Technology Assesment for Two-Phase LNG Expanders Operating for Ten Years in Gas Liquefaction Process

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ABSTRACT

Conventional liquefaction processes for natural gas operate at high pressure through the condensation phase, after which the pressure of the liquefied natural gas, the LNG, is reduced by expansion across a Joule-Thomson valve or a liquid expander before rundown to storage at near atmospheric pressure.

When the condensed fluid is flashed across a J-T valve with constant enthalpy an undesirable amount of LNG is vaporized. The aim of using an LNG expander rather than a J-T valve is to increase the amount of liquid and to decrease the amount of vapour at the expander outlet. By employing a flashing two-phase LNG expander an increased amount of liquid is produced in a near isentropic expansion process.

Flashing two-phase LNG expanders were developed and installed in 2002 and 2003. Since then they have been successfully operating in the field for ten years without failures or interruptions except for routine maintenance shut downs. Flashing two-phase LNG expanders increase the LNG production output continuously by 3 - 5 %.

The presentation covers a technology assessment of the two-phase LNG expanders operating for ten years in the nitrogen rejection process at the PGNiG NRU plant in Odolanów, Poland.

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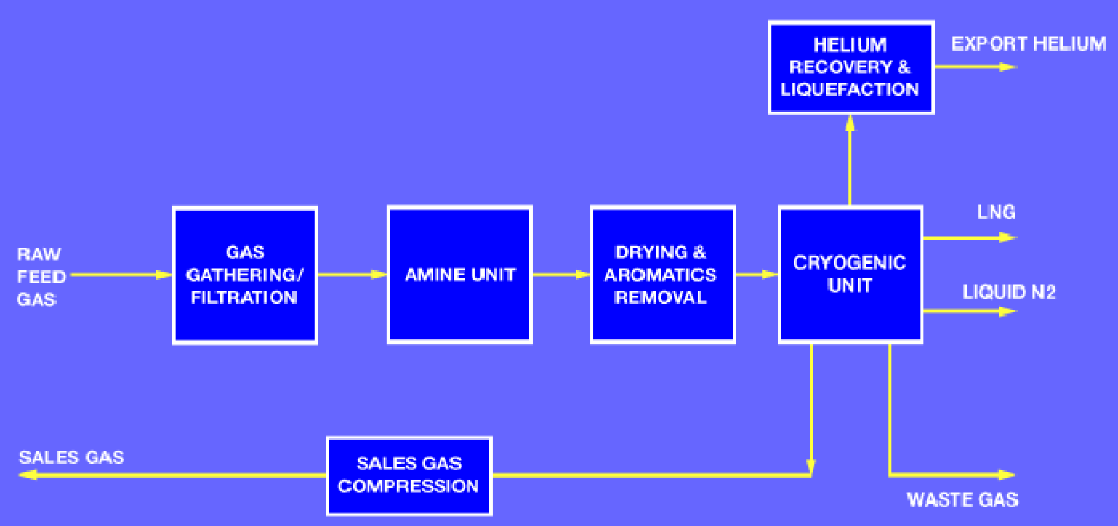
INTRODUCTION

The nitrogen rejection unit at Polish Oil and Gas Company plant in Odolanow (Odolanow NRU) was constructed in the 1970s to remove nitrogen from low BTU natural gas. To accommodate a feed gas having a different composition to the original design range the plant was modified in 2003/2004 with the novel turbine application.
Typical NRU comprises compact heat exchangers, pumps, cryogenic distillation columns and Joule-Thomson valves (J-T valves) linked together in a heavily integrated process to carry out efficient separation into the required products. J-T valves are applied to reduce the pressure of streams entering the distillation columns in order to decrease the stream temperature and assist in the provision of refrigeration to the process. The modification at Odolanow NRU plant consisted of adding turbo expanders parallel with Joule-Thomson valves. J-T valves became then a standby for the expanders being used during start-ups or shut-downs.

