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Advances in Subsea Boosting – *Bridging the Gap Between Multiphase and Wet Gas Production*

Mads Hjelmeland
Arne B. Olsen

FRAMO ENGINEERING

ABSTRACT

Subsea pumping- and metering represents new technologies which may contribute to simplified developments of marginal and remotely located oil & gas fields. The Asia Pacific geomarket has already seen several subsea implementations of the multiphase technologies over the last years which include both subsea boosting- and metering applications (below bubble- point operation). The implementation of these technologies is particularly suitable for both offshore- and subsea operation, and offers the operating company a cost-effective minimum facilities system.

The multiphase technology area and gained experience of successful operation, in combination with the fact that natural gas has increased its value in many parts of the world, drives the next technology step – wet gas compression. However, there are two main system approaches to this challenge;

1. True Wet Gas Compression – subsea rotating machinery working directly on the well stream without or limited pre-processing, or
2. Subsea Gas Compression – marinized dry gas compressors with upstream well-stream processing and associated control systems

This paper describes the development and full- scale test of a Wet Gas Compressor, which is working directly on the well stream without pre- processing. A description of how this technology can simplify complex offshore field developments will be given, as well as an overview of the operating characteristics and main features of the compressor.

1 INTRODUCTION

As the world's need for energy is ever increasing, several major gas field developments are taking place on a global scale. One example is the Snohvit project which went into production in 2006. The field is located some 140km offshore Hammerfest in Barents Sea, at a water depth of approximately 300m. A similar development is the Ormen Lange, which is located some 120km offshore Kristiansund on the west coast of Norway, at water depths in the range of 800- 1100m. The two fields as mentioned here were developed entirely by the use of subsea technologies, producing back to onshore process terminals, hence eliminating the need for offshore production facilities.

A large part of remaining hydrocarbon resources is located offshore in significant water depths, in some locations as deep as 3000 m. The conventional strategy of implementing floating production facilities for offshore processing is in many cases a major challenge, or not viable, as the metoceanic conditions are simply too challenging. Examples of locations with challenging climatic and metoceanic conditions may be the larger part of offshore Norway, as well as the Northwest Shelf offshore Australia, and Gulf of Mexico.

To solve these challenges the strategy has been to execute complete subsea field developments, eliminating the need for floating production facilities producing back to onshore facilities. In general these projects will also face flow assurance challenges which in many cases are so severe that whole developments may have to be abandoned. The Multiphase Compressor represents a viable option to overcome flow assurance challenges, and at the same time extend the production plateau and increase the recovery of hydrocarbons.

The Multiphase Compressor facilitates a new approach for development and exploitation of typical "stranded gas" resources, and is based upon the same principles as numerous multiphase system pump applications. This approach offers the opportunity to perform true wet gas compression, without relying on upstream separation.

2 THE CONCEPT OF SEABED BOOSTING

Seabed boosting offers an alternative- or complementary system, to other artificial lift techniques and a range of advantages in production and field flexibility. In the multiphase flow domain, the Framo helico-axial design is the core technology adopted that best suits all process fluid operations as well as the typical operational challenges of slugging, emulsions and sand production. Today this technology has been developed, tested, and installed in numerous subsea field applications, and hence represents a well-proven core technique to meet the markets' demands. Framo Engineering offers a wide range of subsea pumping systems from single phase pumps (Framo Cx), multiphase pumps (Framo Hx), hybrid pumps (combining these core technologies, Framo HxC) and Multiphase Compressor (Framo WGC), optimising centrifugal technology in a counter rotating method providing a 'true' wet gas compressor with no separation required.

Supplying subsea boosting systems is not just about having in-depth pump knowledge; but also about having knowledge about, and the responsibility of, the total system engineering and deliverables. Understanding the operational process regimes from start-up and continuous flow, through to managing operational upsets such as emergency shutdowns and the process dynamics, is essential. Accordingly a pump system supplier should be having this kind of system knowledge in-house, combined with working closely with an Operator in performing dynamic process simulation modelling in the concept stage. A collaborative effort will lead to maximized hydrocarbon recovery.

3 EFFECTS OF MULTIPHASE BOOSTING – INCREASED OIL RECOVERY

The effect of boosting on hydrocarbon recovery can be significant. Reference is given to Figure 3-1 where this is illustrated. The pressure from the well is used to drive the hydrocarbons (condensate and gas) to the first stage separator. The resistance is made up of a static- and dynamic flow resistance that together represent the system curve.

