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Field Test Results of a Rotary Separator Turbine on the Ram/Powell TLP

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Abstract

This paper will present the design of the Rotary Separator Turbine and skid package used in the first offshore field trial of this technology on the Ram/Powell tension leg platform (TLP) located in the Gulf of Mexico. The RST is a compact gas-liquid separation and power generation device designed to operate on process fluid pressure. This technology offers a potential 50% weight and space savings over conventional vessel separators, and is under development for use on minimum footprint facilities. The purpose of the test was to verify the separation and mechanical characteristics in actual production conditions. An integrated test package installed on the Ram/Powell TLP in June 2000 tested the RST on actual well production.

Rotary Separator Turbine

The Rotary Separator Turbine (RST) enables compact and efficient gas-liquid separation while recovering pressure drop energy. The energy provides liquid pressurization, shaft power, or a combination of the two. Separation efficiency of the gas and liquid meets or exceeds the performance of a conventional vessel separator, with substantial weight and volume reduction. Additional benefits of the RST stemming from the centrifugal separation include foam reduction and improvement in operability due to motion insensitivity.

The RST is a product of high velocity two-phase flow research at the Jet Propulsion Laboratory[1]. During the 1970's and 1980's several prototype turbines were tested in geothermal power applications. A 30" full-scale unit installed in August 1998 at Cerro Prieto, Mexico operates at a power output of 0.5-1 MW.

The first oil and gas application employed the RST as a centrifugal foam breaker for an offshore application. A reaction design RST tested in an onshore gas facility on natural gas/crude mixture provided complete foam breakdown with a liquid carryover of 30 PPM. Further test work in 1996 used a RST for separation of inert gases and crude oil during offshore loading. A pilot plant unit tested on a North Sea shuttle tanker exhibited good separation and performance unaffected by ship motion. A 1997 Joint Industry Program tested a second RST at a major oil and gas flow facility[2].

Operating Principle

Figure 1 shows the basic principles of operation with the liquid and gas flow paths. The four main components identified in the diffuser type RST are the two-phase nozzles, rotor drum, gas path blading, and diffuser scoop[3].

Two-Phase Nozzles

The inlet nozzles convert the pressure energy of the two-phase flow mixture into kinetic energy. Due to the density difference, the gas phase accelerates more rapidly than the liquid. Shear forces, exerted by the high velocity gas, break up the liquid into small droplets. In turn, the small liquid droplets have a large surface area to mass ratio. This facilitates efficient momentum transfer between the liquid and the gas during the pressure decline, resulting in an even distribution of fine liquid droplets suspended in a continuous gas phase of the exit jet.

The rotary separator turbine contains several inlet nozzles evenly located around the rotor circumference to distribute the flow evenly. The two-phase jets impinge near-tangentially onto the inner surface of a cylindrical rotor. The liquid rapidly disengages from the gas to form a layer on the inner rotor rim. To some extent, this liquid layer protects the rim from erosion. The gas forms a free vortex at a smaller radius than the rotating liquid layer.

Separator Drum

Power transfer by liquid drag takes place when the liquid from the inlet jets slows to rotor rim speed by viscous coupling. The centrifugal field generated by the rotating drum (2000-4000 times the force of gravity) forces rapid separation of the gas and liquid. Additionally the high "g" field breaks foam structures. Coupling the output shaft to a hydraulic brake (or other dissipation system) maintains the operating speed below the free rotation velocity.

Gas Path Blading

Figure 1 shows how blading on the separation wheel transfers kinetic energy of the separated gas into shaft power. The gas blading efficiency normally ranges from 0.70-0.85, depending on the specific speed and diameter of the turbine. To keep the pressure drop of the gas phase at a minimum, impulse type blading is used. The ratio between absolute blade velocity and incoming gas velocity ranges from 0.45-0.55.

Diffuser Scoop

The RST uses a diffuser scoop to remove liquid from the separation drum, to pressurize the liquid, and to prevent gas carry-under. The diffuser scoop rests in the rotating liquid layer to convert the kinetic energy of the high velocity fluid into pressure by controlled reduction of the velocity. Figure 2 shows the scoop immersed in the liquid layer (fully or partially) on the rotating rim.