HISTORY OF THE NITROGEN REJECTION FACILITIES IN POLAND/ PROCESS CHANGES

Odolanow NRU is located in Southwestern Poland in Odolanow. It was constructed in the 1970s and comprises two trains, each processing up to 136000 NCMH of raw feed gas. Figure 1 shows a block diagram of one of the processing trains and shows how it is linked to the supply and the sales gas compression.

FIGURE 1 - BLOCK FLOW DIAGRAM



Raw gas is admitted from the plant supply header into each train and the first processing element is an amine unit which removes the carbon dioxide from the gas down to about 5 ppm by volume. The next process block is a thermally regenerated two-stage adsorption system with molecular sieves as first stage which removes water, while the second stage is based on activated carbon to remove heavy hydrocarbons. The dry gas is then admitted to the cryogenic unit which separates the nitrogen from the methane, producing high BTU sales gas, which requires compression before piping into the grid. In addition to nitrogen/methane separation, a stream of crude helium is produced which subsequently enters a helium purification and liquefaction process.

The original incoming gas had an approximate composition as indicated in Table A below.

Table A - Original Feed Gas Parametres.

Helium	0.4 vol%
Nitrogen	42,7 vol%
Methane	56,0 vol%
Ethane	0,5 vol%
Propane+	0,1 vol% max
CO_2	0,3 vol%
Water	Saturated at inlet conditions
Pressure	5,6 MPa
Temperature	10÷15 ˚C
Flow	136 000 NCMH

The sales gas required from the plant had to contain less than 4% nitrogen whilst the waste nitrogen, which was vented to the atmosphere, was required to have less that 1% methane. In addition, the helium recovery was required to be better than 85% having a final purity of 99.999% as liquid at minus 269^oC. The original design required that the sales gas leaves the cryogenic unit at about 1.8MPa.

Over the years of operation, the raw feed gas has been gradually changing as old gas wells become depleted and new ones are brought on line and supply the Odolanow plant. Today the composition has changed markedly with about 32 – 34 % nitrogen in the feed. In addition, the helium content has decreased to a little over 0.2%. Therefore, the refrigeration potential of the feed gas has been reduced because there is now proportionally less nitrogen to expand to near atmospheric and by difference, more methane that is produced at 1.8MPa. This has gradually caused more severe operational problems for the two plants. In order to make up the “cold deficit”, the plant stability was maintained by allowing a larger amount of methane to slip with the waste gas. This was clearly a temporary solution to maintain sales gas output, but resulted in a negative environmental impact and a loss of revenue from the methane emission. The plant was originally capable of producing small amounts of liquid methane or nitrogen for sale to third parties. All of this was severely impaired due to the lower nitrogen content in the feed gas.

In summary, there are several main factors associated with the change of initial composition of the feed gas:

- The environmental impact of increased methane content in the waste gas
- The economic loss as the consequence of methane emission
- Less stable operation of the cryogenic unit
- Inability to produce liquid products (LNG,LIN) for sale

Furthermore, as the gas source becomes depleted, the feed gas pressure may require costly investment in a pre-compression step. It would also be desirable to improve the efficiency of the NRU operation so that even with the drop of the feed gas pressure there will be still enough cold produced in the process to be able to operate in a stable manner. The current feed gas pressure is about 5.3 MPa and is being maintained by adding new gas sources.

As a result, various studies were carried out in the late 1990s and 2000 to address the problem and identify solutions. In addition, helium, the high value product, has decreased in concentration in the feed gas. This made it imperative that any changes to the process would not have any negative effect on the helium recovery. The study work examined many conventional and novel solutions. In order to understand these better the process is described below.

BRIEF DESCRIPTION OF THE CRYOGENIC PROCESS

In the original process, all energy needed for natural gas separation in low temperature units was provided by pressure reduction of the natural gas across Joule-Thomson valves. The original process is shown in Figure 2.