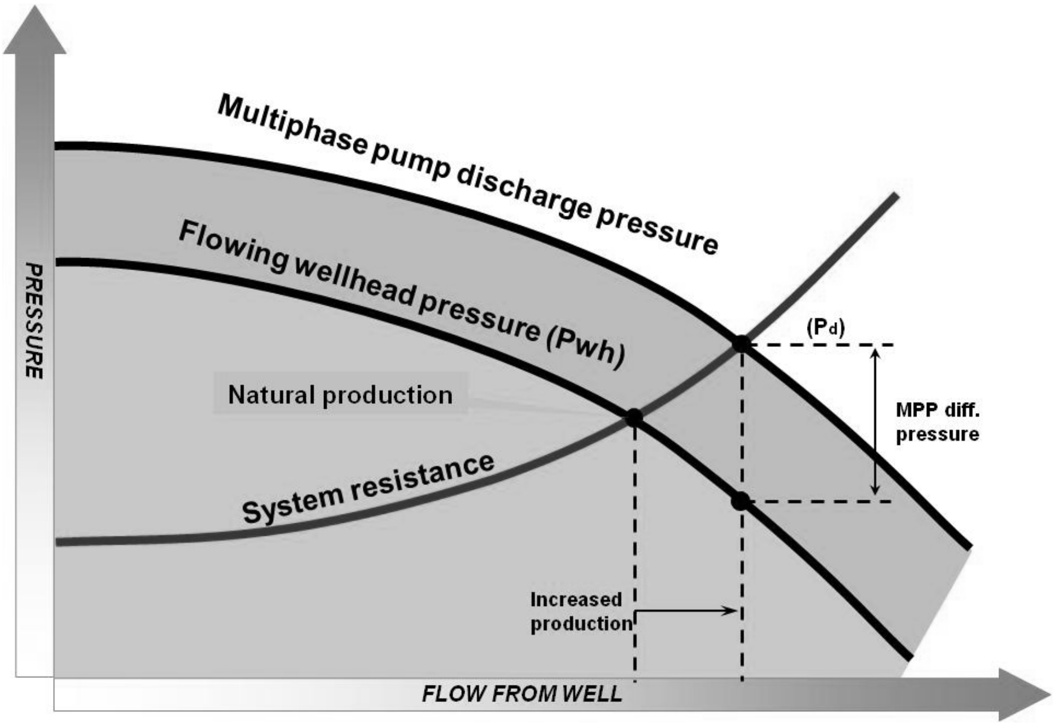

Figure 3-1 Production System Curve

The well production is found from the intersection of the two curves. Installation of a subsea compression system will increase the pressure in the fluid, i.e., adding energy directly to the flow. The effect is as if the flowing wellhead pressure is increased. The flow from the wells will increase until a new balance between the flowing pressure and the system resistance is achieved, and consequently the effect is a net increase in oil production.

4 FLEXIBILITY TO MEET CHANGING CONDITIONS

The development and qualification of the subsea boosting systems over the last 25 years has enabled Framo Engineering to offer a complete range of booster technologies to the industry. The Framo pump program offers high efficiency and optimized pumps over the entire range from single phase liquid up to high gas content flows, defined as “wet gas” applications, on the same physical platform.

The pumps are designed to allow operators to change the pump type if large variations in the flow conditions over the field life makes this necessary. This can be achieved by maintaining all mechanical and electrical interfaces identical avoiding any modifications to be performed on the subsea infrastructure, regardless of pump size and type.

Figure 4-1 presents the overall subsea pump program available, with differential pressure capability as function of the Gas Volume Fraction in the flow. The different pump designs range from the Single Phase Pump (SPP) to the Multiphase Compressor (WGC), and these are all based on the same well proven design platform, with significant field operating experience.