The duty of this device is significant because it must maintain a nearly constant liquid layer during variations in liquid flow rate, while minimizing gas entrainment in the discharged liquid. The scoop design must keep the wake spray at a minimum because such spray may result in liquid carryover to the gas discharge.

Figure 2 also shows the gas barrier device that prevents gas from exiting through the liquid outlet. This device is affectionately termed the "surf rider". The surf rider floats on the liquid layer by balancing the downward force (spring) with the inertial forces of the liquid passing under its flow surface. The primary advantage of the surf rider is self-compensating action over wide variations in liquid flow rates.

Test on Ram/Powell TLP

An integrated skid package installed on the Ram/Powell TLP in June 2000 tested the RST on actual well production. This package can handle 20,000 BPD (3,179 m^3/d) oil and 30 MMSCFD (850 MSm^3/d) gas, at a 1,250 psig (8,613 kPa) inlet pressure. Figure 3 shows a photograph of the skid package on the TLP during installation. This photograph shows the interconnecting piping, skid layout, RST, and support systems.

RST Design

The RST used in this test program the same base unit used for the flow facility test in 1997, with modifications to meet the offshore conditions. Upgrades to the RST include gas path blading, new diffuser that produces lower windage loss and liquid spray, and profiled nozzles to meet the flow rate. The unit has a 24" diameter (nominal) separation wheel, which gives the designation 24 RST. The case of the unit is made of carbon steel (A350) and designed to ANSI 600# use. The 24 RST has eight individually isolatable inlet nozzles, each with a 0.632" diameter throat. The nozzles are externally replaceable and manufactured of 316L stainless steel or 4140 carbon steel. The nozzle exit flow discharges onto a 24" (nominal) diameter separation wheel. The separation wheel is made of HY-80 steel, and the turbine shaft is made of 17-4 PH stainless steel. The diffuser scoop is made of A516 Gr. 70 steel with a 718 Inconel tip.

At the design turbine capacity and pressure drop, the 24 RST should operate at a speed of 3600 RPM. This is less than half the critical speed of 7400 RPM. Changes in the flow conditions on the platform reduced the optimum speed range to 2500-3100 RPM. The individual nozzles allow for an 8:1 turndown in turbine capacity.

The 24 RST used standard seal and bearing components. The turbine seals are a mechanical face seal design that uses diesel fuel as the barrier fluid. These seals are made by BWIP for high pressure pumps. Barrier fluid pressure is maintained from an external pressurization system to 40 psi differential above the case pressure. The bearing system uses Kingsbury thrust and journal bearings, with an external cooling system.

Instrumentation on the 24 RST consists of radial X, Y and axial vibration (eddy current probes), rotary speed (magnetic pickups), bearing and seal temperature, and nozzle inlet and outlet temperature and pressure. The output shaft of the turbine connects to a 2:1 reduction gearbox through a flexible coupling.

Skid Package Design

The skid package for the 24 RST contains all equipment for monitoring, control, data acquisition, and performance measurement. The skid is 233" (5920 mm) long, 94.5" (2400 mm) wide, and 118" (3004 mm) height. The total dry weight is 42,000 pounds (19,068 kilograms). The skid is significantly more complicated than a commercial unit, due to the abundance of analysis and power dissipation equipment.

The sketch in Figure 4 shows the basic piping and instrumentation on the main process flow. Well fluids from the intermediate pressure (IP) header or individual well, initially flow through an on-skid bypass, which controls the upstream pressure to the desired set point. The IP separator sets the downstream pressure, which is 630-670 psig. As the bypass is closed, the inlet and outlet shutdown valves open to allow flow to the 24 RST. A static mixer ensures homogenous multiphase flow enters the splitter. The flow splitter (spider) divides the flow into eight individual streams to enter the RST. A flow control valve (FCV) controls the total inlet stream, and manual valves isolate each nozzle feed stream.

