THE PHILLIPS OPTIMIZED CASCADE LNG PROCESS

A QUARTER CENTURY OF IMPROVEMENTS

by

D. L. Andress

Phillips Petroleum Company

Nineteen ninety-four marked the 25th operating anniversary of the Phillips Petroleum Company LNG plant located at Nikiski, Kenai, Alaska, and nearly two years later the plant continues its exemplary performance. This plant is the first and only base-load liquefied natural gas plant built in the Western Hemisphere solely for LNG export. It uses an early version of the Phillips Optimized Cascade LNG Process for its liquefaction unit and has for the past quarter of a century delivered LNG to its customers, achieving a remarkable record of product delivery. During the past 26+ years the efficiency and throughput capabilities of the Kenai plant have been improved by minor changes in procedures, minor equipment upgrades, and a recently completed efficiency project. Over the same period of time, many other Phillips LNG project studies have led to improvements and further refinements to the liquefaction process employed at Kenai.

INTRODUCTION

The original Optimized Cascade LNG process was developed by Phillips Petroleum Company in the 1960's. The object of this development was to devise a refrigeration cycle that could be utilized in the liquefaction of natural gas that would permit easy startups and smooth operations for a wide range of gas feed volumes and compositions.

Using these criteria as design parameters, computer programs were developed to calculate the total process requirements for a cascade cycle system utilizing propane, ethylene, and methane as the refrigerants. Propane was chosen because it is available in quantity world-wide; ethylene because it would condense methane at a refrigerant pressure above atmospheric pressure and could in turn be condensed by propane; and methane because it is available in the natural gas stream. Applying the computer programs, models were created to optimize the cycle. These models determined the optimal liquefaction train configuration to maximize production yields of LNG.

PHILLIPS CRYOGENIC-LNG EXPERIENCE

Shortly after its founding, Phillips Petroleum Company became a leader in the gas industry, pioneering many developments in gas and gas liquids technology. In the mid 1920s it became the largest producer of natural gas liquids in the U.S.A., a position it maintains today. Phillips has been active in cryogenic gas processing for over 30 years. In this time period the company has designed, built and operated many types of cryogenic facilities such as helium recovery plants, cryogenic NGL plants, ethylene plants, hydrogen purification systems and Kenai LNG plant. During these years, Phillips' technologists have expanded the company's cryogenic expertise through the development of these systems.

Republished with the permission of the Institute of Gas Technology

For 26+ years, Phillips has operated a complete LNG production system. Specific to LNG production operations, Phillips has developed and operated the following: an offshore gas field with its associated gas production facilities; the gas transportation system from the offshore field to the plant; the liquefaction plant; and the storage and LNG loading facilities.

THE KENAI LNG PROJECT

Project Overview

The Kenai LNG project has its origins in the discovery of large natural gas fields in the Cook Inlet Area of Alaska by Marathon Oil Company, Phillips Petroleum Company, and others in the late 1950s and the early 1960s. At about the same time, Tokyo Gas Co., Ltd., and the Tokyo Electric Power Company, Inc., came to the realization that the utilization of LNG might help alleviate Japan's air pollution problems, while at the same time providing a needed energy supply to their county. After the offering of various proposals and a period of negotiations, an agreement was reached whereby Phillips and Marathon would jointly participate in the export of liquefied natural gas to Japan.

In 1967, an LNG sales agreement was signed with Phillips and Marathon as sellers and the two Tokyo utilities as buyers. The original sales contract was for 15 years with an extension option for an additional five years. This was the initial step in a project that was, at the time, the world's largest LNG project. In addition, it was the largest project of any kind in either Phillips' or Marathon's history.

The ownership of the project is split between the two companies on a 70/30 basis: Phillips has the 70% share interest and the responsibility for the operation of the Kenai gas liquefaction facilities; Marathon has the 30% share interest and the responsibility for the operation of the two LNG tankers. Both companies participate in the marketing negotiations with the Japanese LNG buyers. Each company is responsible for its respective share of the feed gas to the plant. The joint Phillips/Marathon operation of the project for more than 26 years along with the excellent seller/buyer relationship with the two Japanese utilities for the same period exemplifies a win/win relationship. An environment of mutual respect and trust among all parties in the project has developed over the project's life.

