Title: Thermoacoustic Natural Gas Liquefier

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Thermoacoustic Natural Gas Liquefier

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Abstract

This is the final report of a two-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). This project sought to develop a natural-gas-powered natural-gas liquefier that has absolutely no moving parts and requires no electrical power. It should have high efficiency, remarkable reliability, and low cost. The thermoacoustic natural-gas liquefier (TANGL) is based on our recent invention of the first no-moving-parts cryogenic refrigerator. In short, our invention uses acoustic phenomena to produce refrigeration from heat, with no moving parts. The required apparatus comprises nothing more than heat exchangers and pipes, made of common materials, without exacting tolerances. Its initial experimental success in a small size lead us to propose a more ambitious application: large-energy liquefaction of natural gas, using combustion of natural gas as the energy source. TANGL was designed to be maintenance-free, inexpensive, portable, and environmentally benign.

1. Background and Research Objectives

Scientists at Los Alamos and the National Institute of Standards and Technology (NIST) recently invented the first no-moving-parts cryogenic refrigerator and built a small experimental version directed toward cooling of infrared sensors on satellites. Development of a more compact version proceeded through early 1995 in a Los Alamos-NIST-Tektronix collaboration. The initial success of these small coolers led us to propose a more ambitious application: large-scale liquefaction of natural gas, using combustion of natural gas as the energy source. We sought to develop a natural-gas-powered natural-gas liquefier that has absolutely no moving parts and requires no electrical power. It would have high efficiency, remarkable reliability, and low cost. In the course of this two-year LDRD project, we have successfully designed prototype hardware, built scale-model research hardware, and initiated a cooperative research and development agreement (CRADA) with Cryenco, Inc.

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The thermoacoustic natural-gas liquefier (TANGL) should be maintenance-free, inexpensive, portable, and environmentally benign. It should enable economic recovery of natural gas from wells too remote to justify construction of a gas pipeline. It should also enable routine small-scale, local liquefaction of natural gas as a transportation fuel, such as for fleet vehicles. It may also be useful in offshore gas recovery from sites inaccessible to pipelines, in small-scale recovery of methane from biological waste, in recovery of natural gas entrained in petroleum, and in local liquefaction of natural gas for a variety of purposes.

Natural gas currently provides 25% of America's energy supply, and domestic gas reserves will outlast oil reserves by many decades at current levels of consumption. Consumption averages 60 billion scfd (standard cubic feet per day), with peak winter consumption much higher. Although most natural gas is still carried from well to user as gas in pipelines, the use of liquefied natural gas (LNG) has been increasing 10-15% per year. Large liquefaction plants and cryogenic storage tanks exist throughout the US close to major consumption centers for seasonal peak shaving. In this practice, relatively constant flow of gas through pipelines from the gas fields to load centers can be maintained throughout the year by liquefying and storing the excess when demand is low in summer and regasifying it as needed when demand increases in winter. LNG ocean transport vessels of 100,000 cubic meters capacity are also commonplace, as are attendant coastal LNG facilities. Fleet-vehicle use of LNG as fuel is increasing rapidly. With a liquefaction temperature of only 110 Kelvin, natural gas has (until now) required rather sophisticated refrigeration machinery. A typical modern, large liquefaction plant costs up to a billion dollars, liquefies a billion scfd, uses 15% of its throughput to power itself, and has substantial operating and maintenance costs. The need for reliable, inexpensive liquefaction equipment is clear. Our thermoacoustically driven pulse-tube refrigerator may meet that need.

Our recent invention of the thermoacoustically driven pulse-tube refrigerator follows a long development of related devices, each directed toward elimination of moving parts from heat engines and refrigerators. Stirling-cycle refrigeration, over a century old, has always required two moving pistons, one of which is in contact with the cold temperature. In 1963, Gifford and Longworth discovered a refrigeration technique that eliminated the cold piston. They called this new technique pulse-tube refrigeration. In 1984, Mikulin made a significant fundamental advance, adding a flow impedance; such "orifice" pulse-tube refrigerators, developed largely at NIST-Boulder, now routinely reach 50 K in a single stage. The addition of a bypass valve to the pulse-tube refrigerator, discovered by Zhu, Wu, and Chen in 1990, improved the efficiency significantly. The pulse-tube refrigerator's importance is primarily due to the elimination of the cold piston, a significant simplification leading to high reliability. Until recently, pulse-tube refrigerators still required one moving piston, at ambient

temperature. We have eliminated this last moving part, substituting for it a thermoacoustic engine. Thermoacoustic engines produce pressure oscillation from heat in an acoustic standing wave resonating at the frequency of the desired pressure oscillation. Although thermoacoustic devices were discovered and explained qualitatively a century ago, DOE/BES-sponsored research at Los Alamos has led to quantitative understanding and practical applications. In short, the invention uses acoustic phenomena to produce refrigeration from heat, with no moving parts. The required apparatus comprises nothing more than heat exchangers and pipes, made of common materials, without exacting tolerances.

2. Importance to LANL's Science and Technology Base and National R&D Needs

This project supports Los Alamos core competencies in complex experimentation and measurement as well as theory, modeling, and high-performance computing. It enhances the Laboratory's visibility and ability to respond to initiatives related to liquefied natural gas technology, natural gas production, energy conversion, cryogenics, and acoustics.

3. Scientific Approach and Results to Date

Los Alamos and NIST built the first thermoacoustically driven pulse-tube refrigerator directed toward cooling infrared sensors on satellites. It reached 90 Kelvin and produced 5 Watts of refrigeration at 120 Kelvin, in agreement with our design calculations. A Los Alamos-NIST-Tektronix collaboration from 1992 to 1995 made progress toward development of a much smaller version suitable for routine cooling of cryogenic electronics.

We have now begun developing a much larger version suitable for use in the natural-gas industry. We have designed prototype hardware, built some scale-model research hardware at Los Alamos, initiated a cooperative research and development agreement (CRADA) with Cryenco, Inc. (Denver, CO), and won a contract from DOE Office of Fossil Energy to support the Los Alamos portion of the CRADA.

At Cryenco, a first prototype is under construction, with capacity of 45,000 scfd (i.e., 500 gallon/day, requiring a refrigeration power of about 7 kilowatts), large enough to illuminate all the issues of large-scale TANGL without undue cost, and to demonstrate the liquefaction of 70% of input gas while burning 30%. This size is appropriate for small fleet-vehicle fuel station applications. At Los Alamos, research with the scale model hardware has been completed to anticipate Cryenco's need for science-based information on performance and

to build firmer scientific foundations under the technology so that efficiency may be improved in the future.

We will assist Cryenco with initial testing of the 500 gal/day prototype in Denver, and proceed with scale-model tests at Los Alamos directed toward elimination of the Cryenco prototype's sodium heat pipes, and coiling of its resonator. Later, also with Cryenco, we plan to develop a one-million scfd (10,000 gallon/day) version; this size is appropriate for small well-head and large fleet-vehicle applications. In parallel, we will continue fundamental research on the technology using our scale-model hardware, to build scientific foundations for more efficient future TANGLs.

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