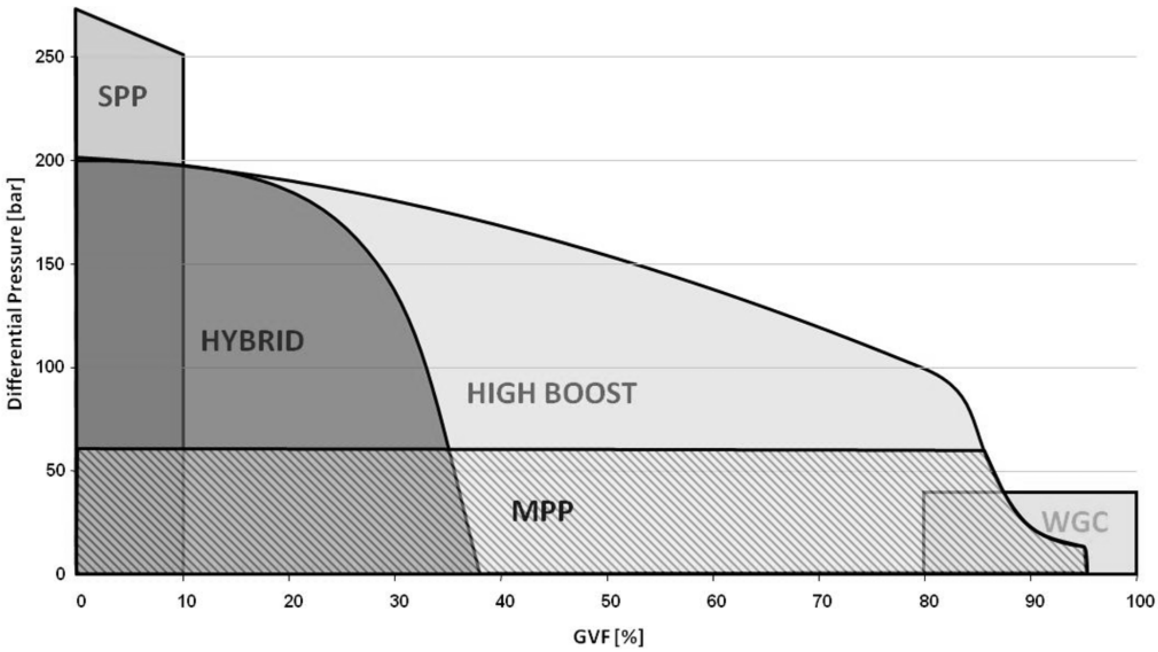

Figure 4-1 Subsea Boosting Portfolio – Total Flexibility

5 THE FRAMO MULTIPHASE COMPRESSOR

5.1 General

The Framo Multiphase Compressor is a counter- rotating compressor with a hydraulic and mechanical design specifically designed for pressure boosting of unprocessed well stream. The integrated and fully encapsulated design of the compressor unit is based on the well proven subsea design Framo has developed for our subsea booster pumps.

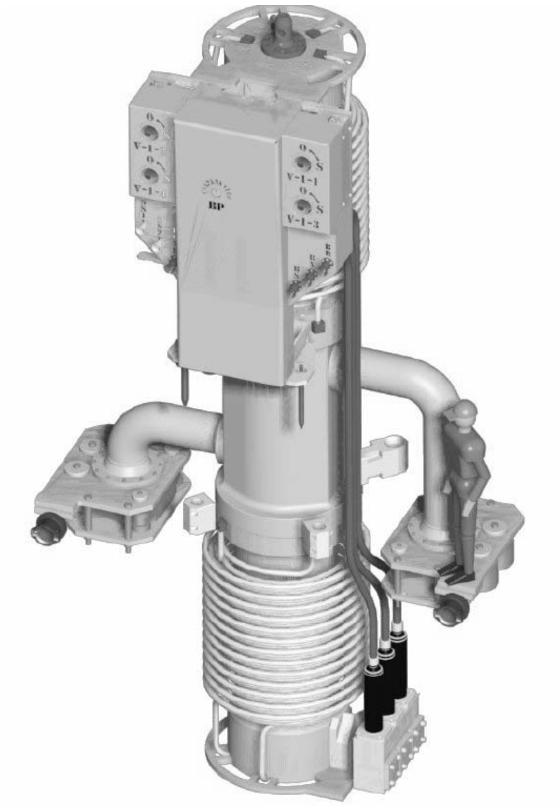

Figure 5-1 Subsea Multiphase Compressor

The machine consists of an upper- and lower drive section and the hydraulic section is located in centre. In Figure 5-1 a general arrangement of the compressor is shown, with the electrical motors located on the inside of where the cooling coils are located. There are standard subsea process connections, bringing wet gas to- and from the compressor. In front there is an ROV interface panel, used for hooking up various instrumentation jumpers and providing access to barrier fluid valves used during installation and retrieval of the unit.