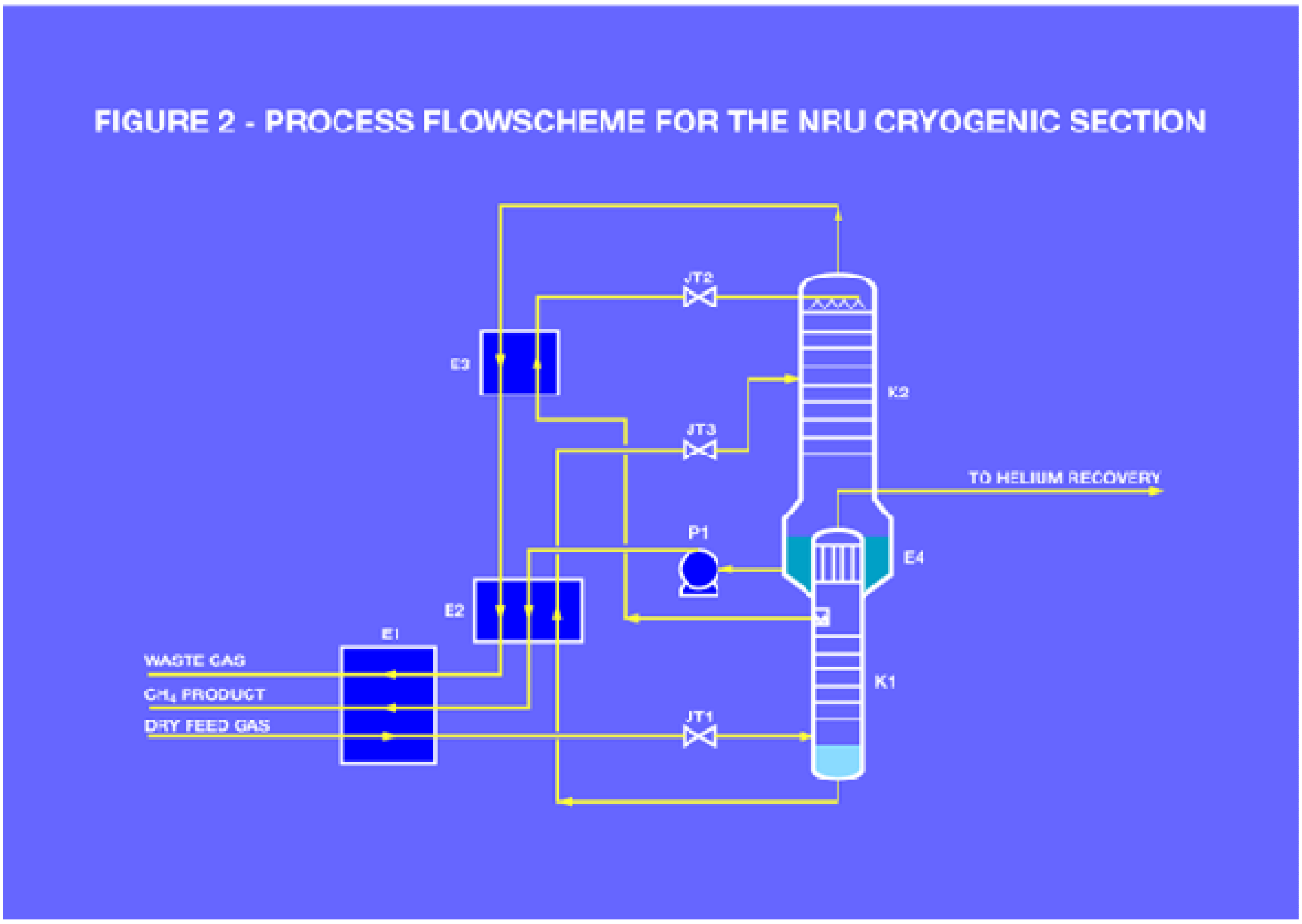


FIGURE 2 - PROCESS FLOWSCHEME FOR THE NRU CRYOGENIC SECTION

The dry feed gas is admitted into E1 of the cryogenic unit where it is cooled at 5.3MPa, condensed and subcooled before it is passed through JT1 for expansion to the lower column K1. The pressure in the lower column is about 2.1MPa and thus there is some flash into the lower column. The “rich liquid” from the base of K1 is then subcooled in E2 against returning colder methane liquid and gaseous nitrogen streams to about -150^{o}C. Then it passes through JT3 where the subcololed rich liquid expands to 0.2MPa, thereby creating some flash before entry into the upper column.

