Thermodynamics Design Project: Fall 2010
Liquefication of Natural Gas

1 Introduction

Nautral gas is composed primarily of methane and other light hydrocarbons, is a source of energy widely used in the United States and around the globe for the heating of homes, electricity generation and as a fuel for fleet vehcicles. Natural gas is the cleanest fossil fuel, making it attractive even though it has a lower energy density that oil or coal.

Natural gas is usually transported in gas form over land via pipeline. For transport between continents, or other areas that are not served by pipelines, natural gas is liquified to reduce its volume by a factor of 600, and transported in specially designed ships. Liquified Natural Gas (LNG) accounts for approximately 7% of the world's demand for natural gas, with Japan, Korea and Taiwan the major importers.

Liquefaction of natural gas requires cooling to the boiling point of methane $T = -162$ C at 1 atm. Over the last 40 years, a number of processes have been developed for the liquefaction of natural gas: Phillips Optimized Cascade, APCI mixed refrigerant process, Statoil/Linde mixed fluid cascade, and Axens Liquefin. Because of the large amount of LNG processed every year, small improvements in energy efficiency can yield sizable cost savings.

Figure 1: Qatar natural gas liquefaction facility. Image from: http://energyview.com.au

This project consists of two major components. In the first, groups are to solve the material and energy balances for the included reference case. After successfully completing this assignment, groups are to develop an improved process where energy consumption is minimized. The process must be capable of producing 5.0 MTPA (million tons per annum) of LNG.

To aid in the writing of the report, it is suggested that students obtain a copy of "Writing Style and Standards in Undergraduate Reports," by Sheldon Jeter and Jeffrey Donnell, ISBN 0-9679121-7-2. This text is required for the lab courses ChE 3220 and ChE 3820.

2 Reference Design: Cascade Refrigerant Cycle

In the 1960s, Phillips Petroleum (now ConocoPhillips) developed the "optimized cascade process," Figure 2, for the liquefaction of natural gas produced in Alaska so that it could be transported to Japan. The cascade process is one of the oldest methods for producing LNG, and is still in use at various facilities around the globe. It was designed as a robust, failure tolerant system that would allow for smooth operations over the course of many years.

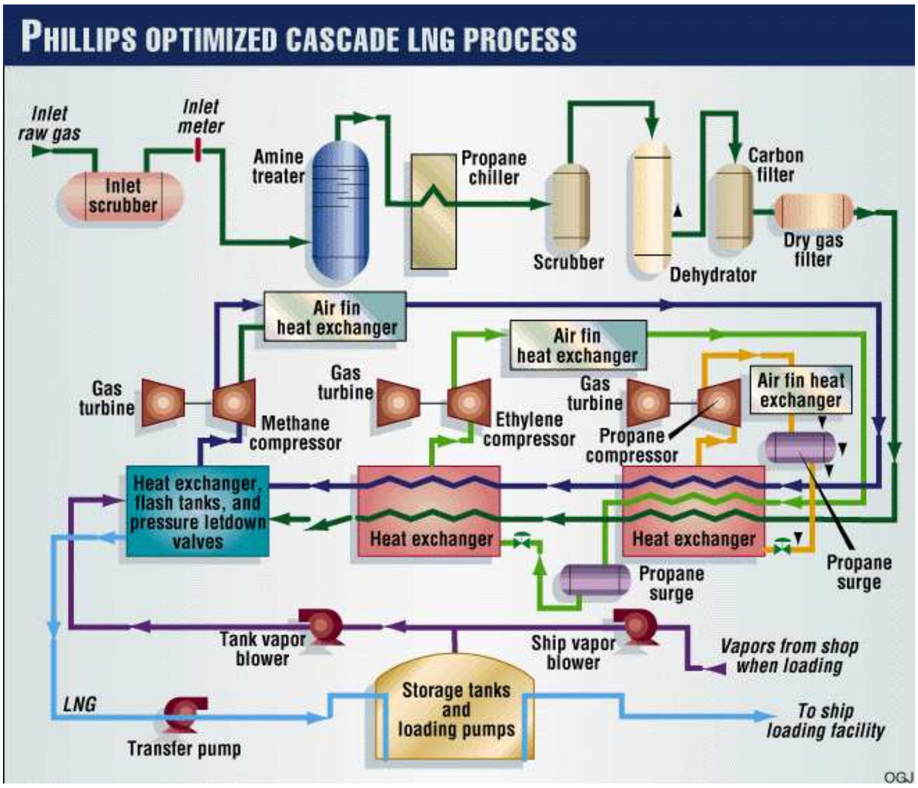

Figure 2: Phillips Optimized Cascade Process. Image from: http://ogj.com

In this process, natural gas is cooled to -162 C and condensed by undergoing heat exchange with propane, ethylene and methane in three distinct stages. The use of multiple stages is necessary to reach the temperatures required to liquefy natural gas. Propane is used in the outer-most loop because it is widely available at low-cost. Other fluids could, perhaps, be substituted with similar performace. Ethylene is used because it is able to condense methane at pressures above 1 atm and can be condensed by propane. Methane is used in the inner-most refrigeration cycle because it is available as part of the natural gas stream.

