Before the companies can make use of the new technologies in the field, there are many safety, health, environmental, and economic factors that must be addressed and evaluated to determine that the new technologies are suited to the purpose for which they are intended.

In the context of the qualification of new technologies, the term *proven technology* refers to technology that has a documented track record of operation in the field under similar or equivalent operating conditions to those expected for the new application. On the other hand, *limited, unproven, or new technology* may be used to address the use of components or systems with a proven track record for a new application that will require operation under different conditions than those previously encountered. It also can refer to the use of newly developed technology (without a track record) for a known application.

The DNV RP-A203 (2001) “Qualification Procedures for New Technology” is a method for classifying technology gaps for new technology and designing a qualification process to close those gaps. The purpose of following this procedure is to reduce the risk normally associated with the introduction of the new technology. It is recognized that new technology must be considered, and by following this procedure it can be done so in a risk managed way. Although the main intent of the document is to cover the qualification process for components, equipment, and systems to be used for offshore hydrocarbon exploration and resource development, the principles also can be used for onshore applications, as well as for the qualifications of technology not intended for hydrocarbon services.

The DNV procedure accounts for the application under consideration (pressure, temperature, and depth) and the previous application experience that the industry has. When considering the technology itself, the procedural classifications include proven field history, limited field history, and new or unproven technology (Table 1).

Table 1. Guideline for Technology Classification.

	Technology		
Application Area	**Proven**	**Limited Field History**	**New or Unproven**
Known	1	2	3
New	2	3	4

Where,

1 = No new technical uncertainty exists
2 = New technical uncertainty exists
3 = New technical challenges exist
4 = Demanding new technical challenges exist

The general approach is based on the identification of the technology readiness level, which is based on the degree to which the technology has been developed (new or known) and how it has been applied in the past *(new, limited field history, or proven)*. This standard suggests the application of a reliability assessment that encompasses all of the components and subcomponents of the new technology with the intent to verify that it will be able to meet its functional specifications safely and economically. This is typically done via a failure modes, effects (and criticality) analysis *(FME[C]A)* that also may be combined with a hazard and operability *(HAZOP)* analysis. These activities allow the identification of the risk factors associated with the failure modes. The risk factors are determined as a combination of the failure probability and the consequence of said failures. The ranking of these factors allows the identification of critical risk factors (which should be the main focus of the technical qualification program) to ensure that they are properly addressed and eliminated during the different phases of product development and testing. It is important to note that all risk factors should be documented in the FMEA forms, and none should be removed, even if they are not considered to be critical. The DNV standard offers information about how to evaluate the probability of occurrence of the identified risks, how to evaluate the consequences of occurrence, and guidelines on how to rank the risks. It also includes information on how appropriate maintenance planning and condition monitoring can be used as risk mitigation tools for risk factors that cannot be eliminated by design.

Proper identification and ranking of the risk factors are of paramount importance for the success of the technical qualification program; therefore, the risk analysis and evaluations should be done by cross-functional teams integrated by qualified personnel (including end-users), and having combined experience that covers the areas that are being evaluated.

The number of activities and levels of testing that will be incorporated into the qualification program will depend on the technology readiness level and the number of critical risk factors that are identified. An important feature of the qualification program described in the DNV guidelines is the feedback loops among the data that are generated during each activity that is part of the qualification process. After every activity is completed, the FMEA and HAZOP results should be updated and the qualification program should be revised or updated accordingly. Figure 3 shows a schematic of the main activities that occur during the technical qualification process.

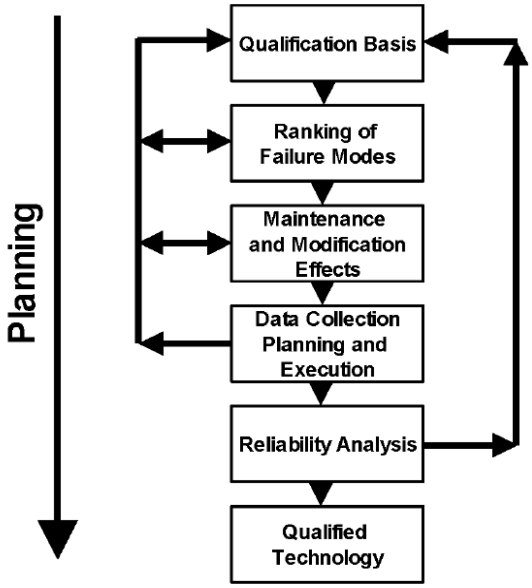

Figure 3. Schematic of Main Qualification Activities. Ref. DNV-RP-A203 (2001).