The upper column operates at about 0.1MPa and carries out the main distillation between nitrogen and methane. Reboil to this column is provided by condensing nitrogen at 2.2MPa in the top part of the upper column. This condensed nitrogen (high purity - of less than 10ppm methane) is drawn from a downcomer seal as a sidestream from the upper column, subcooled in exchanger E3 before it is expanded across JT2 and admitted to the top of the upper colum, K2. This nitrogen stream provides the necessary reflux to purify the nitrogen waste gas which returns through E3, E2 and E1, before it is vented to atmosphere. Therefore, the expansion valves JT1, JT2 & JT3 provide all of the refrigeration to the process. The methane product pump P1 raises pressure of the methane product from 0.2MPA to about 1.8MPa before the methane is evaporated and reheated in E2 and E1. The methane product is then compressed to about 5.0 MPa to enter the grid. The block diagram in Figure 2 shows process flowscheme in the cryo section of NRU.

Over the years Odolanow NRU plant has seen the nitrogen reduce from 42% to 33% now. It is expected that there may be a further reduction in the nitrogen content. As nitrogen in the feed decreases, the amount of nitrogen reflux also decreases in proportion to the methane that enters the upper column. Consequently, the distillation process does not perform as well as before and methane content in the waste gas increases.

CONCEPT DEVELOPMENT

The study work that was carried out led to selecting the most effective way of providing refrigeration to the upper column. The analysis included, among others, the following options:

- separate cycle to produce cold to provide to the upper column;
- gas expander after partially condensing the feed;
- pre-separation column or separator upstream of the double-column;
- extra trays in upper column;
- import of liquid nitrogen to assist in cold production;
- replacing JT1, or JT2 or JT3 with expanders.

After study the addition of an expander in parallel with Joule-Thomson valve JT3 was seen as most promising. JT3 became a standby for the expander.
Expansion turbines are always more efficient since they carry out “isentropic” depressurisation which generates work instead of isenthalpic depressurisation across a Joule-Thomson valve, which generates no work. Turbines take energy out of the process bringing about greater cooling of the streams passing through them and thus increase overall process efficiency.
The choice of this location for an expander meant that the liquid entering the expander was well subcooled ensuring a good quality single phase at the inlet. The outlet would produce 10 – 30 mole% flash which was an unsual service. This translates to 80 – 95% by volume of liquid. This issue represented a significant challenge from two aspects. The first is the two-phase flow stability for a fluid rising to the upper column entry point for all the cases. The second, and by far the most challenging, was the design of an efficient turbine which converted not only the hydraulic energy into useful work, but also the gas expansion energy.

The first issue was successfully addressed by correct selection of the fluid regime for all the likely scenarios, use of specially design piping and entry systems to prevent surges and vortices causing problems with pressure stability at the turbine outlet and flow stability at the upper column inlet.

The second issue was to source turbines able to expand into two phases. Test programs dating as far back as the 1980s had confirmed this prospect, however no commercial application of the technology was found. Confidence that two phase expanders would be feasible was established after an engineering study which was further supported by knowledge that:

- a similar duty was tested using a Pelton wheel open expander in air separation;
- a “gas” type expansion turbine was tested with flashing liquid nitrogen;
- there was evidence that one of the Ebara liquid expanders was producing flashing flow at its outlet since there was helium present in the gas;
- there would be no cavitation in this situation since the conditions were expanding and not collapsing gas bubbles;
- there was evidence in the field that gas oil separation facilities at the wellhead had liquid expanders that were seeing two-phases at the outlet.