The gas and liquids exit the turbine via separate flow paths. The exiting dry gas passes through a filter/coalescer vessel to capture any liquid carryover (LCO). An annubar meters the filtered gas, and a pressure control valve (PCV) controls the exiting pressure. A turbine meter on the filter dump measures the carryover liquid. A coriolis mass flow device meters the turbine discharge liquid (for density and flow). A PCV controls the liquid discharge pressure before it recombines with the gas stream. The exit stream leaves the skid and reports to the IP separator.

The turbine case drain consists of a horizontal pipe with a level control valve (LCV) and drain trap. The purpose of the case drain is to remove any collected liquids before start-up. Most liquids are removed from the case drain with a drain trap, and sent to the flare header.

The hydroblast jet-flow system removes built-up solids from the separator drum surface. The hydroblast consists of a small flow line from the main process stream that feeds a small nozzle inside the 24 RST. This nozzle directs a high velocity jet onto the separator drum immediately in front of the diffuser scoop inlet. As solids build up on the separator drum they are periodically (manual) sprayed with this jet, which fluidizes the solids to exit with the liquids. The well flow exhibited no solids, which precluded the use of the hydroblast system.

Performance Measurement

The main purpose of this test program is to assess the separation capabilities of this technology on actual production conditions. Secondary analysis includes power output and mechanical integrity. An on-skid PLC monitors, controls, and measures separation and mechanical performance. The control system consists of a PanelView touch screen for operator interface and a ControlLogix PLC. A dedicated data server, connected to the PLC via Ethernet, provides both data logging and trending.

Liquid Carryover. Liquid carryover into the gas stream is of primary importance in the operation of the RST, as it will determine the quality of the gas sent to the compressors. During operation of the 24 RST the LCO is collected with a filter/coalescer used as a reference vessel. This vessel captures particles 3 microns and greater and will give an accurate representation of liquid in the gas stream. Liquid carryover varies with speed, GLR, diffuser scoop configuration (with or without the surf rider), and liquid stream backpressure. The LCO in this program varied from 0.1-1.0 % depending upon the configuration.

Gas Carryunder. Gas carryunder (GCU) is of second order importance in measuring separation efficiency. Gas reporting to the liquid stream is not detrimental to the overall process system, as downstream equipment removes this residue gas. The initial system design allowed for GCU measurement with the coriolis mass meter, as the coriolis meter measures liquid density, which changes with the amount of GCU. The amount of GCU in this test was controllable, however it was not quantifiable with the coriolis meter. All cases of GCU proved to be out of range for the meter.

The 24 RST in this test requires a surf rider to prevent GCU into the liquid stream. Removal of the surf rider early in commissioning, due to start-up difficulties, left the inlet of the diffuser scoop open. Varying the backpressure on the liquid line, with the PCV, controls the amount of GCU. Additionally by comparing the exit gas flow rate to a baseline (no gas carryunder) condition, the amount of GCU is accurately determined.

Operation of the RST with no LCO or GCU yields 100% separation efficiency. Approaching this operating mode is one goal of the test program. Increasing the liquid exit line backpressure reduces the GCU, however it also increases the LCO. The opposite effect is also true. After thorough investigation, a point was then determined in which a balance between the two is set to minimize GCU and LCO. Data analysis is ongoing in order to quantify this optimum operation point for varying speed, flow, and GLR conditions.

Power Output. At nameplate design pressure drop and flow conditions, the 24 RST will provide a gross power output of 150 kW. Changes in well conditions and platform process configuration resulted in less one-half the nameplate flow capacity. The low flow and speed conditions provide a gross power output of 30-40 kW. A portion of this power drives the cooling fans (hydraulic motor), while the excess power dissipates across a hydraulic brake (control valve).

Mechanical Operation

Platform regulations prevented the use of a drive motor/generator on this package. This constraint required both a cold start of the turbine on process fluids and a non-electrical method of energy output dissipation. A turbine cold start requires only the process fluid pressure to provide energy for operation. High velocity fluids exiting the inlet nozzle impact a static turbine wheel, which must "spin up" to speed. The spin up time ranges from 30 seconds to 5 minutes depending upon the flow and pressure drop.

