Turbo Expander Technology Contribution in Development of Ethylene Plant Process

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ABSTRACT

Ethylene plant process and turbo expander technology developments have been interrelated and dependent on each other's. Design improvements and technology innovations associated with inflow radial turbine, turbo expander, have been the main motivation for the improved and more productive ethylene plant processes. The early process design that was based on Jule Thompson expansion valve was replaced by the process designs that utilize several stages of expander - compressor or expander- generators.

The latest technology innovation that was embraced by the ethylene plant engineering companies and the owners was expander-compressor with active magnetic bearings. The early applications of expander-compressor with magnetic bearings began in the 1980's

The present product improvement activities by turbo expander suppliers are to reduced number of expansion stages. High head and low flow coefficient expander wheel as well as high peripheral speed wheels are being developed to achieve the latter objective.

The next innovative technology that is knocking at the door of ethylene plants is expander - high speed permanent magnet generator with magnetic bearings.

In this paper the authors present a brief history of ethylene plant process, expander technology developments and show their reliance. The authors will also present their suggestions about the next innovation of the expander with high speed generator.

INTRODUCTION

The beginning of ethylene production in an industrial scale goes back to 1919 and George Cume who established the bases for the modern chemical industry, [Spitz 1988]. The new technology of steam cracking was then utilized in the first commercial scale ethylene plant at Clendenin, WV/USA, in 1920 by Union Carbide [Frost 2014].

M. Piccotti has made an excellent research about the present state of the art of ethylene production technologies, [Piccotti]. He reports that high technology equipment have significantly contributed to improve the "conventional ethylene technology". M. Piccotti refers to turboexpander technology as one of the contributors. In conclusion he states that the steam cracking base ethylene technology remains as the most practical and economical technology for large industrial ethylene plants for a foreseeable future.

Stone & Webster for more than 70 years and KTI with more than 40 years' experience in ethylene process are among the first ethylene process developers who utilized an expander configuration in the cryogenic section of the process. The expander is utilized to boost the Ethylene plant refrigeration, by expanding hydrogen rich overhead vapor (off gas), before flowing to the fuel gas system for the cracking furnace.

The use of an expander in ethylene plants is to allow greater ethylene yields to be achieved by provided the deepest level of cryogenic refrigeration possible and thereby recovery any remaining ethylene that is present in the plants final tail gas. Typically the limit in ethylene plant refrigeration is set by the lowest ethylene refrigeration compressors operating suction pressure at around the -100 Deg. C mark. To produce levels of refrigeration lower than this the initial approach was the simple JT expansion valve utilized on the methane recovery steps associated with the de-methanisers however in plants that primarily crack ethane rich feedstock's and have very low molecular weight tail gas that are primarily rich in hydrogen this physically is not possible due to hydrogen's reverse JT effect. The only solution in this instance that can be employed is an expansion of this hydrogen rich tail gas through an expander which recovers work from the gas and thereby produces the low cryogenic temperatures that are need for improved yield.

An expander's load configuration in an ethylene process depends on the process requirements and the plant design preferences. In the older installations that were mostly small capacity plants an oil brake (hydraulic brake) was utilized to use the expander power for oil circulation in a closed loop. Expander-compressor and expander-gear-generator were the preferred configurations as the capacity of the ethylene plants grew larger and larger. In an expander compressor configuration the expander back pressure could be lower and hence more refrigeration will be produced. The compressor end will boost up the expanded process fluid to the needed fuel gas pressure.

In the oil brake and the expander - compressor configurations both the expander wheel is directly coupled to the oil brake impellor or compressor impeller on the same shaft. This is an attractive from of a machine design configuration and compactness. Careful attention to the details in the impellor sizing dimensions for both are needed. When sized correctly they have an inherent self-limiting feature but are less tolerant of an “off design” operation where mismatch in the power/speed curves of the expander wheel and the driven oil brake or compressor impeller result.

Technip reports that the current ethylene production capacity will grow to 200 MMTA by the year 2020 with an average annual growth of 3.5 %, [Laugier 2013].