2.1 Base Case

For the base case solution, your group will solve the material and energy balances for a simplified version of the Phillips optimized cascade. The relevant details of the process are shown in Figure 2.1. The efficiencies of each compressor is 85%. Natural gas enters the process at 20 C, 1 atm (gas) and leaves at -162 C, 1 atm (liquid). The production rate of LNG is 5.0 MTPA.

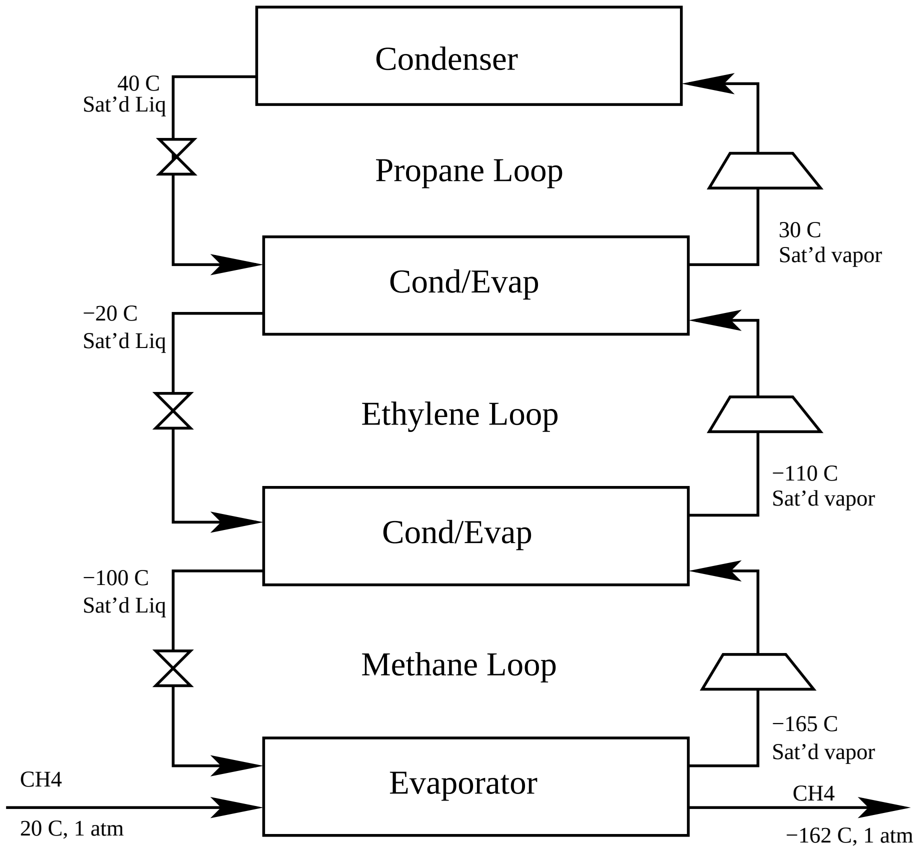

Figure 3: Base Case: simplified cascade process.

3 Optimal Design

In this section of the project, groups are expected to devise improved designs of the LNG process that will result in significantly reduced energy requirements. At a minimum, groups should consider recycling/reuse of process streams (both mass and energy), and the use of "economizers." Students may also propose entirely new designs, but such designs must be supported with rigorous material and energy balances. Students are expected to critically evaluate a minimum of 2 additional designs. Detailed calculations must be performed and presented in the final report for each design.

3.1 Grading

1. 70% technical content, 30% written report.
2. Complete solution of the reference case is necessary for a passing grade on this assignment.
3. Spelling and/or grammatical errors will result in a 2% reduction in grade per error.
4. Expectations for specific aspects of the report can be found in the included report grading rubric.

4 Deliverables

1. **DUE 10/27/2010**: 50% of project grade (35% technical content, 15% report): Completed the reference design, which includes:
   (a) A clearly labeled process flow diagram.
   (b) A table listing all process flow rates (kg/h), with labels consistent with the process flow diagram.
   (c) A 1-2 page description of all assumptions made and methods used for calculations.
   (d) An organized and complete set of calculations. These may be done by hand or in Excel or MathCAD.
   (e) Students are to submit their work electronically via Blackboard, and on paper at the beginning of class on 10/27/2010.
   (f) Late projects will receive a grade reduction of 5% per day.
2. **DUE 11/23/2010**: 50% of project grade (35% technical content, 15% report): Final report. Length of text and figures in the body of the report is restricted to 15 pages. The report consists of:
   (a) Abstract
      - A summary of your most important results.
   (b) Introduction

- State the problem to be solved in your own words. Should be at least 1/2 page.

(c) Results and discussion

i. Results are to be presented as tables or graphs.

ii. Text will describe methods used to calculate each quantity and any assumptions that were made.

iii. Discussion is used to explain results. Why was a particular design chosen? What are the pros and cons?

(d) Conclusions

(e) References

- References include the source of any equations used, cost data, graphics or pictures not created by you.

