



TECHNICAL PAPER

Title: Liquid Expanders in the Phillips Optimized Cascade LNG Process

Authors: Cyrus Meher-Homji – Bechtel Corporation
Non-Bechtel authors: Wesley Qualls, Anthony Eaton

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LIQUID EXPANDERS IN THE PHILLIPS OPTIMIZED CASCADE LNG PROCESS

DILATATEURS LIQUIDES AU SEIN DU PHILLIPS OPTIMIZED CASCADE LNG PROCESS

Wesley R. Qualls
LNG Licensing Engineer
Wes.Qualls@ConocoPhillips.com
Anthony P. Eaton, Ph.D., P.E.
Director of LNG Product Development Center
Tony.Eaton@ConocoPhillips.com
ConocoPhillips Company
3000 Post Oak Boulevard – Mail Stop 59
Houston, TX 77056
United States of America

Cyrus B. Meher-Homji, P.E.
Principal Engineer
Bechtel Corporation, Turbomachinery Group
3000 Post Oak Boulevard
Houston, TX 77056
United States of America
cmeherho@bechtel.com

Abstract

Throughout the chemical and petroleum industries, liquid expanders offer the potential to improve process efficiency by recovering otherwise unused energy. Within the LNG industry, only a few of the more recent facilities utilize liquid expanders and typically only where the entering and exiting streams are fully liquid. Within the Phillips Optimized Cascade LNG Process, as with most processing technologies, a large potential exists to recover energy associated with flashing pressurized and saturated or slightly subcooled liquid stream(s). Once this energy is recovered, the next step involves integration of the energy within the process for optimal utilization. In addition, the corresponding temperature drop associated with expansion provides further opportunities for heat integration. Recent advances in liquid expander technology provide a promising future for flashing liquid expansion. Several liquid expander designers are actively marketing expander solutions for flashing liquid streams.

This paper will explore and discuss available liquid expander technology as well as the locations within the Phillips Optimized Cascade LNG Process providing the most beneficial application(s). The paper will also focus on methods for practical integration and utilization of the recovered energy.

Résumé

Les dilateurs liquides permettent, dans l'industrie chimique et pétrolière, d'améliorer les performances des procédés en récupérant l'énergie inutilisée. En ce qui concerne le secteur du GNL, seules quelques-unes des installations les plus récentes utilisent des dilateurs liquides et en général, uniquement lorsque les courants entrants et sortants sont complètement liquides. Il existe, au sein du Phillips Optimized Cascade LNG Process tout comme dans la plupart des techniques de traitement, d'importantes possibilités de récupération de l'énergie associée à la détente des courants de liquides pressurisés, saturés ou légèrement sous-refroidis. Une fois cette énergie récupérée, il s'agit ensuite de l'intégrer dans le procédé pour une utilisation optimale. De plus, la chute de température correspondante associée à la dilatation facilite l'intégration calorifique. Les récentes avancées en matière de technologie des dilateurs liquides sont de bon augure pour la détente de la dilatation des liquides. Plusieurs concepteurs de dilateurs liquides commercialisent déjà des solutions de dilateurs pour la détente des courants de liquides.

Cette présentation explore et examine la technologie actuelle des dilateurs liquides ainsi que les points, au sein du Phillips Optimized Cascade LNG Process, qui offrent les applications les plus avantageuses. Cette présentation aborde également les méthodes d'intégration et d'utilisation pratiques de l'énergie récupérée.

1.0 INTRODUCTION

Technology development is a key consideration for the continued success of any licensed process employed in competitive industries. Within such industries, conceptual improvement or enhancement ideas are typically generated through a series of exercises such as brainstorming, cost cutting, technology exchange, customer feedback, and/or debottlenecking studies. Ideas are then developed based on various criteria such as cost of development, return on investment, industry acceptance, marketability, or development time required. Ideally, though not always the case, development ideas are rated with those generating the largest return on investment receiving the most focus. Of course, concepts resulting in substantial improvements while providing little economic downside generally prove the most attractive.