RADIAL INFLOW TURBINE, TURBOEXPANDER

Radial Inflow turbine, or turboexpander, is a century old technology that has successfully been utilized in cryogenic natural gas processing since the late 1950’s [Agahi 2005] , [Bloch 2001]. Figures 1, 2 and 3 depict an expander cross section, expander variable inlet guide vanes (IGV) and expander load configurations.

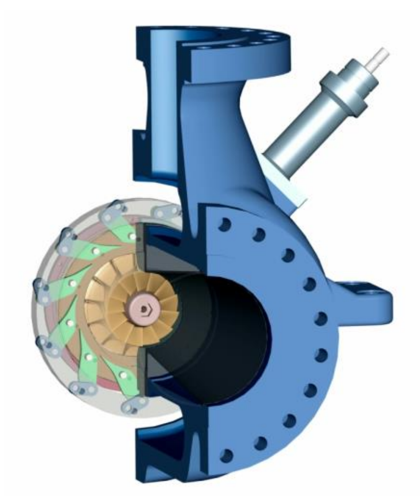


Figure 1. Expander Cross Section

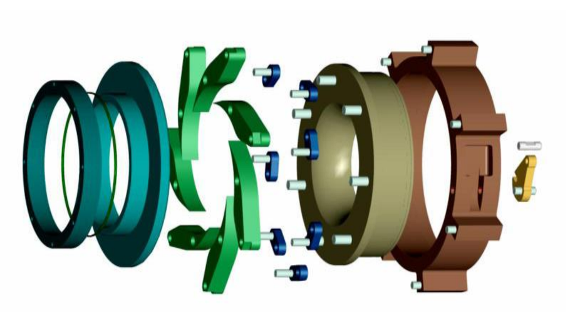
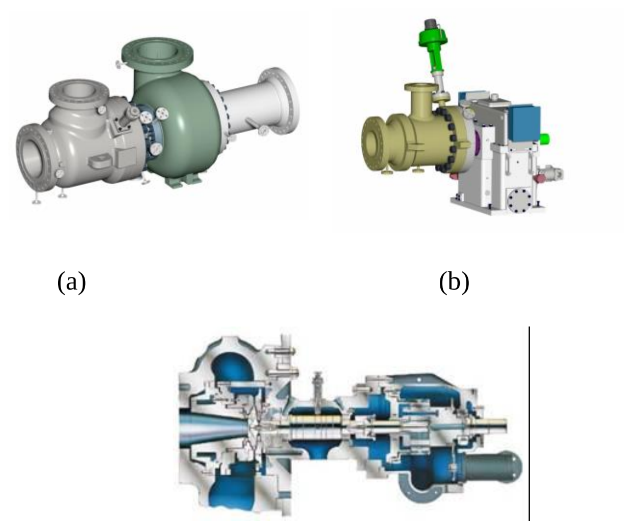


Figure 2. Variable Inlet Guide Vanes

The high isentropic efficiency and variable IGV are the most interesting and useful design features for the processes where turboexpanders are used.



(a) (b)

(c)

Figure 3. Expander Load; (a) Expander-Compressor, (b) Expander-Generator and C)

Petrochemical processes such as ethylene were using external refrigeration and Joule Thompson expansion for the refrigeration needs in the cryogenic section of the plants in the first decade or so. As ethane cracking ethylene plants commercialized and the associated higher hydrogen concentrations in the final tail gas stream proved to be beyond the capabilities of external refrigeration and the existing Joule Thompson expansion approach. The reverse Joule Thompson effect that hydrogen has in effect heats up the final tail gas during JT expansion. The obvious need for an internal expander approach if the levels of cryogenic temperatures were to be achieved in ethane cracking ethylene plants was born.

The turboexpander application in petrochemical industries began in the early 1970’s. Additional cooling resulting from the high isentropic efficiency of the turboexpander improved ethylene plant yield and hence more and more plants were configured to utilize an expander in the cryogenic section.

The latter application demanded more challenging designs due to low molecular weight process gas, high rotational speed and the resulting high wheel peripheral speed. Oil mist migration to the downstream process equipment such as coldbox was another challenge for the plant operation. Figure 4 shows a typical process flow diagram of the cryogenic section of an ethylene plant.