The concept that was designed for the plant had a greater amount of flash than any of the above examples which represented the greatest challenge.

The expander was located taking feed upstream of JT3, routing it to the upper column to approximately the same entry point as before, except with a special arrangement for the piping. The liquid is well sub-cooled at that point since it exits exchanger E2 at below -150^{o}C at that point, and is at a pressure of 2.1 – 2.4 MPa. The rich liquid contains about 1/3 nitrogen and the rest is methane. Hence, when it is expanded to 0.24MPa, it produces some vapour through the turbine.

It was decided that the Ebara turbine lent itself well to exporting power, since the generator is located inside the vessel that houses the turbine. The control of the unit was facilitated by Variable Speed, Constant Frequency (VSCF) turbine speed control, using the level signal from the lower column, K1, making the expander act like a control valve. In practice, this control method works well and Variable Frequency Drives (VFD), of which the VSCF is a derivative, have been used in many areas, including pump control at Odolanow NRU. This site confidence helped in the selection of this control route.

With the rich liquid cooled down further than from the control valve, JT3, more cold is routed to the upper column and the separation of methane from the nitrogen waste gas stream is considerably more effective compared to the previous J-T arrangement.

TWO-PHASE EXPANDER DESIGN CONCEPT

Two-phase expander design concepts fundamentally follow existing single-phase turbine and expander technology. The hydraulic energy of the pressurized fluid is converted 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.

The generator is submerged in the cryogenic liquid and mounted integrally with the expander on a common shaft. The cryogenic induction generator uses insulation systems specifically developed for cryogenic service giving submerged windings significantly superior dielectric and life properties. Lubrication for the bearings is provided by an internally designed system which takes a small portion of the liquid passing into the turbine and routing it to the bearings. This produces some inefficiency, but the design of this system is far simpler than the typical external oil lubrication system. This was another attractive feature of the “canned” turbine design since the revamp required a smaller plot area, less connections to the main process with no need for seal gas.