The cold start scenario prevents proper operation of the surf rider, due to turbine flooding. As per design, the surf rider opens fully at near operating speed. During the ramp up time fluids enter the turbine however they cannot report to the liquid outlet until operating speed is reached. The fluids then flood the turbine, which further lengthens the ramp up time. Removal of the surf rider during commissioning allows liquid backpressure to control the GCU.

Power produced through the RST output shaft provides on-skid useful work. The gearbox drives a positive displacement pump, which circulates hydraulic oil through a closed loop. The pressurized fluid in turn drives hydraulic cooling fan motors. Excess power dissipates by pressure drop across a control valve.

Accomplishments

This test program has yielded many significant results, and firsts for this technology.

- First self-started/self-powered RST on actual well production.
- First self-contained, monitored, and controlled multiphase turbine package for offshore installation.
- Tested on liquid flow range of 3,000-11,000 BPD and gas flow range of 5-15 MMSCFD (@ 800-1250 psig).
- Controllable GCU (0-20 %) and LCO (0.1-0.5 %).
- Demonstration of mechanical operation (vibration, seal, lube, hydraulic, etc.) well within industry limits.
- Full scale project implementation requiring interface with engineering and operation staff, as well as facility production and safety systems.
- Detailed application knowledge on interface and interaction of RST into pre-existing separation system (for retrofit use).

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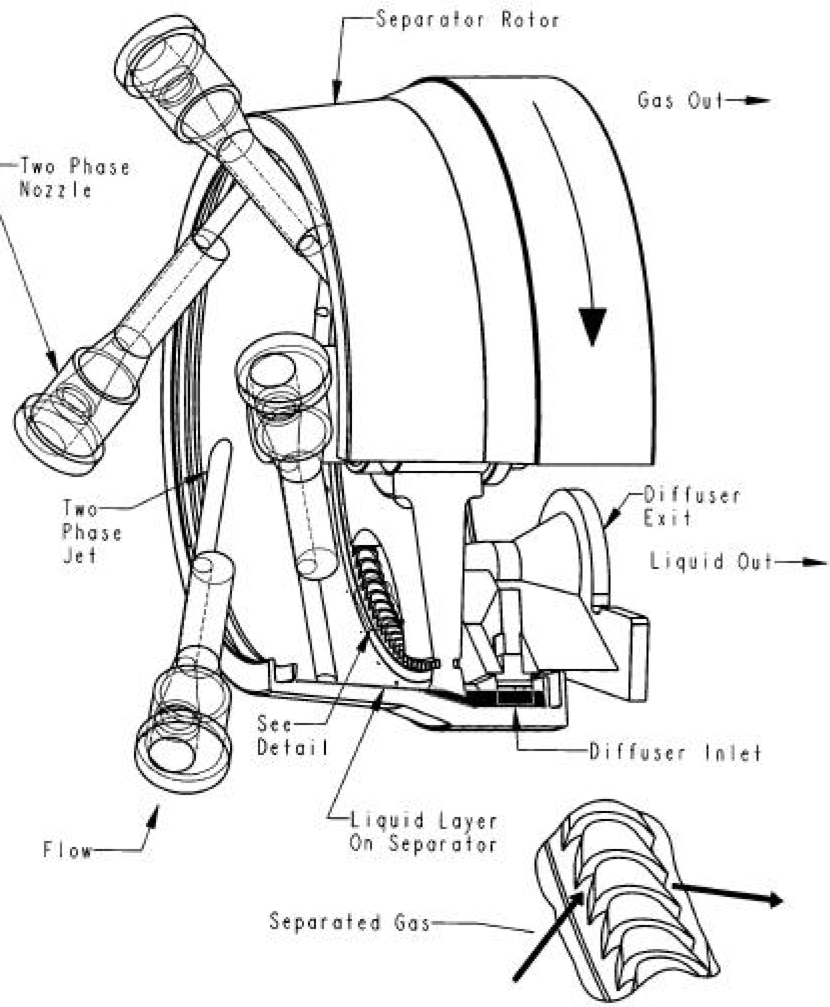

Fig. 1-Flow path sketch of a diffuser scoop type RST.