The processes described were used by the OEM in the design of the magnetic bearing system for the motor and compressor, in the design of the ICS single lift package, and in the design of the ICS dry and wet test facility.

In some instances, the design details of the system or components to be qualified are proprietary to the OEM and a disclosure of all of the data obtained during an internal qualification program are not available to a system integrator or the end-user. Under these circumstances, full functional and endurance testing according to the operating specifications of the equipment (agreed to by the OEM, system integrator, and end user) will be used to document the qualification of the technology for the given application.

Many OEMs, system integrators, and end-users have company-specific guidelines that are used for the qualification of new equipment for oil and gas applications. It is very likely that these guidelines will vary to some extent with respect to the DNV guideline summarized above. However, the intent remains the same—to ensure that the appropriate equipment is selected for the specific application, and that the new technology is appropriate for the service to which it is intended.

The following section will describe the use of a DNV modeled qualification process during the development of a new product that incorporates a separator into a centrifugal compressor.

Development and Testing of the Separator Compressor

The compact separator compressor technology was based on several proven technologies. Prior art included designs associated with multiphase separator turbines published by Rawlins and Ross (2001) and Ross, et al. (2001). A rotary separator uses density-based separation of liquid and gas, enhanced by centripetal acceleration, similar to traditional static cyclonic separators. A major difference between rotary separators and static cyclones is the maximum centripetal acceleration used. Static cyclones are limited to about 300 g's of centripetal acceleration because of reentrainment on static surfaces. Because of the use of a rotating outer wall in the rotary separator, g-forces of more than 20,000 have been used successfully. This significant increase in allowable g-forces translates into a more compact unit or better performance for similarly sized units.

The qualification program included the testing of a separator compressor prototype under wet gas conditions. The compressor chosen for this technology demonstration was a legacy design, which put some limitations on the size and shape of the separator. The compressor was a four-stage natural gas transmission compressor. This unit has 12.8 inch impellers, 3 inch shaft diameter, and a 35 inch bearing span. It uses tilt-pad bearings with oil film seals. The compressor casing is shown in Figure 4. In order to fit the separator into the existing casing, the first two stages were removed. Figure 5 defines the basic components of the first build rotary separator design.

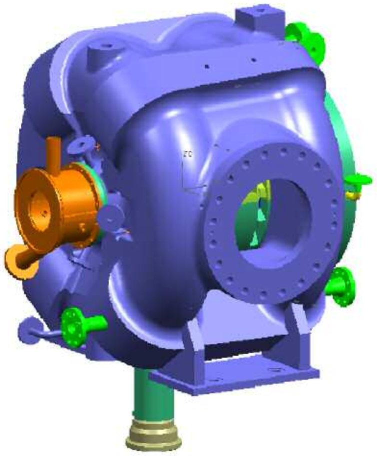

Figure 4. Compressor Casing. Bearing Span 35 inches.

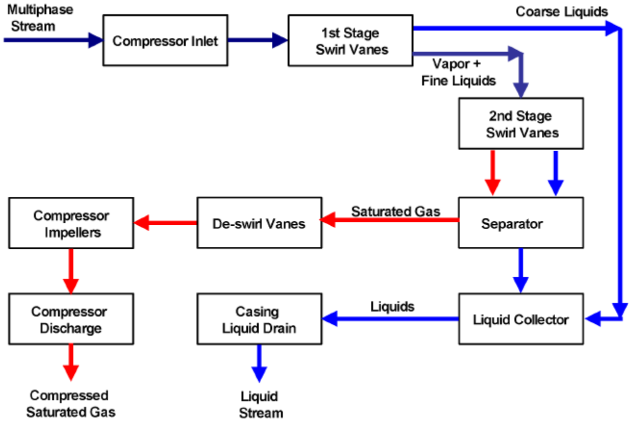

Figure 5. Main Components of Separator-Compressor.