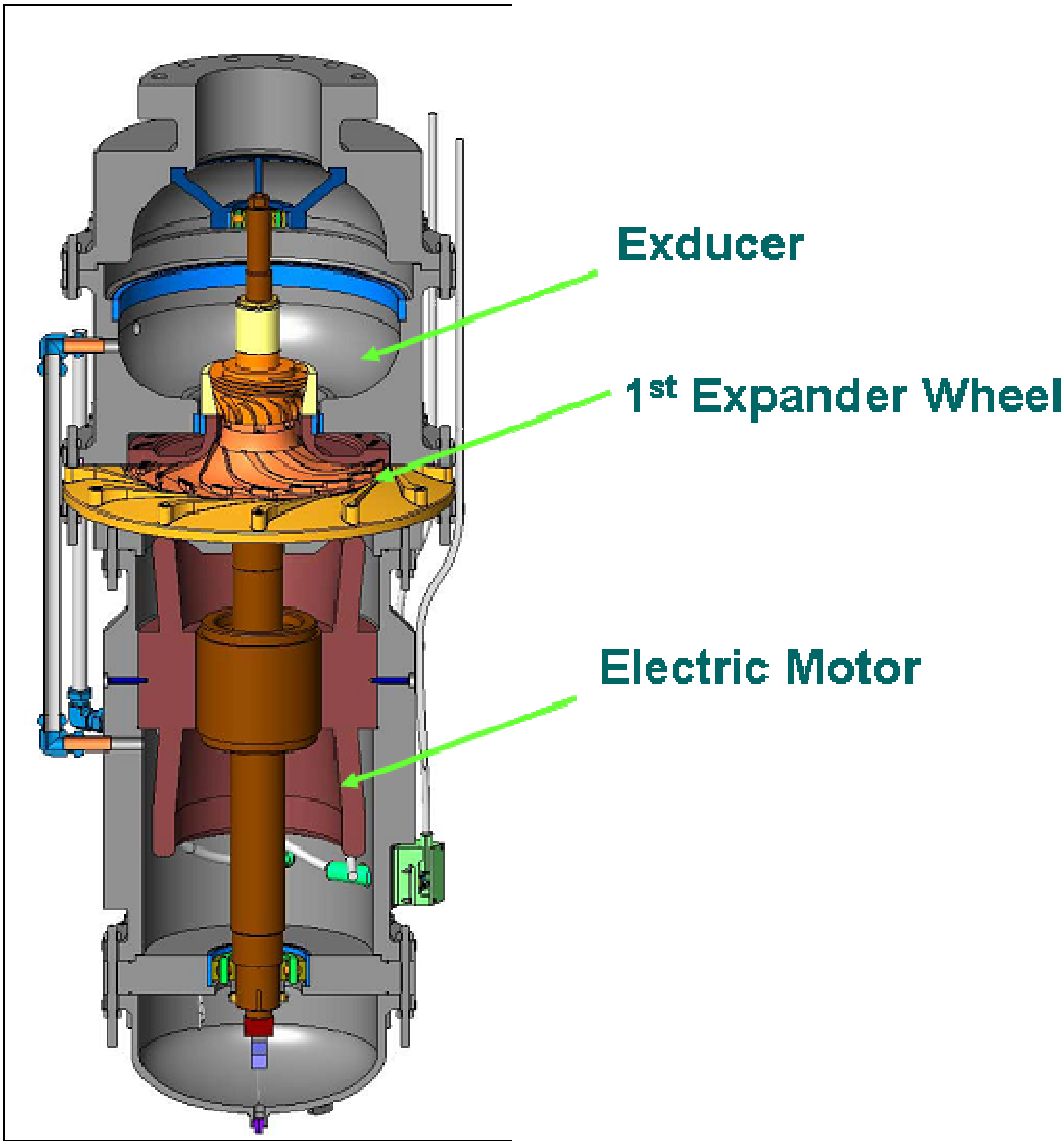


Figure 3 - Ebara Two-Phase Expander Cross Section

Figure 4 shows the cross section of a typical Ebara International Corporation cryogenic two-phase submerged expander. The expander consists of a nozzle ring generating the rotational fluid flow, a radial inflow reaction turbine runner and a two-phase jet exducer.

Symmetrical flow is achieved in the two-phase expander by utilising a vertical rotational axis to stabilize the flow and to minimize flow induced vibrations, with the direction of flow being upward to take advantage of the buoyant forces of the vapour bubbles. (Expanders with horizontal rotational axis generate asymmetric flow conditions which can result in higher vibration levels.) The hydraulic assembly is designed for continuously decreasing pressure to avoid any cavitation along the two-phase flow passage.

FIELD EXPERIENCE USING TWO-PHASE EXPANDERS

To upgrade low-methane natural gas by extracting undesired nitrogen, two Ebara two-phase expanders (one on each train , located in parallel to JT3, see Figure 2) were installed at the Odolanow NRU shown pictorially in Figure 3. During the optimisation period modifications were made to the turbine runner and exducer in order to enhance power output and hence cold production.

The operations staff had an excellent feel for the cryogenic unit behaviour and were able to contribute considerable support in process and turbine improvements. As of October 2004 until today the expanders have been running with unchanged arrangement /configuration.

The operational statistics for the two expanders M110/1 & M110/2 (one on each train) is presented in Table B below.

