Two-Phase LNG Expanders Replace Two-Phase Joule-Thomson Valves

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INTRODUCTION

As part of the liquefaction process of natural gas, the condensation phase requires the gas to be at a very high pressure, after which the pressure is reduced by expansion across a Joule-Thomson valve. During this pressure reduction process, the condensed fluid is flashed isenthalpically across the valve and into a phase separator vessel [1]. These pressure drops across a Joule-Thomson valve create very high turbulent friction losses, wasting energy as frictional heating of the fluid.

In contrast, a two-phase expander achieves the same pressure reduction while shaft power is generated from a near-isentropic expansion process. This keeps the frictional heating in the process to a minimum [2]. Thus, the substitution of two-phase flow expanders in place of Joule-Thomson valves in refrigeration applications increases overall system efficiency and can generate electric power in lieu of previously wasted two-phase energy [3].

In addition to the condensate phase of LNG production, two-phase expanders may also be used in cryogenic distillation processes. Dissolved nitrogen in pressurized LNG degrades the quality of the liquid. Expansion of low grade pressurized LNG across a two-phase expander extracts nitrogen from the LNG by vaporization while reducing the temperature of the remaining liquid. This Nitrogen rejection process is essentially cryogenic distillation, which upgrades the quality of the LNG while increasing overall production through temperature reduction [4].

DESIGN METHODOLOGY

Two-phase expander design concepts essentially follow existing single-phase turbine and expander technology. The hydraulic energy of the pressurized fluid is converted to electric energy by first transforming it into kinetic energy, then into mechanical shaft power and finally to electrical energy through the use of an electrical power generator [2].
Figure 1. Ebara Two-Phase Expander Cross Section
Electric power generation in cryogenic technology consists of two basic concepts. First, the generator may be an air cooled machine, mounted outside the cryogenic liquid and coupled to the expander as described by T. Bond [3], or the generator may be submerged in the cryogenic liquid and mounted integrally with the expander on a common shaft [4]. In this second application, the cryogenic induction generators must use insulation systems specifically developed for use in submerged windings. These have been found to have significantly superior dielectric and life properties than the systems commonly use on air-cooled machines. [5].

![Figure 2. Two-Phase Hydraulic Runner Assembly](image)

Figure 2. Two-Phase Hydraulic Runner Assembly

Figure 1 depicts the cross section of a typical Ebara International Corporation cryogenic two-phase submerged expander. As may be seen, the induction generator and the hydraulic expander are mounted on a common shaft. The expander consists of a nozzle ring generating the rotational fluid flow, a radial inflow reaction turbine runner and a two-phase jet exducer. Figure 2 depicts an enlarged cross section of the two-phase hydraulic runner assembly. Figure 3 shows the mounted jet exducer from the top.

To generate symmetric flow conditions, Ebara’s two-phase expander is designed with a vertical rotational axis. Expanders with horizontal rotational axis [1,2,3] generate asymmetric flow conditions can result in higher vibration levels. In addition, the flow direction of the Ebara two-phase expander is upward to take advantage of the buoyant forces of the vapor bubbles, to stabilize the flow and to minimize flow induced vibrations [6]. The hydraulic assembly is designed for continuously decreasing pressure to avoid any cavitation along the two-phase flow passage [7].
FIELD EXPERIENCE USING TWO-PHASE FLOW EXPANDERS

To upgrade LNG by extracting undesired Nitrogen, two Ebara two-phase expanders were installed at the Krio Polish Oil & Gas Nitrogen Rejection Plant (Figure 4) in Odolanow, Poland. Figure 5 shows the two-phase expander assembling and Figure 6 the expander installation.
Figure 4 Nitrogen Rejection Plant in Odalanow, Poland

Figure 6 Expander Installation

Figure 5 Assembling the Expander
Two-phase expanders operate at variable speeds in order to adjust to the changing mass flows and pressure conditions of the plant. Figure 7 presents the hydraulic performance of the two-phase expander with differential pressure and efficiency versus mass flow for different rotational speeds.

Efficiency is defined as the ratio of electrical power generated divided by the hydraulic power input. Hydraulic power input is the product of mass flow and differential pressure. The solid vertical red line depicts rated mass flow and the horizontal dotted line indicates rated differential pressure.

Figure 8 presents the tested and measured points from Figure 7, but revised to depict differential pressure and efficiency versus volumetric flow. The specific volume of fluid changes during the expansion process across the expander and is shown in Figure 9 as a quadratic interpolation between the inlet and outlet specific volume. The horizontal dotted line in Figure 8 indicates the rated differential pressure. The solid red parabolic curve in Figure 8 indicates the rated volumetric flow. As may be noted, the rated volumetric flow increases with increasing differential pressure due to the expansion of the two-phase fluid.

**Figure 7. Two-Phase Hydraulic Performance**

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Figure 8. Two-Phase Hydraulic Performance

Figure 9. Two-Phase Flow Specific Volume
BENEFITS ANALYSIS

The ultimate objective of all improvement efforts in liquefaction process technology is to increase economic benefits while simultaneously reducing the environmental impact of LNG production. Replacing inefficient valves with power recovery turbines for single-phase or two-phase expansion reduces the related plant power input by factors ranging from 3 to 5 times the expander’s power output.

It is significantly more efficient to cool the LNG stream using two-phase expanders instead of single-phase expanders or other devices. Figure 10 presents the LNG temperature drop versus the power output for the previously described two-phase expander. As may be seen, the cooling effect on the LNG stream is directly related to the power output.

Figure 10. Cooling Effect of Two-Phase Expansion

SUMMARY

Ebara two-phase expanders have been operating at the nitrogen rejection plant in Odolanow, Poland in excess of one year. Throughout that period regular inspections have shown no incipient failures in bearings or materials, vibration levels have been less than 20% of API 610 allowable limits and the ability to produce high grade LNG using less power and in an environmentally friendly manner has been conclusively demonstrated.
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