For the case of the integrated separator/compressor, the separator performance and range become linked to the compressor characteristics, which requires analytical optimization to achieve high levels of overall performance. Development of new turbomachinery products typically involves several design iterations, each followed by a series of analyses and tests. Conducting physical tests to optimize design is often very expensive and/or time consuming. In this development study a virtual test approach was used. Computational fluid dynamics (CFD) analyses methods, similar to published by Chochua and Maier (2007), were used for multiphase separator analyses. First, the numerical model was validated and calibrated against available test data. Then a procedure for virtual test iterations was developed. The procedure involves creation of fully parametric solid models linked to the available CFD and finite element analysis (FEA) capabilities. Automated mesh generation and automated pre- and post-processing were used to minimize design iteration cycle times. Figure 6 shows an example of CFD based flow field of a separator design using multiphase CFD using a commercially available Navier-Stokes solver. In this example, a mixture of gas and liquid droplets enters the separator stage. The larger particles and slugs are separated in the static (cyclonic) separator zone under the centrifugal forces induced by the stationary swirl-generating vanes. The downstream separator zone scrubs the smaller liquid droplets. The CFD results were used to create and calibrate an analytical prediction tool. Then, the analytical tool was wrapped into the optimization software package that guided the key design parameters to their optimum.

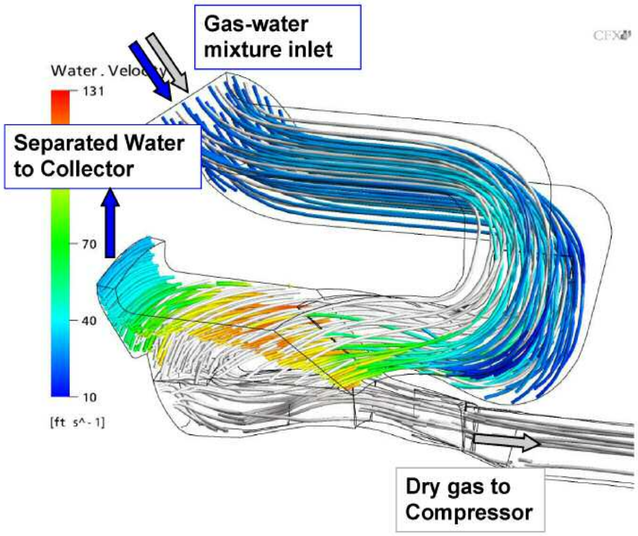

Figure 6. CFD Modeling of Rotary Separator.

The initial analytical design phase was concluded by the development of the first prototype based on the recently developed technologies for the compressor and separator. This prototype was tested in a wet gas test loop developed by the OEM to support the qualification of this new technology. The two main performance characteristics of the separator experimentally measured were separation efficiency (defined as the ratio of liquid carryover to inlet liquid flow), and separator pressure drop (normalized by an appropriate dynamic pressure component—in this case based on the meridional flow velocity at the first impeller eye). To assess operating characteristics, the separator was tested over a range of gas flows, liquid flows, suction pressures, and shaft speeds. In addition different liquids were used to investigate the effects of surface tension and the gas/liquid density ratio over the separator performance.

The integral separator compressor was tested in the closed loop system shown in Figure 7. The gas portion of this loop was a standard compressor test loop with discharge throttling and after-coolers. A liquid flow loop that consisted of a liquid storage tank, liquid pumps, liquid injection system, secondary liquid separator, and gas break vessel was added in parallel with the gas loop. The test loop allows the individual controlled variation of the gas and liquid flowrates as well as changes in the pressure of the test stream inside the loop to simulate a variety of field conditions. Water and light hydrocarbon liquids can be used in combination with several test gases to cover the needs of the technology qualification. During the testing, liquid was injected into the gas loop just upstream of the compressor inlet. Under normal operation the separator removed the majority of liquids from the wet gas stream, and gravity drained them into the gas break vessel located below the separator/compressor unit. Separator efficiency was measured using a secondary stationary separator (gravity + cyclonic) installed between the gas coolers and the liquid injection ports. The separator/compressor was driven by a high-speed, air-cooled, direct-drive, variable-speed electric motor, which was directly connected to the compressor via a flexible coupling. A combination of turbine type flowmeters and weighed, timed volume techniques were used to assess separation efficiency. Figure 8 shows a photo of the experimental test rig.