Table B – Hours in Operation

	M 110/1	M 110/2
Total hours in operation	85 001	70 070
Yearly average hours in operation	8017	6761
Hours in operation between bearings replacement (average)	13258	13082
Hours in operation between bearings replacement (maximum)	29535	17645

The expanders generate significant quantity of electricity; it is consumed at the plant , mainly in the helium refining process. The statistics of power generation in the last years is as below:

Table C – Electricity generated by expanders

	M 110/1	M 110/2
2010	450,5 MWh	338,4 MWh
2011	454,1 MWh	422,6 MWh
2012	386,4 MWh	444,5 MWh
2013 (Jan-July)	250,1 MWh	166,4 MWh

Basing on the operational experience the two-phase expanders technology can be assessed as follows :

Installation / co-operation with other equipment

- The expanders required limited modification of the existing equipment and consequently their installation is normally very easy and retrofitting can be done very quickly.
- The expanders operate surprisingly quietly; they are not heard while working with neighbouring equipment of average noise level below 80dB.

Process issues

- The employed expanders have made the process really flexible in terms of its adjustment to changing mass flows, varying from 60% to 100% of nominal duty. Even with such considerable changes they assure easy and precise regulation of level in the lower columns of both trains, which is of fundamental value for stable running of the process. The two-phase expanders operate at variable speeds in order to adjust to the changing mass flows and pressure conditions of the plant.
- By the use of the presented method one can run the process of nitrogen and methane separation even with short-term carbon-dioxide increases without having to prepare expensive and extensive additional carbon dioxide removal steps. The employed liquid two-phase expansion turbine can accept short term higher carbon dioxide concentration with no danger of plugging or consequent shut-down of the whole NRU. This added tolerance is only temporary, since the plant would have to be thawed out later on in any case. Whilst one would not design a new plant in this way, it gives operations staff more flexibility and a greater on-stream time.

Thermodynamic effects

- Cooling the methane-rich liquid feed to the upper column is significantly more efficient using two-phase expanders rather than single-phase expanders or other devices. (Figure 4 presents the LNG temperature drop versus the power output for the previously described two-phase expander and the cooling effect on the LNG stream is seen to be directly related to the power output.)

Due to the greater temperature difference achieved by the expander, the heat exchangers (particularly E3) operate in a more efficient and flexible way minimizing the danger of heat sinks, sometimes popularly described as “cold leaving out of cold box”.