Including flashing liquid expanders in the Phillips Optimized Cascade LNG Process provides an excellent example of such an idea. Flashing liquid expander(s) allow for efficient energy recovery that can be utilized elsewhere, resulting in improved process efficiency. In addition to recovered energy, another important consideration is improved liquid (LNG) recovery. Note that the term “flashing liquid expanders” is differentiated throughout this paper as that having a two-phase outlet stream containing a significant quantity of liquid as would typically be encountered through the expansion of a saturated or slightly subcooled liquid stream. Vapor expanders yielding smaller quantities of liquid by expanding light hydrocarbon vapor are fairly common. Highly subcooled liquid expanders are also fairly common.

Due to technological challenges and the conservative nature of the LNG industry, flashing liquid expanders have traditionally met with resistance. On the other hand, the competitive nature of the LNG industry combined with an increased demand for LNG is now providing the driving force for flashing liquid expander development and implementation. Equipment vendors are answering this particular industry demand by offering the equipment and associated assurances required. The paper will present two prominent configurations for recovering and reusing energy through the integration of flashing liquid expanders within the Phillips Optimized Cascade LNG Process.

Operational reliability has always been a key consideration in the development and implementation of any innovation within the Phillips Optimized Cascade LNG Process. The historical and current reliability of the process are viewed as a key factor to both past and continued success. Consider that improved thermal efficiency at the expense of process availability would be of little value. Every tradeoff must be carefully weighed and considered in terms of life-cycle return on investment. Flashing liquid expanders are somewhat unique in the sense that they offer a method of improved process efficiency while providing little operational downside. As in most cryogenic expander systems, a JT (*Joule Thompson*) valve is provided in parallel to the expander. Thus if the expander drops offline for any reason, the parallel JT valve automatically adjusts as necessary to prevent an overall process shutdown. As overall process downtime is not an issue, an equipment spare is not required, making an expander addition even more viable.

2.0 THERMODYNAMIC PRINCIPLES [1]

In a simple refrigeration vapor-compression cycle, as shown in Figure 1a, the refrigerant is compressed to a pressure where the fluid can be condensed at constant temperature using air, cooling water, or another refrigerant. An ideal compression path as shown in the line from A to B would be isentropic. Of course, in reality one can only approach that path. After condensing, saturated liquid must be returned to its original lower pressure state by some type of expansion process. Most often employed is adiabatic expansion across a valve as shown in the line from C to D. However, pressure drop across a valve is highly irreversible providing no ability to extract work. On the other hand, valves are by far the most common means of expansion due to their simplicity, reliability and relative low cost.

Utilizing an expander in place of an expansion valve provides the ability to return the refrigerant to its original lower pressure state using a more isentropic path, as shown in Figure 1b with the line from C to D'. Again, in reality one can only approach that path. Energy recovered from the fluid can be used elsewhere. In addition, a fluid exiting an expander (D') is much closer to the phase envelope than a corresponding fluid at the outlet of an adiabatic valve (D), as shown by comparing Figures 1a and b. Thus, a fluid exiting an expander contains a comparatively higher percentage of liquid and a corresponding lower percentage of vapor. These facts are important for consideration of flashing liquid expanders following discussion.