Liquefaction Process

Kenai LNG Plant uses an early version of the Phillips Optimized Cascade LNG Process. The cryogens used are propane, ethylene, and methane. The plant has a single liquefaction train with parallel gas turbine/compressor sets on each refrigeration circuit. Also a gas turbine driven fuel gas compressor was utilized to compress the flash vapors from storage and loading facilities into the fuel system. Total installed brake horsepower of the compressors was 84,600 (63.1 mW). The original design capacity of the plant was 172.6 million standard cubic feet (~4.9 million standard cubic metres) of gas per stream day delivered aboard ship; this is equivalent to roughly 49,000 barrels (~7800 cubic metres of liquid) per day of LNG, as shown in Table 1.

Kenai Plant Capacity at Startup

	Plant Tailgate Capacity (24-Hour Average)	Each Kenai LNG Storage Tank	Polar Alaska Tanker Capacity
Trillion Btu	0.174	0.8	1.6
Million CF/day	173	800	1600
Barrels	49,000	225,000	450,000
Million cu m (gas)	4.9	23	45
Cu m (liquids)	7800	36,000	72,000
Tonnes Equivalent	3300	15,000	30,000

Table 1

Plant Capacity Increases

Kenai plant production capacity was increased during the mid-1970s, when it was thought that LNG sales could be made to the West Coast. The plant capacity was increased to 200 million standard cubic feet (~5.6 million standard cubic meters) per day LNG equivalent by replacing the propane compressor rotors and enlarging the propane condensers, as shown in Table 2. This incremental volume was to be delivered to Northwest Natural Gas Company. However, this sale never materialized.

Kenai Plant Capacity in the Mid 1970s

	Plant Tailgate Capacity (24-Hour Average)	Each Kenai LNG Storage Tank	Polar Alaska Tanker Capacity
Trillion Btu	0.2	0.8	1.6
Million CF/day	200	800	1600
Barrels	57,000	225,000	450,000
Million cu m (gas)	5.6	23	45
Cu m (liquids)	9100	36,000	72,000
Tonnes Equivalent	3800	15,000	30,000

Table 2

By 1989, at the conclusion of the extension of the original Kenai gas supply contract a new contract with the Japanese buyers was successfully negotiated. This contract requires the delivery of gas from Kenai to Japan through the year 2004, with another option for extension through the year 2009. The new contract also specified that the annual contract delivery quantities were to be increased through the 1990's. To meet this demand modifications at the plant to remove bottlenecks in the production process were required. Also new, larger ships were to be utilized. In 1990, a series of plant tests and studies to define the modifications required were initiated. These tests and studies provided several options to be considered.

The optimum combinations of plant modifications selected were:

- Install an auxiliary fuel gas compressor
- Install two new cooling tower cells
- Install a larger vapor blower
- Minor upgrade and modifications, i.e., fan blades, control valve trim, etc.

These various modifications were implemented over a two year period, completion being achieved during the early summer of 1993. In August, 1993, a full scale plant test was conducted at Kenai plant to confirm that the efficiency project objectives were met. The new plant capacity based on the results of the plant test is presented in Table 3.

Kenai Plant Capacity in 1994

	Plant Tailgate Capacity (24-Hour Average)	Each Kenai LNG Storage Tank	Polar Eagle Tanker Capacity
Trillion Btu	0.22	0.8	2
Million CF/day	220	800	2000
Barrels	64,000	225,000	550,000
Million cu m (gas)	6.2	23	55
Cu m (liquids)	9900	36,000	88,000
Tonnes Equivalent	4299	15,000	3700

Table 3

So, over the years the plant has had its capacity increased from the initial LNG production volume of 172.6 million standard cubic feet (~4.9 million standard cubic metres) per day LNG equivalent to today's 220+ million standard cubic feet (~6.2 million standard cubic metres) per day LNG equivalent. An approximate 28% increase in LNG production capacity has been achieved by simply debottlenecking the plant at various times and with no modification to the cryogenic section of the liquefaction train.

THE PHILLIPS OPTIMIZED CASCADE LNG PROCESS - 1996

Over the past quarter of a century, many improvements to the Phillips Optimized Cascade LNG Process have been made. One change that has been incorporated in the LNG process over the years is the modification of the methane refrigerant circuit such that it is now an open circuit or a feed-flash system rather than the original closed circuit as used at Kenai. The major advantage of this modification is that it eliminates the separate fuel gas compressor. Also storage vapors and vapors from tanker loading are recovered and fed back to the liquefaction train and reliquefied rather than being routed directly to fuel or flare, thereby increasing LNG production (see Figure 1).