5.2 Hydraulic design

The impellers of the Multiphase Compressor are extremely robust, designed to perform with high efficiency, but still managing to handle operational conditions of 90 – 100 % GVF, without upstream gas scrubber or other forms of pre-processing/ separation of fluids. Every other stage is driven respectively by the upper or lower motor, which means that the process of providing energy to the well stream is combined with flow-stream alignment in the axial direction. The absence of the diffusers removes multiphase recovery losses that would otherwise result of this static part. The compressor is a dynamic machine providing lifting height or head and the resulting pressure boosting is provided by this head. Speed is an important factor as the relation between head and speed is given by equation (1).

$$\Delta h = f(\omega^2) \tag{1}$$

The pressure boost, which the production system benefits from, is given by the relationship in equation (2).

$$\Delta p = g \cdot h \cdot \left[\rho_G + (\rho_L - \rho_G) \cdot (1 - GVF)\right] \tag{2}$$

Where g is the acceleration of gravity, ρG is the density of the gas, ρL is the density of the liquid and GVF is the gas volume fraction. This relationship shows that by obtaining a good mix of the phases, which will be the case with the counter-rotating principle, an enhanced density effect will result and increased differential pressure is achieved. The counter rotating mixing effect provides an efficient cooling of the machine even when there are liquids present in the well-stream. This enables higher pressure ratio capability of the compressor.

One of the key features with the Framo WGC design is elimination of surge. It is a very important part of the design strategy for this machine, that it will not require a complex and comprehensive subsea process and control system. It is even doubtful if an anti-surge system on a multiphase system would work, as the accuracy of measurement of the multiphase flow is not presently good enough. The impellers in the WGC are designed with an angle of attack and have a blade loading that avoids phase separation and boundary layer separation, and consequently surge phenomena are avoided.

5.3 Mechanical design

The compressor is designed in three main parts; upper electric motor, compressor section and lower electric motor. The shafts are supported by radial and axial hydrodynamic bearings. Tilt pad thrust bearings are provided in both the motors and the compressor section. Internally pressurized mechanical seals are used as primary seals for reasons of environmental control of the seal face area and to avoid possible erosion problems. A barrier fluid system is used to provide overpressure protection, lubrication and cooling of the compressor critical parts on a continuous basis, during all modes of operation. Suction and discharge flanges are designed to support nozzle forces as specified. All auxiliary connections are either integrally flanged or welded.

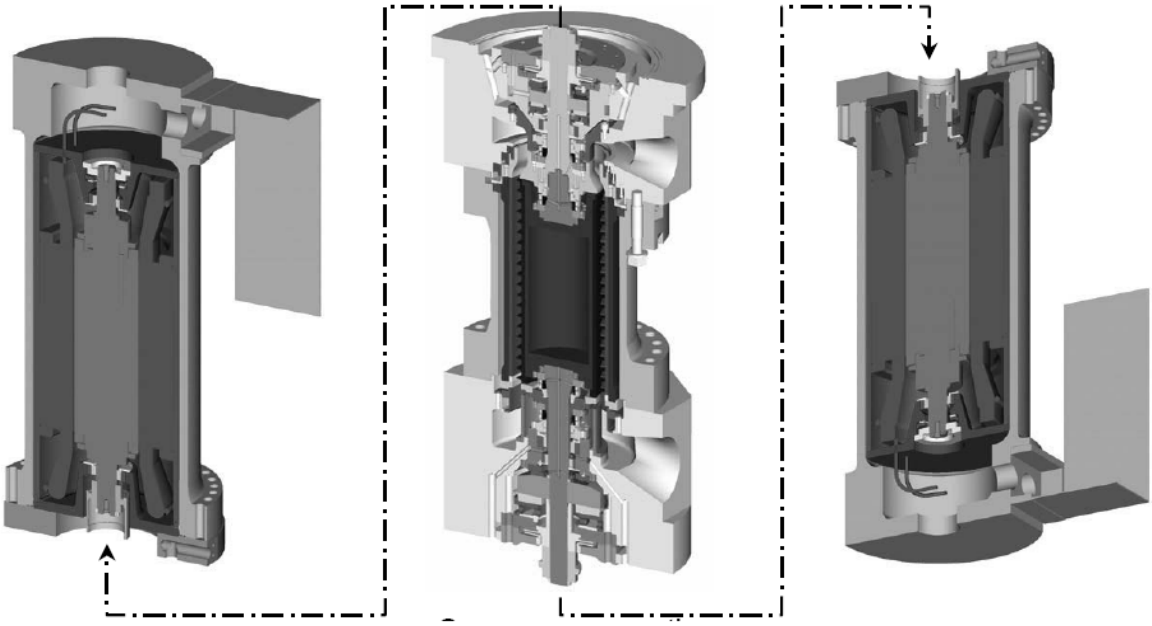

Figure 5-2 Cross section of Left; upper motor, Centre; hydraulic section, Right; lower motor