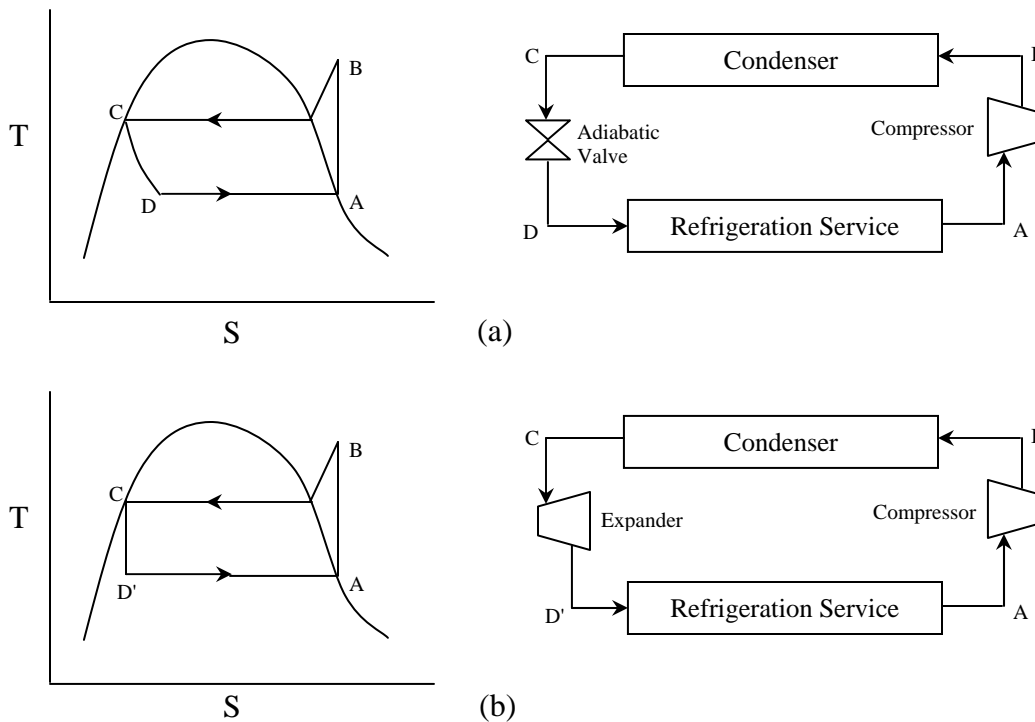


Figure 1 “Ideal” Vapor-Compression Refrigeration Cycles [1]

3.0 LIQUID EXPANDERS IN THE OPTIMIZED CASCADE LNG PROCESS

Although not the simple vapor-compression cycle shown in Figures 1a and b, the thermodynamic principles remain the same for including flashing liquid expanders in the Phillips Optimized Cascade LNG Process (POCLP). In the methane refrigeration system, successive flashes are utilized to lower a saturated or slightly subcooled LNG stream from 40 bara or greater to near atmospheric pressure. In the open cycle methane system, typically employed in the POCLP, recovered LNG liquids are continuously yielded while making up with feed. The flash vapors are compressed and recycled to the process, with a portion typically used as fuel. Thus one or more expanders employed in the successive flash stages provides i) a means of recovering otherwise lost energy, alternatively used to assist with compression requirements, ii) a higher percentage of recovered LNG, and iii) a lower percentage of vapor, directly resulting in lower vapor recompression requirements.

Expander/compressor cycles may be employed in a variety of configurations within the Phillips Optimized Cascade LNG Process. Figure 2 represents one embodiment set forth in a patent issued to Phillips Petroleum Company [2], now ConocoPhillips Company. Of course to eliminate overall process downtime, expanders are in placed parallel with expansion valves for both the high and intermediate stages. Recovered energy is utilized to assist with compression requirements for the respective stages.

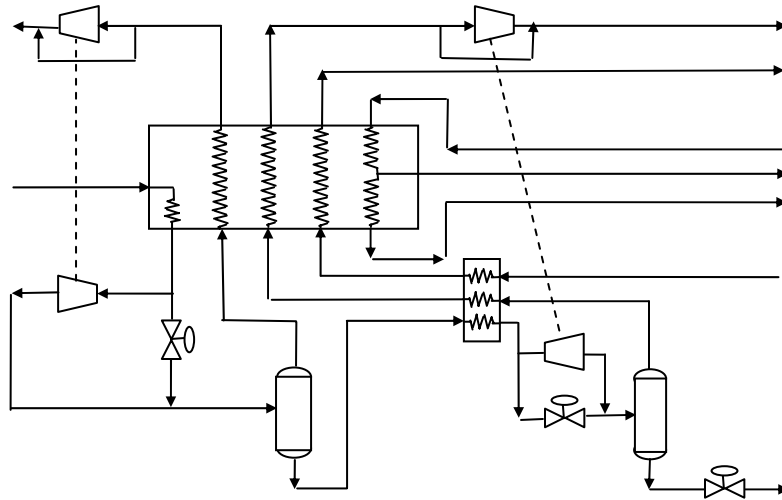


Figure 2. Flashing Liquid Expanders on High & Inter-Stage Compression [2]

For the configuration shown, recovered energy may be directly coupled through mechanical means or indirectly coupled through electrical means. The configuration as presented readily lends itself to either method. Alternatively, generated electricity from recovered energy may be routed to the facility power grid for use elsewhere. For simplicity, other expander/compressor configurations offering similar or less significant improvements are not included for discussion.