Other modifications to the basic Kenai plant configuration that could be considered are the replacement of the dual gas turbines/compressors used on each refrigerant, as at Kenai, with a single gas turbine/compressor on each refrigerant, particularly if two or more liquefaction trains are to be installed at the site. Also, if the feed gas has significant amounts of C2+ hydrocarbons a hydrocarbon liquid draw system would be included. There are still other modifications that can be incorporated in the Phillips Optimized Cascade LNG Process that would increase its operational effectiveness in LNG production.

Over the years since 1969 LNG projects have been studied from the original Kenai plant size of 1.2 million metric tons of LNG production per liquefaction train per year to 3.5 million metric tons of LNG production per liquefaction train per year. With the Phillips Optimized Cascade LNG Process very large LNG trains can be constructed due to the manner in which the liquefaction trains can be configured using plate-fin type heat exchangers.

Phillips Optimized Cascade LNG Process
Process Schematic

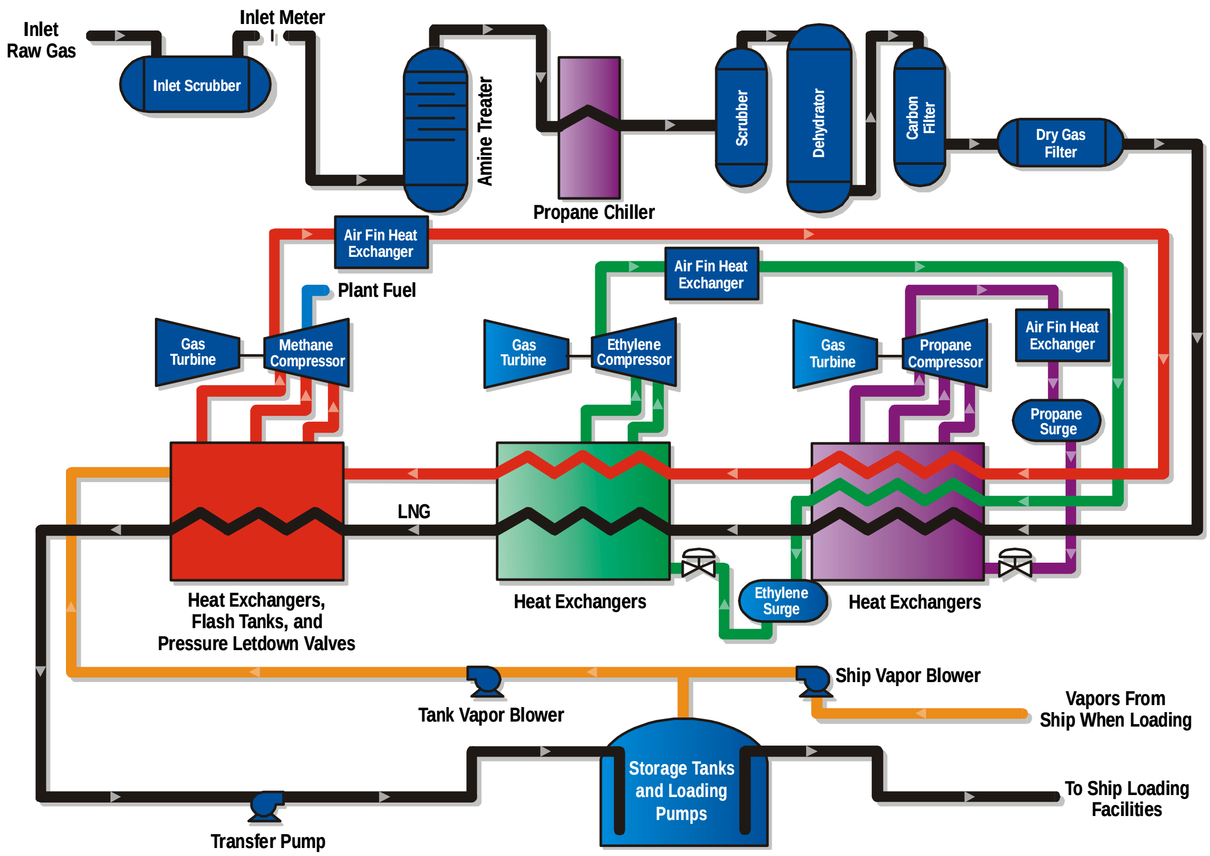

Figure 1

Special Features of the Phillips Optimized Cascade LNG Process

Among the special features of the Phillips Optimized Cascade LNG Process are:

1. PRODUCTION FLEXIBILITY. As the composition of feed gas changes, withdrawal points for optimum production of LNG and NGL change. Multiple-stage processing lends itself to making withdrawals as necessary to minimize the cost of producing NGL products.