The electric motors are oil filled. The oil inside the unit is circulated through external filters and oil cooler by means of an impeller on the electric motor shaft. The impeller provides supply of oil to the seals, bearings and couplings. The circulation is internal to the compressor assembly; the HPU on shore supplies only constant pressure top up oil to the compressor. The basic design philosophy for both inner- and outer rotors is to maintain stiff shaft characteristics, low levels of residual unbalance and adequate damping over the whole speed range. Low vibration levels result even though the 1st natural frequency for both rotors occurs below the maximum speed of 4,500 rpm.

5.4 Coolings systems

5.4.1 Barrier fluid

The upper and lower motor has a separate barrier fluid system. The generated heat from the process, as well as from bearings and seals, is transferred to the seawater by a set of cooling coils made from stainless steel tubes installed externally around the motor section on each end of the compressor. Four parallel coils will be used for each cooler. The oil is circulated through the cooler by the shaft mounted circulating impeller.

The barrier oil cooling and lubrication circuit is basically composed of two parallel lines, one for the motor in series with the cooling coils and one for the internal circulation through the bearings and seals. The design is mainly focused on obtaining appropriate cooling for the critical elements, such as the mechanical seals and thrust bearing, while achieving practical coil dimensions and pressure drop for the circulation impeller.

5.5 Process

Subject to the process parameters for the application, flowing temperatures and required differential pressure in the system, a process cooler may be required to be installed. The nature of gas compression inherently results in a significant temperature increase across the compressors, and subject to the flow line design temperature a cooler may be installed to lower the temperature of the compressed fluids.

As the process cooler will be installed in line with the multiphase compressor(s) it is proposed retrievable to eliminate any flow assurance related issues. FIGURE presents a model of the process cooler as designed for a North Sea subsea compression application. The principle of cooling is free convection and is based on a mechanical frame work for process piping.

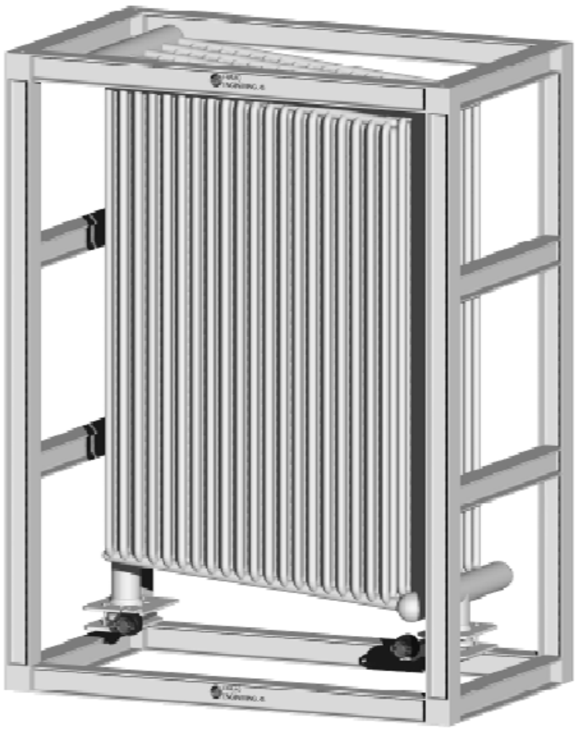

Figure 5-3 Process Cooler

6 SUBSEA SYSTEM DESIGN

There are several options for how to package and install the Multiphase compression system hardware. Further assessment and development of the design basis will identify the number of Multiphase Compressor stations to be applied in each case. Framo Engineering has developed a generic station concept, where the station has two compressors, operational valves, required process equipment, electrical power supply and variable speed drive equipment and required instrumentation/control systems. The Framo Dual Pump Station WGC is based on the subsea pump stations as designed, manufactured and installed over the last 15 years, and thus has more than 900 000 running hours.