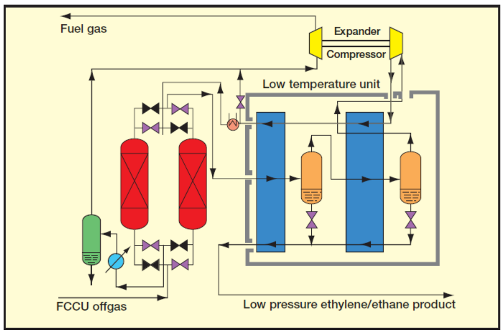


Figure 4. PFD of Cryogenic Section of an Ethylene Plant

TURBOEXPANDER CONFIGURATIONS IN THE ETHYLENE PROCESS

Turboexpander with oil (hydraulic) brake load was the only configuration used in the early ethylene plants in the 1970's, Figure 5.

Figure 5. Expander-Oil Brake

Expander – compressor was the next configuration to be utilized in an ethylene process. The expander compressor has an advantage of the deeper cryogenic temperature due to further expansion of the off gas, harnessing cryogenic power for compression and more expander control for the off design conditions, Figure 6 shows cross section of an expander-compressor and Figure 7 a typical performance curve of an expander-compressor.

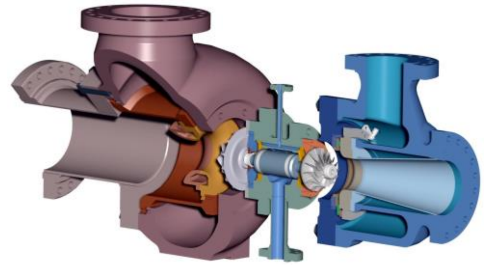


Figure 6. Expander-Compressor Cross Section

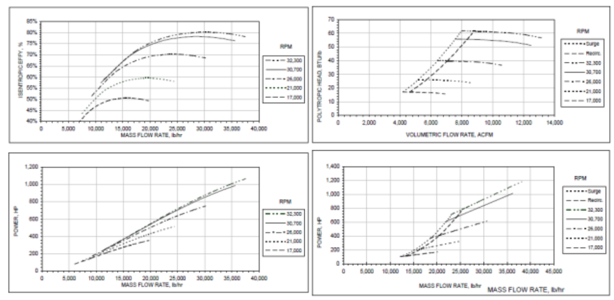


Figure 7. Expander—Compressor Performance Curves

Expander –gear –generator was another configuration that some ethylene processes chose for the cryogenic section. In this configuration the expander drives an induction generator through an external or an integral gear box, Figure 8.

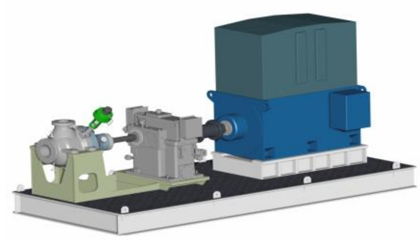


Figure 8. Expander-Gear Generator

TURBOEXPANDER TECHNOLOGY INNOVATIONS FOR ETHYLENE PLANT APPLICATIONS

DRY GAS SEAL

Oil mist migration to the downstream process of an turboexpander causes too much troubles and may result in plant shut down. The oil mist accumulation and subsequent freezing in the fin plate exchanges inside the coldbox will eventually shut down the plant for thawing and cleaning of the heat exchangers.

The Fife Mossmorran Ethylene Plant in Edinburgh, Scotland began operation in the early 1980's. The cryogenic section of the plant has multiple expanders-gear- generator units. The plant operation requested the Original Equipment Manufacturer (OEM) of the turboexpander equipment to explore retrofitting the original labyrinth sealing system with dry gas seal. The original expanders were designed with labyrinth seal and oil drainer system. The labyrinth seals were replaced by dry gas seal in the early 1990's, Figure 9

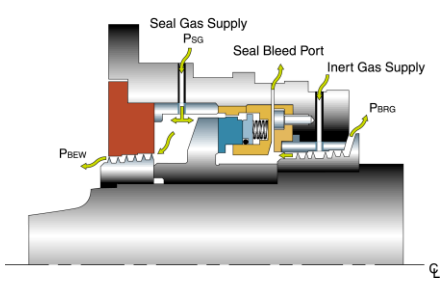


Figure 9. Dry Gas Seal

Table 1 depicts a typical expander process conditions, pressure and temperature, for a four stage expander configuration.