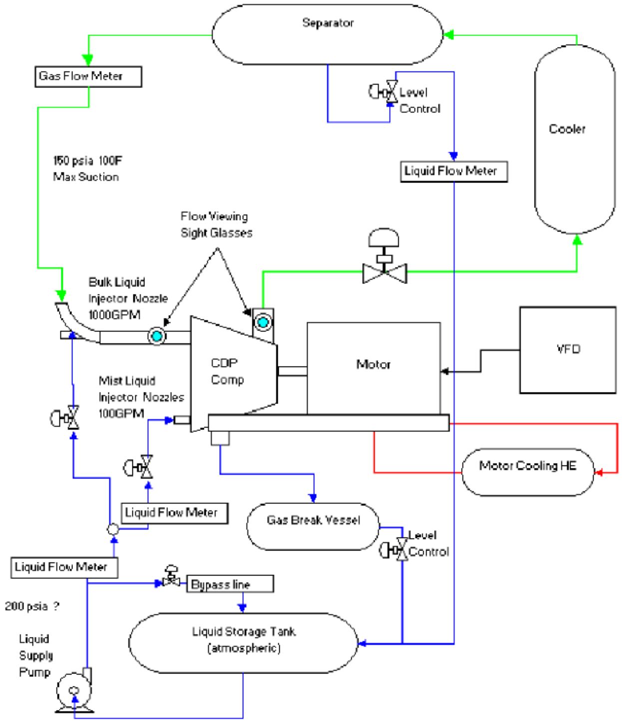

Figure 7. Schematic of Multiphase Test Loop.

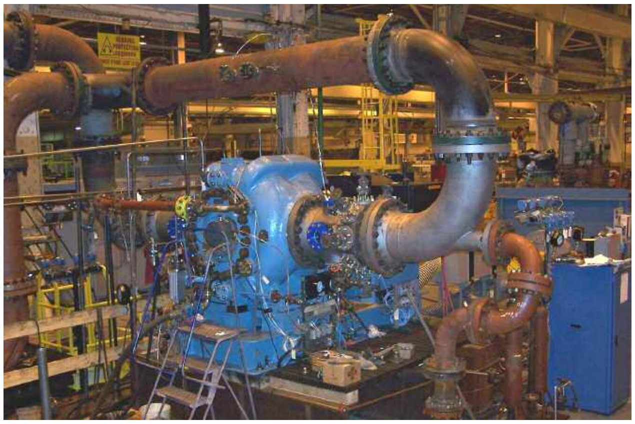

Figure 8. Experimental Test Rig.

After completion of the initial experimental study, the test results were used to calibrate the CFD model, which in turn helped to gain a better understanding of the high-speed flow physics, and, hence, guide the design to a higher level of performance. The subsequent application of the design methods, combined with additional testing and feedback loops, allowed the development and qualification of high-efficiency and compact separator compressor geometries that can be integrated into a centrifugal compressor casing and applied for oil and gas services. The whole design and testing process resulted in separator compressor liquid separation and aerodynamic efficiencies that were equal to or better than traditional component capability.

APPLYING THE NEW TECHNOLOGY

The ICS has been developed using a building block approach; therefore, it maximizes the application of technology and components with a proven track record in the field. This approach reduces the overall risk associated with the use of the system and also reduces the time required to introduce the product line to the marketplace. Figure 9 shows a schematic of a typical compression process. A wet gas stream enters the compression train through a scrubber where the liquids are removed and the vapor components continue through a section of compression, where the pressure of the gas is increased by the work applied to it by the compressor. The compression of the gas causes a temperature increase, therefore, a process cooler must be included in the system to reduce the temperature of the gas as it exits the compressor. A reduction in the gas temperature typically causes some of the process components to drop out as liquids, producing a wet gas stream at the discharge of the cooler. The above process may be repeated several times until the desired pressure level is achieved. The different color dotted boxes illustrate how the OEM's different building blocks may apply to this process.

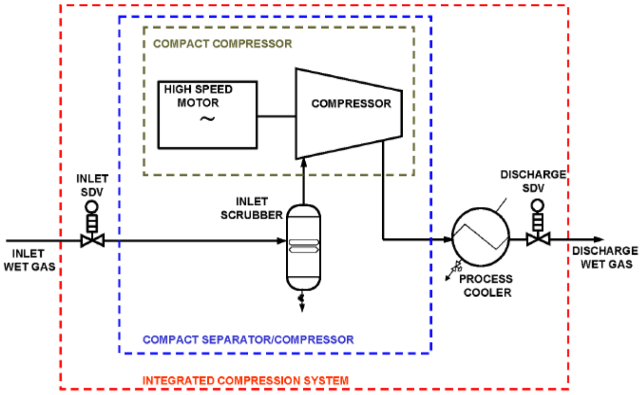

Figure 9. Schematic of Single Section Compression Process.