2. NITROGEN REMOVAL. Removal of nitrogen from the feed gas minimizes the power requirements per million Btu of product and lowers marine transportation costs. Nitrogen is removed in a unique rejection scheme. Also, fuel is provided in a manner that eliminates the need for a separate fuel gas compressor.

3. VAPOR RECOVERY. Storage tank vapor is returned to the methane refrigeration system to recover both the vapor and its refrigeration. No special equipment other than a vapor blower is required to recover the vapor and its refrigeration since the vapor is processed through existing liquefaction equipment.

4. RATE FLEXIBILITY. Liquefaction unit operation is possible over a range of near zero to one hundred percent of capacity. Recycle capability is designed into the compressors to permit operation completely independent of actual feed gas load. Heat exchangers operate smoothly at all load levels. This allows smooth operation of the total plant during start-up, shutdown and periods of reduced throughput.

5. MINIMAL SPACE REQUIREMENTS. Compact plate-fin type heat exchangers are used extensively in this process. The use of this type of equipment allows construction of a compact, easily modularized plant.

6. EASE OF OPERATION. The process utilizes pure component refrigerants of essentially constant molecular weight. This fact greatly simplifies the operation of the compression systems[)]. Considering the basic liquefaction plant, this point is well expressed in the words of a former Kenai Plant Operations Superintendent, who said, “It’s the simplest operating design in the world”.

ACKNOWLEDGMENTS

The author expresses his appreciation to Ellen Inman and Linda Odum for typing and editorial assistance and to the management of Phillips Petroleum Company for permission to present this paper.

REFERENCES

1. "Alaska Still the New Frontier for Energy Development," Philnews, November, 1982, pp 8-12.

2. Barber, H. W., et al., "Current LNG Technology," Proceedings of Fiftieth Annual Convention of Natural Gas Processors Association, 1976, pp 92-97.

3. Barber, H. W., et al., "Optimized Cascade Process Works Well for LNG Plants," Oil & Gas Journal, April 17, 1972, pp 86-94.

4. "The Big Look in Alaska," Philnews, April, 1969, pp 16-20.

5. Culbertson, L., et al., "Liquefaction Plant Experience at Kenai," paper presented at the 3rd International Conference and Exhibition on Liquefied Natural Gas, Washington, D.C., September 24-8, 1972.

6. Harper, E. A., et al., "Trouble Free LNG," Chem. Eng. Progr, 71, 11 (November 1975), pp 75-9.

7. Horn, John, et al., "Alaska to Japan LNG Project - Kenai Revisited," paper presented at the 4th International Conference and Exhibition on Liquefied Natural Gas, Algiers, Algeria, June 24-27, 1974.

8. Phillips Petroleum Company, Kenai Liquefied Natural Gas Operations, Bartlesville, Oklahoma: Phillips Petroleum Company, First Edition, n.d.

9. Phillips Petroleum Company, Kenai Liquefied Natural Gas Operations, Bartlesville, Oklahoma: Phillips Petroleum Company, Second Edition, n.d.

10. Phillips Petroleum Company, "LNG Showpiece After 20, Years of Operation," Performance, May/June, 1990, Number 103, pp 19-20.

11. Krusen, L. C., "Propane Refrigeration System Upgrades at the Kenai LNG Plant," paper presented at the 10th International Conference on Liquefied Natural Gas, Kuala Lumpur, Malaysia, May 25-28, 1992.

12. Phillips Petroleum Company, Liquid Natural Gas, Bartlesville, Oklahoma: Phillips Petroleum Company, n.d.

13. Phillips Petroleum Company, Liquefied Natural Gas, Bartlesville, Oklahoma: Phillips Petroleum Company, n.d.

14. Phillips Petroleum Company, Phillips Optimized Cascade Cycle for Liquefaction of Natural Gas, 1993.

15. Phillips Petroleum Company, Phillips Optimized Cascade LNG Process, Bartlesville, Oklahoma: Phillips Petroleum Company, n.d.

16. Krusen, L.C., "The Kenai LNG Plant Efficiency Project: Making A Good Thing Even Better", paper prepared for LNG 11, Birmingham, England, July 3-6, 1995.