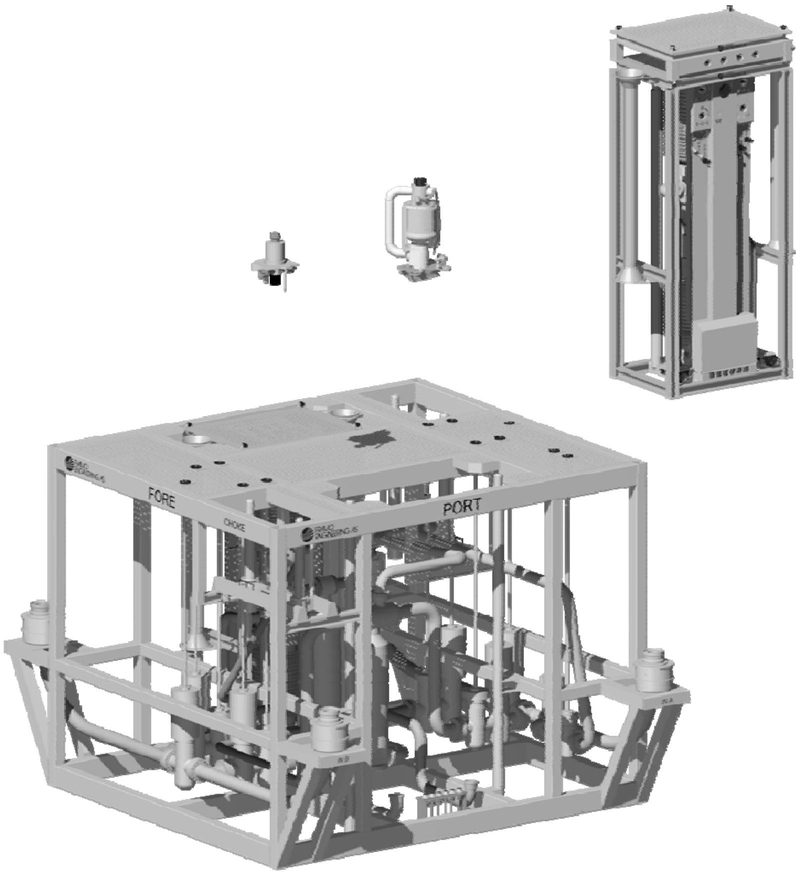

Figure 6-1 Subsea Framo Dual Compressor (FDS)

Figure 6-1 presents the subsea station concept, and is conceptually designed such that both step-wise, or ‘all in one’, installation of compressor capacity is possible. In a field development scenario where gradually increasing compression capacity will be required over a long period of time, the capital expenditure can be phased over that period. Even though there are significant infrastructure investments that are required from day one and the equipment they involve of such a nature that a one- time installation is required, the cash flow improvements resulting from a modularization where the station can be populated in 50% capacity increments.

The modularization and subsea interfaces follows normal industry practices, applicable for control pods, jumpers, chokes etc. The largest retrievable module on the station is the Multiphase Compressor module which weighs in the range of 60 tons.

In fields where environmental conditions require over- trawl able structures to be installed this is normally designed as a combined Protection – and over trawl able Structure. This is illustrated in Figure 6-2.