In recent years, there has been a lot of work by many OEMs to develop compact compressors that integrate single- or multistage centrifugal compressors with a high-speed electric motor driver. Most of these systems enclose a process gas-cooled motor and one or two sections of compression into a hermetically sealed high-speed compact compressor as shown by Crowley and Gilarranz (2006). These systems focus on the integration of the motor and the compressor and leave the rest of the compression system untouched (refer to the green inner dotted box in Figure 9). Most of the current compact compressors have been used for gas pipeline applications, where the gas is relatively clean and free of liquids. When these compact systems are used for upstream applications, there is a high risk for liquids to carryover through the scrubber during process upsets. Although wet gas can be compressed directly using centrifugal compression technology as shown by Brenne, et al. (2005), doing so will impose a penalty in the efficiency of the compression process, as the power requirements for the machine will increase due to the presence of liquids. The introduction of these liquids into the compressor has the potential to cause erosion and fouling of the internal components of the machine. This will result in a reduction of efficiency and will increase the life-cycle cost of the equipment due to operation at lower performance levels and a decrease in the time between required maintenance of the unit.

The integration of the OEM's compact centrifugal separator into the compressor casing addresses these issues. This system is represented by the blue dotted box in Figure 9, which indicates that the separator, compressor, and motor are integrated within the pressure containing boundary. The liquids removed by the centrifugal separator are drained into a small gas break vessel located beneath the compressor casing, where they are collected and discharged into the customer process. For the case on multiphase pipelines, the liquids can be reinjected into the gas stream downstream of the compressor stages. For applications in which the end-user does not operate multiphase pipelines, the liquids can be drained from the gas break vessel into a closed drain collection system for proper handling. In subsea applications the liquid is injected into the separator compressor discharge line employing proprietary technology.

By removing the liquids and potential sources of fouling before they enter the compression components, the performance and reliability of the system are improved. The performance is also improved because the compressor can now handle the gas stream with the higher-levels of performance that are characteristic of dry gas compression systems (without the added power consumption that is required to handle the liquids).

Thus, the integrated compression system takes the boundary of the compression package beyond the traditional mechanical train and applies innovative packaging concepts to integrate the process piping, instrumentation, coolers, and valves into a compact compression module. This new concept of compression modularization is lighter than the traditional result applying a multideck layout for the equipment. This design allows all of the components of the compression system to be in close proximity of the separator/compressor/motor. This results in the reduction of valve and piping interconnections that are required at site, and provides the potential to reduce the size and weight requirements of the supporting platform or floating vessel in which the compression modules will be installed. Alternatively a smaller and lighter package can allow the end-user to handle a larger throughput for a given platform footprint. The integrated compression system can also be used to debottleneck existing platforms or processes, where space restrictions or weight considerations do not allow the application of traditional compression trains. The scope of the ICS is shown schematically by the red dotted box in Figure 9. Note that the ICS includes all of the components of the compression system.

Examples of the New Technology Applications

A key building block of the ICS is the integral high-speed motor driven, oil-free, sealless compressor, which for the case of the ICS also incorporates an integral gas/liquid separator inside the casing. The OEM has recently delivered the first compact compressor, which will be used at a gas storage and withdrawal facility. This machine does not have an integral separator, but does include the rest of the components of the compact compressor mentioned in previous sections. The machine will be used to withdraw the last 2 billion cubic feet (bcf) of gas from the 30 bcf storage field, and will boost the pressure of the gas before it is fed into an existing compression train. The end-user does not own any gas; his business is based on charging a fee for storage of gas for different customers. Any gas that is not returned on demand must be replaced at market prices; therefore the last 2 bcf that are withdrawn with the help of the compact compressor represent a liability of approximately $16MM at a gas price of $8 per MMBtu.

The unit is a three-stage compressor with a maximum continuous speed around 7200 rpm, designed to handle a flowrate of about 400 MMSCFD of pipeline quality natural gas, with a molecular weight of 17 lbm/lbmole. The pressure rating of the compressor is about 3000 psig, which was set to meet the requirements of the end user. However, the compressor is operating at a significantly lower pressure level. The electric motor is powered through a variable frequency drive, and the power grid has a maximum supply capability of about 9 MW.

The compact compressor was shipped in the first quarter of 2008 and, at the time of writing this paper, it was undergoing startup and commissioning operations in the field. It is important to state that the compressor achieved a flange-to-flange polytropic efficiency level above 86.5 percent during the factory acceptance testing prior to shipment. Figure 10 shows a picture of the electric motor-driven compressor unit prior to boxing for shipment.