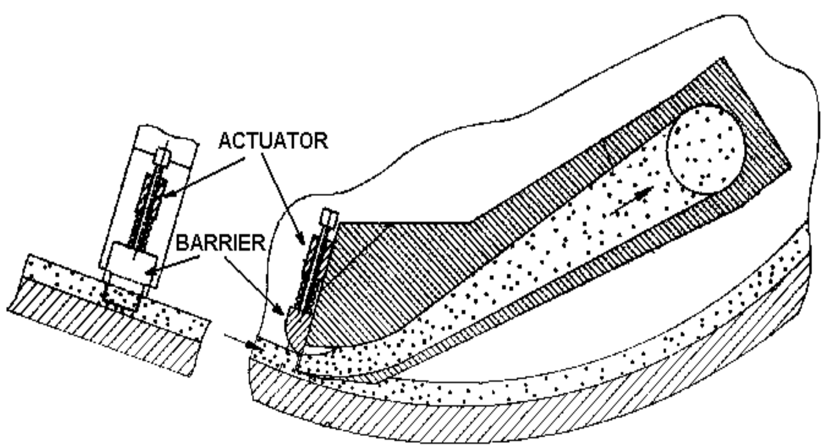

Fig. 2-Schematic of the diffuser scoop with "surf rider".

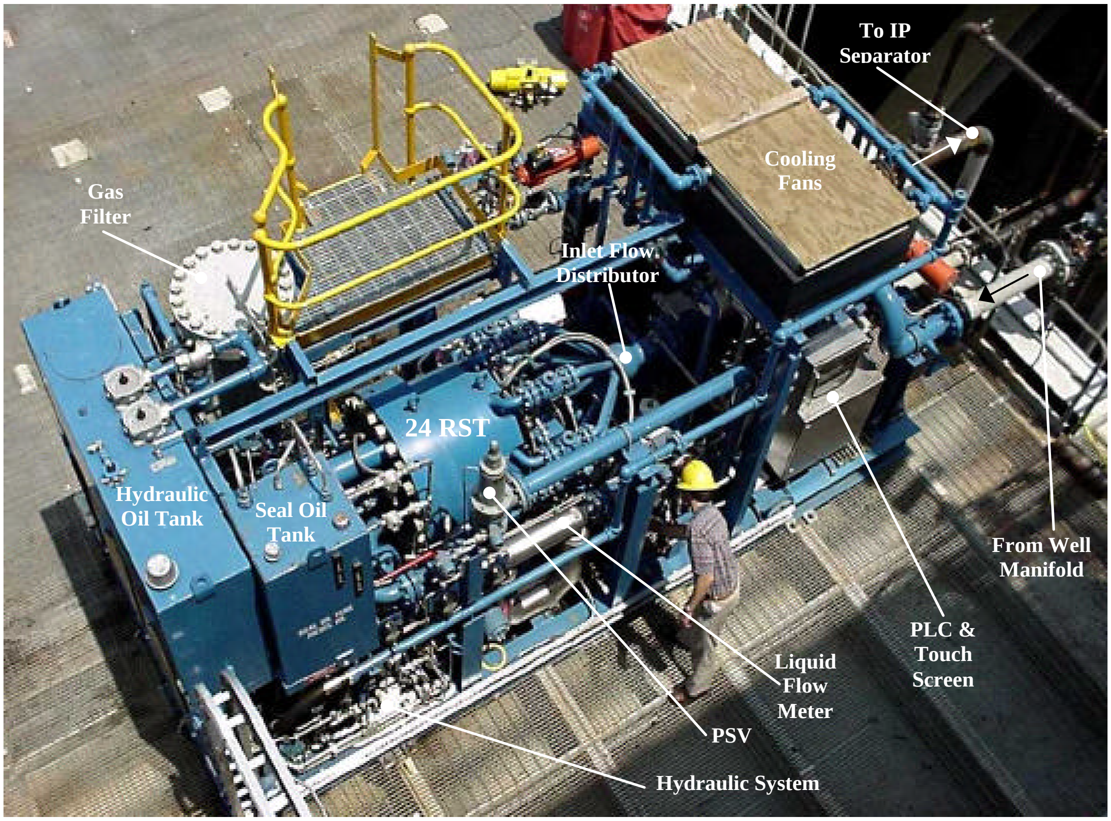

Fig. 3-Photograph of skid package during installation.