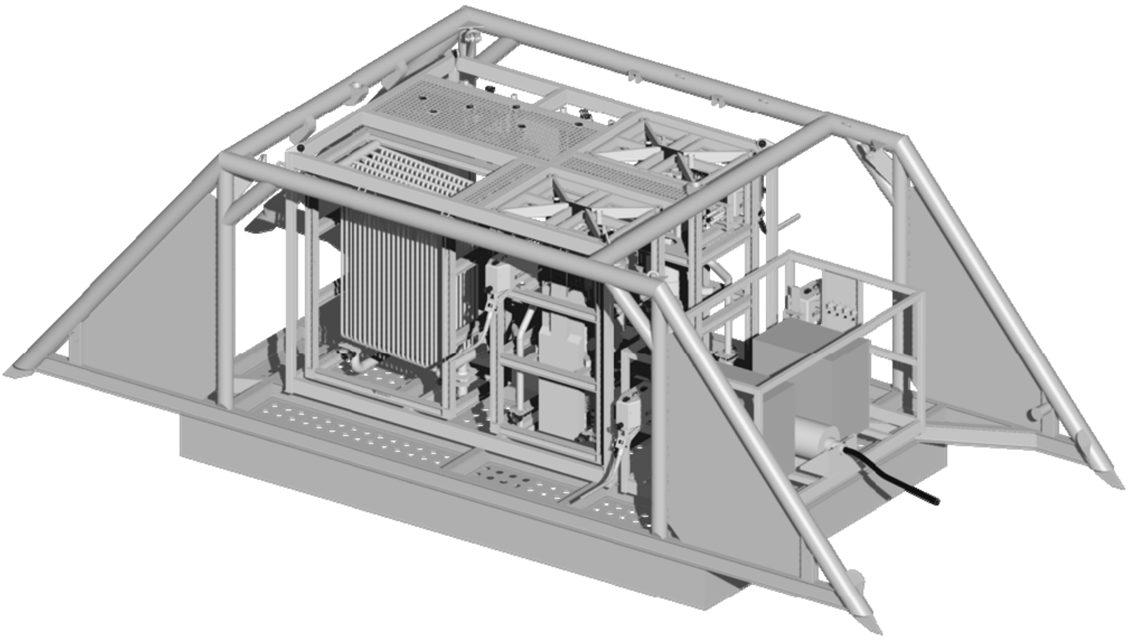

Figure 6-2 Subsea Framo Dual Compressor – In protection structure

7 SUMMARY

This paper presents the latest technology advance within subsea compression, a true Multiphase compressor which is working directly on the well stream without pre- processing.

In line with the increase in global demand for energy, the number of gas field developments in remotely located offshore areas is ever increasing. The Framo Multiphase Compressor represents an attractive field development concept for recovery of hydrocarbon resources located in deep waters and remote fields.

The technology is designed specifically for subsea operation, but is also ideal for installation in offshore unmanned facilities.

The Multiphase Compressor represents a simplified systems approach to subsea compression, building on the experience of more than 120 years of accumulated run time of seabed rotating machinery. While conventional wet gas compression systems are really subsea separation systems utilizing marinized dry gas compressors with upstream well- stream processing as well as a liquid pump, the Multiphase Compressor will handle unprocessed well stream comprising, condensate and water. Figure 7-1 presents a principle flow diagram of the subsea Multiphase Compressor System.

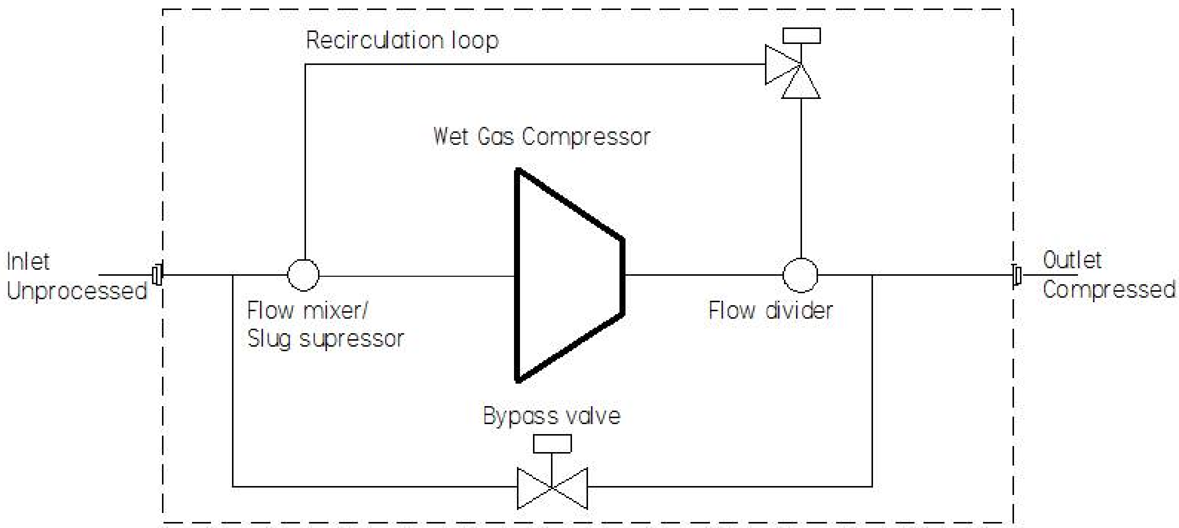

Figure 7-1 Principle flow diagram for Subsea Compression System

Subsea Multiphase Compressors are available today. They build on more than 25 subsea multiphase boosting systems that are in operation worldwide, and now offer a real alternative as a field development concept.