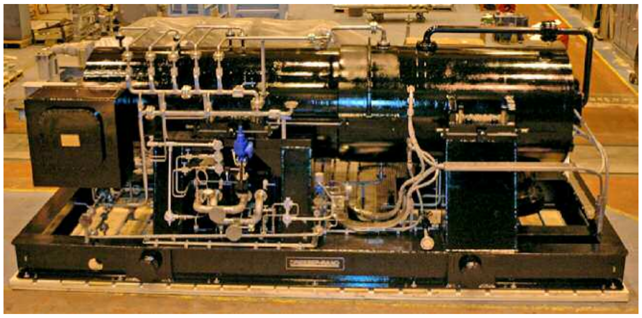

Figure 10. Compact Compressor—Prior to Shipment to the Field.

In addition to this unit, the OEM has recently sold the first ICS module to an oil and gas operator in South America, for installation in an existing offshore platform used for export gas and gas lift service. The ICS will be used to boost the pressure of the gas exiting two existing three-section gas turbine driven compressor trains. The customer will lower the discharge pressure of the existing trains to increase the gas flow handled by the compressors. The ICS module will utilize the OEM's compression technology to boost the gas pressure from the trains back to the current pressure levels required at the discharge header of the platform.

The gas at the ICS inlet will be cooled to 111.2°F (44°C) and is wet; therefore, the ICS will incorporate the proprietary centrifugal separator technology. The inlet pressure to the ICS will be set at about 2150 psia, with a discharge of about 2500 psia. The gas molecular weight is expected to be around 19.65 at the inlet to the ICS module and will be reduced to about 19.04 after the wet gas stream passes through the separator, which will remove about 25 gallons per minute of condensate from the gas stream. The gas volume fraction is in the order of 98.5 percent at the inlet to the separator. The gas flow rate handled by the ICS module under the design conditions will be 2,000,000 Nm^3/d (70 MMSCFD). A variable frequency drive will be used to adjust the separator/compressor/motor speed to adapt the ICS to the varying operating conditions expected by the end-user. The factory-tested ICS unit is scheduled to ship to the site in the fourth quarter of 2008. The compact size and reduced weight of the ICS module will allow the installation of the factory-tested package within the existing platform facilities, with a minimum disruption in the production associated to the platform. The general arrangement of the ICS module for this application has been shown in Figure 2. Figure 11 shows a simplified process diagram of the application with the main ICS components highlighted in red.

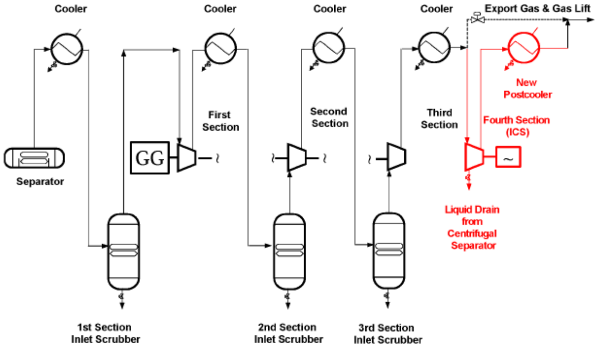

Figure 11. Integration of an ICS Compression Module into an Existing Platform.

CONCLUSION

Technical qualification of new technology is of paramount importance to allow the OEM, system integrator, and end-user to manage the risk associated with the applications of new technology within the oil and gas industry. This is not only the case for the use of new technology to address the needs of known applications. It is also a requirement before proven technologies are integrated into a product that is applied to new applications

This paper presented a summary of the process that was used by the OEM to qualify the incorporation of a centrifugal gas/liquid separator into a centrifugal compressor casing that is one of the building blocks of the novel integrated compression system.

The team employed an iterative process between design, analysis, and testing to validate, calibrate, and optimize the design methods utilized in the development of an integrated separator. The use of these refined techniques resulted in the development and qualification of a compact separator compressor for oil and gas applications, within a reduced total project cycle time and budget.

The integration of a centrifugal type separator inside the compressor/motor casing allows the removal of liquids and small particles that may be part of the inlet stream before they reach the compressor stages, improving the reliability of the system and extending the life of the motor/compressor components. Furthermore the integrated design reduces the size and weight of the package as it allows the removal of the gravity-based scrubbers.

Because the motor, separation system, compressor, and gas coolers are contained within the same process module, the ICS can be supplied as a complete compression system packaged in a compact, cost-effective, single-lift package.

The first application of the ICS concept will be used to boost the pressure of two existing gas turbine driven compression trains, to allow the end-user to increase the throughput handled by an existing offshore platform used for an upstream export gas and gas-lift application.

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