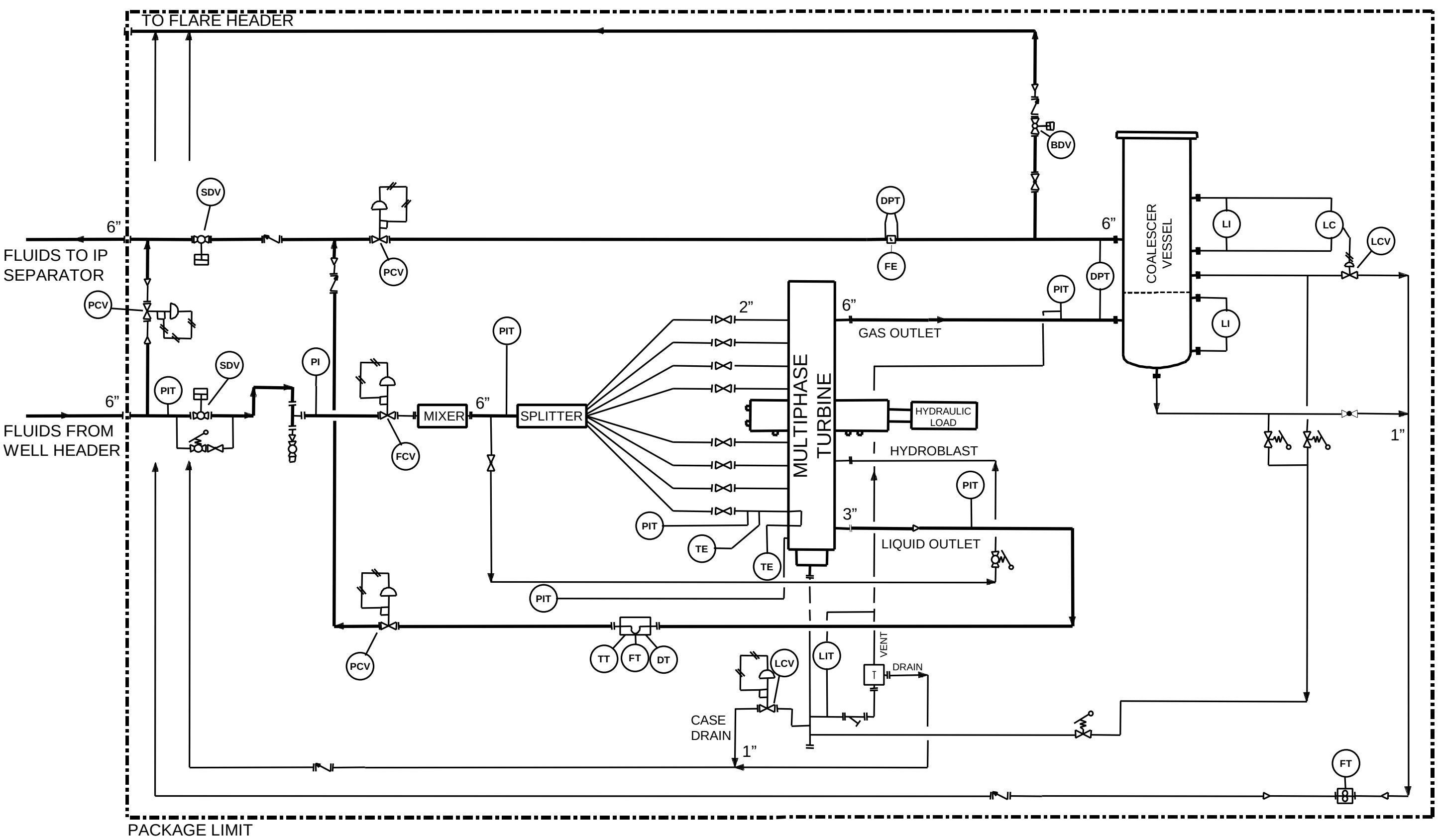

Fig. 4-Schematic P&ID of skid system.