	P1 (Bar)	P2 (Bar)	T1 (C)
Stage -1	30	20	-100
Stage-2	20	15	-115
Stage-3	15	10	-130
Stage-4	10	6	-140

Table 1. A Typical Pressure and Temperature Values for a Four Stage Expander Configuration

Installation of the dry gas seal in a turboexpander is challenging and demands special seal design. The dry gas seal has to be fitted in a tight space, rotate at a high speed and operate in a cryogenic temperature environment.

The most challenging dry gas seal design was implemented in the 1990's for an ethylene plant in Qatar. The dry gas seal was designed for 45,000 rpm and – 200 C design temperature.

HIGH TIP SPEED WHEEL

The hydrogen rich gas is normally the process stream for expander –compressor in the cryogenic section of an ethylene plant. The molecular weight of the process varies between several process licensors' designs. It varies between 2.5 to 7.5 kg mol/kg. The expander and compressor enthalpies are normally high due to lower molecular weight and hence the rotational speed is to be high to produce an acceptable isentropic efficiency.

Utilizing high tip speed wheels in the ethylene plants could reduce the number of expander stages and increase the isentropic efficiency by at least 2-3 %. The wheel material for this type of application is usually 7000 series aluminum alloy.

The high rotational speed does not cause any major design concerns for the expander wheel because it is smaller in diameter compared to the compressor wheel and cold temperature enhances the aluminum properties. The compressor wheel tip speed, on the other hand, is normally in excess of the limit for standard grade aluminum. The OEM had to utilize special and high strength aluminum with fine grain structure 10. Another challenge for the high stress wheels is to avoid fatigue with the required separation margin for rotor dynamics.

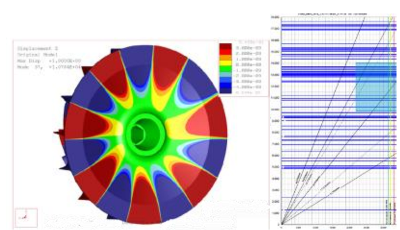


Figure 10. Compressor Wheel and Campbell Diagram

Resonance frequencies tuning is achieved during the design stage and verified during bench testing to avoid interference with multiples of passing frequencies Figure 10.

An ethylene plant in Malaysia had several stages of expander-compressor with the record highest tip speed of 450 m/s at the time of design/manufacturing in the mid-1990.

The current state of the art for material selection, design tools and advances in wheel - shaft attachment methods allow the wheel tip speed of over 500 m/sec, at the maximum operating speed.

ACTIVE MAGNETIC BEARINGS

An expander - compressor is an ideal turbomachine for application of active magnetic bearings (AMB). The overhung wheels and inherently balanced axial loads are in line with the limitations of AMB in comparison to the oil bearings. The bearing housing is pressurized with process gas to the compressor suction pressure for a completely sealed bearing housing and in compliance with the required electrical area classifications. Ethylene plant turboexpanders are relatively low pressure which simplifies the bearing load capacity requirements.

The early attempt to design an expander-compressor with the AMB was for a plant in the USA in the 1980’s. That project was not as convincing for the operational team as it should have been and there were setbacks in acceptance of the expander-compressor with AMB in oil and gas industries in general and in ethylene plants in particular.

That reluctance lasted more than five years until an offshore platform and an onshore plant in Norway went into operation with several expander-compressor trains with AMB. Those installations paved the way for expander-compressors with AMB in oil, gas and petrochemical industries. As a matter of fact expander-compressor with AMB became an unwritten standard for the ethylene plants since mid-1990. The next wave of ethylene plants in Qatar, Abu Dhabi, Kingdom of Saudi Arabia, Singapore, Germany, Sweden, China, etc., had expander-compressors with AMB, Figures 11, 12.

