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Author(s): Sue J. Goff, CIT-PO
Greg W. Swift, David L. Garnder,
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Technologies for the Oil and Gas Industry

Sue J. Goff*, Greg W. Swift and David L. Gardner

Abstract

This is the final report of a five-month, Laboratory Directed Research and Development (LDRD) project at Los Alamos National Laboratory (LANL). We performed a preliminary design study to explore the plausibility of using pulse-tube refrigeration to cool instruments in a hot down-hole environment for the oil and gas industry or geothermal industry. We prepared and distributed a report showing that this appears to be a viable technology.

Background and Research Objectives

Electronic instruments are used in the hot, high-pressure environment of drilled wells at depths up to several kilometers where temperatures are over 200 Centigrade and pressures are thousands of pounds per square inch. Using such instruments on drill collars instead of merely in logging tools is one of the most interesting technical challenges of the next generation of drilling equipment. Maintaining such electronics cool enough to operate in this hostile environment will be difficult, especially since even high-temperature superconducting electronics is being considered.

In cryogenic engineering, the orifice pulse-tube refrigerator (OPTR) is the simplest, cheapest, most rugged and reliable low-power cryocooler. The ratio of hot-to-cold temperatures (in absolute temperature units, such as Kelvin) and cooling power of interest in deep drilling are comparable to those routinely achieved with cryogenic OPTRs, so it may be that OPTRs are the coolers of choice downhole.

In this short LDRD project, we performed a preliminary design study of such a cooler, with enough details to begin meaningful discussion of real engineering issues with drilling experts.

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

Well drilling and well logging are vital components of the nation's energy infrastructure. At LANL, geothermal wells and geothermal energy, as well as pulse-tube refrigeration, are important areas of research and development.

*Principal Investigator, e-mail: suegoff@lanl.gov

Scientific Approach and Accomplishments

We performed design calculations for three target design criteria:

1. cooling at 30°C in a 300°C environment,
2. cooling at 75K in a 50°C environment, and
3. cooling at both 75K and 30°C in a 250°C environment.

These specific temperatures were chosen arbitrarily as representative of what is possible. The primary goals were low cost, reliability, and small package diameter. At the end of the study, we concluded that all three designs are promising.

A downhole pulse-tube refrigerator must be supplied with mechanical power and must reject waste heat to the well environment. It seems to us that circulating mud or other fluid pumped from the surface will be available in the most interesting situations (such as logging while drilling), so we assumed use of a hydraulic motor powered by the mud to provide shaft power to the refrigerator, and will assume rejection of waste heat to flowing mud. However, other options are fully compatible with our designs. For example, if electric power or rotary power can be supplied to the unit, then either could provide the shaft power; if no forced mud flow is available to carry away waste heat, then natural convection of the fluid in the hole could be used with some reduction in performance.

In our designs a rotating shaft driven from below at roughly 2400 rpm moves bellows-sealed pistons longitudinally via a wobble plate. The wobble plate is the mechanism used in some torpedo engines, in about half of automobile air-conditioner compressors, and in some hydraulic equipment, so it is a fairly conventional, rugged, reliable, inexpensive technology. Each wobble plate drives 4 pistons at relative phases of 0, 90, 180, and 270 degrees; each of these pistons drives a pulse-tube refrigerator. Four pistons equally spaced in phase is the minimum number yielding smooth torque on the shaft, independent of rotation frequency (recall the large flywheels needed for 1-cylinder and 2-cylinder internal combustion engines). We expect that automobile-engine design practice will serve as an excellent guide for design of our wobble mechanisms with this lubricant.

Helium gas at an average pressure of 40 bar = 580 psia will be the thermodynamic working substance, with the pistons causing pressure oscillations of 0.4 MPa amplitude. The lubricated space around the wobble plates and other bearings will contain gas at the same average pressure, so there will be no average pressure difference across the bellows.

For quantitative calculation of cooling power etc. for a given size, we have relied on our own code, DeltaE, which enjoys widespread use for pulse-tube refrigerator design and analysis.

As of October, 1997, we have no funding to continue this work although we would enjoy building one of these coolers. We are sharing this information freely in the hope that others will be able to build one or improve the design. The summary report, "Downhole Pulse Tube Refrigerators," is available on request.

Publication

Swift, Greg W. and Gardner, David L., "Downhole Pulse Tube Refrigerators," Los Alamos National Laboratory Report LA-UR-97-3985, available on request.