(f) Process flow diagrams and process description

(g) Numerical calculations

(h) HYSYS simulation

Table 1: Report grading rubric

Criteria	Exemplary	Proficient	Marginal	Unacceptable
Description of problem	Concisely presents the goals and constraints of the project.	Has the major elements of the project goals but may be missing minor details.	Present, but is vague, or fails to concisely report the technical purpose of the project.	Missing or poorly written by the author.
Solution to problem	Describes a complete solution to the problem, including a recommendation to build or not build. Summarizes major points to be covered in detail in the body of the report.	Mostly describes a solution that meets the requirements but is missing some information	Present, but is vague. Leaves the reader unclear about what the final solution is, or how it would be implemented.	Missing, or fails to discuss what was designed.
Pros and cons of alternative design schemes.	Describes in detail the pros and cons of various methods, and the reason the optimal design was chosen. References to external sources are made when appropriate.	Describes pros and cons of various methods, but may lack justification or references for certain decisions.	Misses large technical categories that should have been considered. Limited references to external sources, or poorly organized.	Missing or lacking all references. Pros and cons of alternative processes not discussed.
Process description	Completely describes the flow of energy and materials through the process. Flow rates and important temperatures and pressures for all streams and equipment are tabulated and referenced on the process flow diagram. Refers to appendices for supporting calculations.	Describes process flow diagram, but minor pieces of information are missing. Has a logical description of how materials move through the process.	Present, but does not include many flow rates or streams. Description does not match stream tables or process flow diagram.	Missing, or does not match the process flow diagram and stream table. Does not refer to appendices for calculations. Devoid of logical flow.
Process flow diagram (PFD)	All equipment and streams are clearly and properly labeled. PFD is consistent with the stream table.	PFD contains minor errors in labeling.	PFD is missing labels or is confused.	PFD contains major errors, or is inconsistent with the stream table.

Table 2: Report grading rubric

Criteria	Exemplary	Proficient	Marginal	Unacceptable
Stream table	Stream table is logically organized and matches PFD. Temperature, pressure, and flow rate information is present. Units are listed clearly in all cases.	Stream table similar to the exemplary case, but has minor errors.	Stream table contains significant relevant information, but is missing key data or illogically organized.	Stream table is missing, units not clear, does not match PFD, or is poorly organized.
Raw material and utility requirements	Lists all raw materials that enter the process, including water and air. Has units and sources listed for all materials.	List most of the materials, but many not match some of the other report information, such as the PFD or stream table.	No units and does not list sources. May be missing some utilities or does not match appendices.	Missing, does not refer to appendices, no units and does not reflect other information in report.
Economic Analysis	Reports overall equipment costs, utility costs and raw materials. Gives yes/no recommendation on the project. Sensitivity analysis is performed on major inputs to the process. Sources of cost information are listed.	Missing some categories, but all major costs are still included. Sensitivity analysis is performed on 1-2 major items. Gives a yes/no recommendation on the project.	Leaves out many details or is simply a “data dump”. Fails to give a recommendation of yes or no.	Is missing or does not convey enough information to make an informed go, no-go decision.
Appendices	Organized in separate sections, references are made for calculations. Typical ChE student could reproduce all results from the data presented. Calculations are clear with no missing steps.	Meets most of the exemplary criteria. Some minor steps in calculations left out.	Present, but lacking organization and or missing references. Major parts of calculations left out. Difficult for a classmate to reproduce. May be missing some major sections.	Totally unorganized or illegible.
Assumptions	Lists all major assumptions used in the design process with references to support them.	List most major assumptions with a few references to support claims.	A partial list of major assumptions but may be missing references.	Missing.
References	Includes all relevant references in correct format and referred to in the appropriate sections in the text.	Some minor problems with format or use in the text.	Many errors.	Missing or not referenced in the text at all.

Table 3: Report grading rubric

Criteria	Exemplary	Proficient	Marginal	Unacceptable
Detailed calculations	Calculations are thorough, legible, organized in a logical fashion and contain references for formulas. A reader familiar with the process would be able to quickly spot mistakes and could reproduce all of the work presented. All intermediate numbers are supported by referenced data.	Some detail is missing from the exemplary case or equations can be followed with difficulty.	Present, but missing so much detail that they cannot be independently verified.	Missing, completely disorganized, no units and irreproducible.
Grammar	No typographical, grammatical or spelling errors.	More that 2 typographical, grammatical or spelling errors.	More than 3 typographical, grammatical or spelling errors.	More than 5 typographical, grammatical or spelling errors.
Presentation	Report is clearly organized, printed on paper of uniform quality with clear, laser printed text. Figures are reproduced clearly. Color figures are printed in color. All pages are numbered consecutively. Report is stapled or held together with a binder clip. Report is not bound.	Minor deviations from the exemplary case. Inkjet printed.	Report contains mismatched paper. Inconsistent use of fonts (size/color). Color figures printed in black and white. Not stapled. Bound or submitted in a folder.	Report is folded, wrinkled, etc. Dirty. No staple or binder clip. Poor print quality.