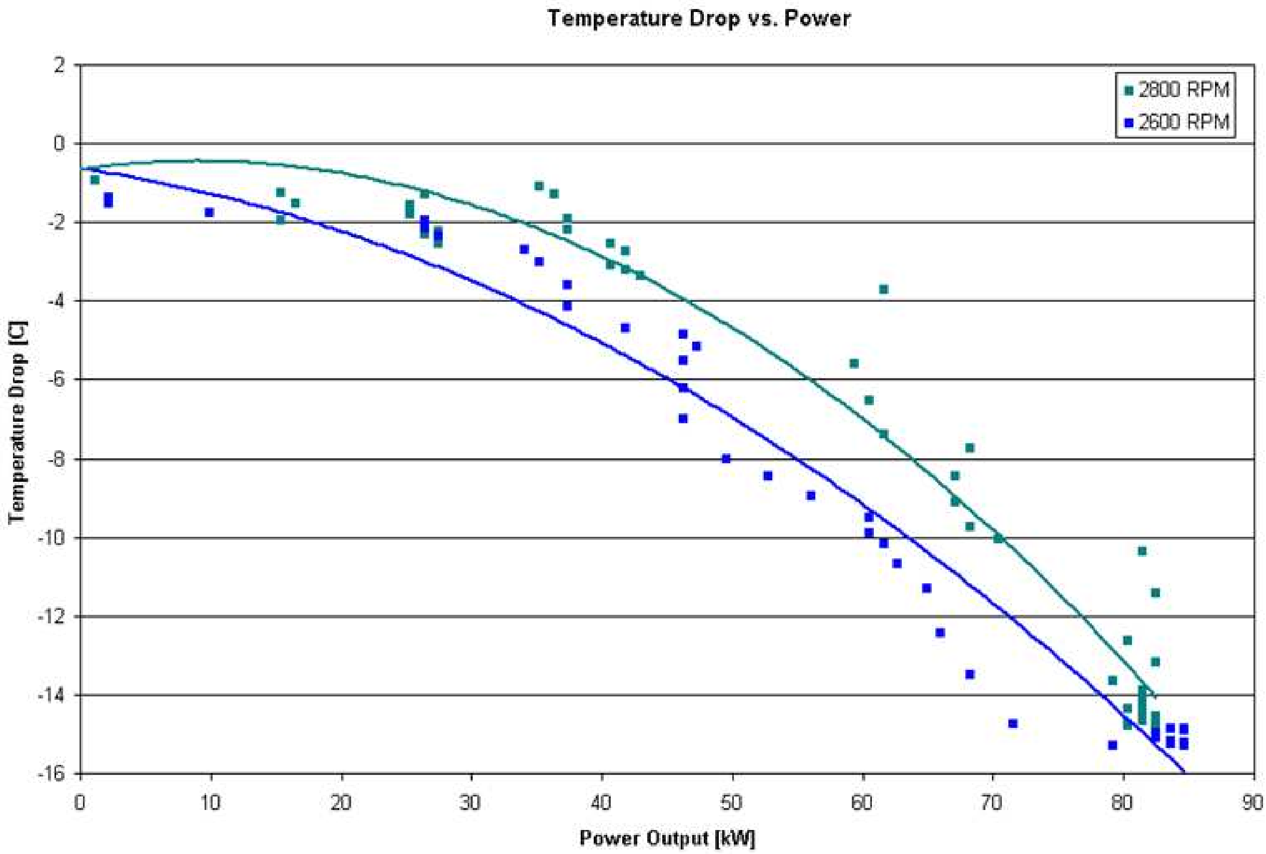


Figure 4 – Temperature Drop vs. Power Output

Feed gas pressure / product pressure

- The use of this two-phase expander in place of JT3 allows the sales gas product from the NRU to be at considerably higher outlet pressure, increasing by approximately 0.2MPa. The benefits of this have appeared as lower compression requirements downstream of the NRU, thus with lower fuel gas consumption per compressed unit. It means that the methane pumps can operate at a higher discharge pressure than before.
- The described process, being very efficient, allows for running it at a lower feed gas pressure (though this is not a big issue for Odolanow NRU at the moment). In case of reducing pressure of the feed gas from depleting sources one could postpone the decision to install an expensive pre-compression step.

Direct impact on business

- The NRU has the facility to produce either liquid nitrogen or LNG for sale to third parties. With the expanders operating there is a significant increase in LNG output from the NRU of up to 250% compared to when Joule-Thomson valves, JT3 in Train 1 and Train 2 were in operation. Alternatively, the plant was able to produce similar quantities of liquid nitrogen for export. Both LNG and liquid nitrogen can be withdrawn from the double column arrangement into vacuum insulated storage tanks for loading into road tankers and export.
- While the original design was for 42% nitrogen in the feed, with the 33% now, the waste gas methane content rose to above 3% with very poor plant stability and frequent operator intervention. Because of the higher efficiency of the described process employing Ebara liquid two-phase expansion turbines the upper column feed is colder which helps to further cool the upper colum top section leading to a lower methane content in the waste gas (even down to 0,3%).

- Employing liquid two-phase expansion turbines in the separation of nitrogen and methane will allow generation of energy that can be used for export or as a drive power for another duty.
- Due to the high efficiency of the process presented above there is a possibility of taking out of the process considerable amounts of low-pressure LNG or a liquid nitrogen stream, running the nitrogen methane separation in a stable manner at the same time. The possibility of producing LNG may be useful for the plants where the Peak Shaving concept is going to be applied.

SUMMARY

One of the most significant benefits of the turbine operation has been the enormous flexibility that the plants now have. The process is easy to operate and controllable with no danger of shut-down even with considerable changes of feed gas parameters. The operators can precisely adjust the process parametres and are therefore able to rapidly optimise in order to:

- Maximise sales gas output.
- Maximise helium recovery.
- Minimise methane content in the waste gas.
- Withdraw up to 30 t/day LNG per train.

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