4.0 SIMULATION RESULTS OF INCLUDING FLASHING LIQUID EXPANDERS

The effect of adding flashing liquid expanders to the Phillips Optimized Cascade LNG Process is perhaps best illustrated through actual simulation results. The conditions used for simulations are based on a typical facility utilizing the Phillips Optimized Cascade LNG Process.

For comparison purposes, two simulation cases were considered. For the first case, an expander with associated compression utilizing recovered energy was added to the high stage open loop methane system. The second case considered the combined effect of expander/compressor cycles included on both the high and intermediate stages, as presented in Figure 2. In both cases, a conservative adiabatic efficiency of 75% for the expanders was assumed. Additional methane compression availability is realized through i) lower vapor compression requirements and ii) recovered energy from the respective expanders. In order to fully utilize the additional compression availability, the cascaded refrigerant loops (propane, ethylene and open cycle methane) were rebalanced such that no excess power remained in any one refrigerant service. The results of both simulation cases are included in the table below.

Table 1. Results For HS & IS Expander/Compressor Additions

Expander/Compression	LNG Production (% Increase Over Valve)	Overall Thermal Eff. [3] (% Increase Over Valve)
HS Flash	5.04	0.45
HS & IS Flash	6.97	0.61

The optimized results presented in Table 1 clearly indicate that flashing liquid expanders offer significant improvements in efficiency and LNG production. As compared to the results of using adiabatic expansion valves, the simulation results reveal a 0.61 percent increase in overall facility thermal efficiency [3] and a corresponding increase in LNG production of almost 7%.

5.0 EQUIPMENT CONSIDERATIONS

A number of manufacturers offer equipment capable of flashing liquid expander applications. The nature of the equipment available falls into two categories. The first is derived from LNG pump technology and incorporates additional components to extract additional energy from expanding vapors generated during the pressure drop. The second is derived from vapor radial inflow expander technology, and is closely related to dense phase turbo expanders.

The shaft power produced by the expander can be used to drive a number of devices, including centrifugal compressors, electrical generators, or pumps to name a few. A significant decision must be made in deciding how best to integrate the expander and associated recovered energy into the overall process. Consideration must be given to potential consequences of expander trips and associated loss of driven device(s) within the process.

A conservative approach in expander applications is the use of a hydraulic brake to dissipate the energy created by the expander. With this configuration, the only consequences of an expander trip are the loss of efficiency associated with carrying out the flash across an adiabatic JT valve versus the flashing liquid expander. There are no further consequences to the facility associated with the loss of a driven device such as a compressor or generator.

6.0 DEVELOPMENT OPPORTUNITIES

At the time of writing, flashing liquid expanders in the Phillips Optimized Cascade LNG Process are a regular consideration debottlenecking efforts as well as new projects. The authors of this paper are currently aware of only one flashing liquid expander in operation worldwide. Thus, incorporating this equipment will require diligent technical review to ensure that overall facility availability is not compromised. The review would encompass rotordynamics, aerodynamics, impeller materials, erosion resistance due to two-phase flow, as well as special condition monitoring approaches. Thus far, the effort is progressing with promising results.

The specific application under consideration is to increase LNG production by placing flashing liquid expanders in parallel with the high and intermediate stage expansion valves in the open cycle methane circuit. On some projects, piping “stub-outs” were intentionally included in the original design for this future purpose.

For the driven device(s), electrical generation is most often proposed in order to supplement on-site power requirements. As a risk mitigation measure, the use of a hydraulic brake unit is under consideration, allowing the equipment to be proven with minimal upset risk to the facilities. For a debottlenecking project, where integration of recovered energy is not easily accomplished, this may prove the most cost effective as well.

7.0 REFERENCES CITED

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