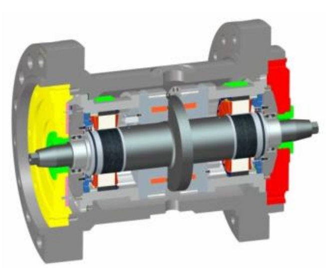


Figure 11, Expander-Compressor with AMB

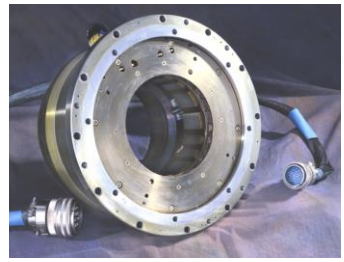


Figure 12, An AMB Cartridge

An ethylene plant in Germany requested a very unique design for its expander compressor back in the late1990’s. The request was to design the expander, compressor, bearing housing and the AMB for the minimum temperature of -200 C.

TURBOEXPANDER CONTROLS IN AN ETHYLENE PLANT

Ethylene plants are normally configured with multiple stage expanders that operate in series. Speed control of the expander stages, particularly with compressor load, is an important issue and should be considered at the design stage. The optimal recommended method in cascade control arrangement is as follows:

The IGV's of the first stage to be controlled by the inlet pressure with an override provision if the unit approaches its over speed alarm only. The IGV’s will be closing if the expander reaches to the alarm speed

The IGV’s of the subsequence stages are to be controlled individually based on the speed of the first stage expander and the override if the individual stage speed approaches to its over speed alarm .

EXPANDER-HIGH SPEED-GENERATOR

There are many ethylene plants in the world that have installed expander-oil brake or expander –gear-generator units in their cryogenic section. The plants with oil brake are the older plants that were smaller in size and capacity. Utilizing expanders with AMB for those ethylene plants with oil brake and generator does not make much sense because it does not get rid of lubricating oil altogether.

An innovative idea that is considered by an ethylene plant with expander-oil brake and could be adopted by more ethylene plants in the future is a hermetic expander wheel directly mounted onto a common shaft with a DC permanent magnet brushless high speed generator. This arrangement brings together the mature technology of expander wheels and active magnetic bearing hermetic systems to the developing high speed permanent magnet motor/generator technology. This interesting approach would allow the limitations of the fixed geometry of compressor oil brake impellors and their power /speed relations ships to be removed. Permanent magnet brushless generator/motors use an electronic commutation system that would allow optimum expander wheel speeds for both design and off design conditions. In effect the reverse is also applicable in that a motor version of the hermetic expander but configured with a compressor impellor would also potentially deliver the attractive feature that expander re-compressor systems have in that they can work across a wider pressure ratio for greater refrigeration effect and still satisfy the tail gas to fuel gas recovery inlet pressure requirements. By splitting the expander re-compressor into two discrete hermetic assemblies would also allow the location of the two units to be optimized in relation to the cold box entry and exit points for the tail gas to fuel gas recovery.

This configuration when and if possible will be with AMB and hence the expander package will be oil free. It may further allow an ethylene plant to operate at several off design conditions that is not possible with oil brake due to limitation in the expander control in general and thrust load management in particular, Figure 13.

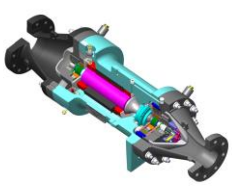


Figure 13, An Expander High Speed Generator

The major advantage of this configuration is the compact design because of speed of rotation and the fact that the rotating parts are all on the same shaft. Sealing system of an expander-high speed generator is also less complicated than the other configurations.

CONCLUSIONS

It is almost a century since an ethylene plant in the industrial scale has been in operation. Turboexpander technology has contributed to the ethylene production for more than half a century. Several innovations in turboexpander technology have been implemented because of its application in the cryogenic section of the ethylene plants. The expander design with dry gas seal, active magnetic bearings and special aluminum alloy wheel have come around to serve ethylene production and improve plant productivity. Expander with high speed generator will be the next innovation for application of expander in the ethylene plants.

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