ANALYTICAL MODELS FOR DETERMINING ICE CORE TEMPERATURES

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OBJECTIVE: The Polar Ice Coring Office (PICO), operated by the University of Alaska Fairbanks for the National Science Foundation, is charged with the development and operation of ice coring drills and augers for scientific research. It is believed that ice cores recovered by these devices from Greenland and Antarctica will provide a continuous environmental record of the past several centuries. Scientists are currently analyzing different aspects of the core and the gases trapped in the frozen ice to determine what global climatic conditions were in the past. Recovering these cores from great depths in ice sheets without damage and contamination is the primary objective of PICO.

ENVIRONMENTAL CONSIDERATION: Common to all deep-ice sampling devices to date has been the use of thousands of gallons of drilling fluids, such as diesel fuels, trichloroethylene, fluorocarbons, etc., in a designated pristine environment. Because of environmental concerns and the fact that contamination of the core may interfere with the exact chemical composition of the ice and trapped gases, thereby leading to inaccurate results, the search for an alternative deep ice core drilling fluid is continuing at PICO. We are also aware that new protocols are under discussion that may prohibit the use of conventional drilling fluids, or if allowed, may require the fluids to be pumped out of wells and removed from polar regions -- a very expensive alternative.

HOT-WATER-MECHANICAL DRILL: In response to these concerns, PICO has introduced a conceptual design (Kelley and Koci)[1] for a hot-water-mechanical drill suitable for coring through thick ice caps in less time than it now takes, with hot water acting as the drilling fluid. The internal flow geometry of a hot-water coring drill is shown schematically in Figure 1. A very important factor in this design is to ensure that the heat transmission from hot water to the ice core does not melt and damage the integrity of the core.

ANALYTICAL STUDY: For this reason, in the first phase of this study we have developed analytical solutions to determine the temperature distribution in cylindrical ice cores while they are subjected to different initial and boundary temperatures. The cores are analyzed by three models: (1) an infinite cylinder model; (2) a semi-infinite cylinder model; and (3) a finite cylinder model. We have developed the theories and computer programs for all three models which have been described by Das *et al.*[2]

In the infinite cylinder model only radial heat conduction is considered. In the semi-infinite model, heat flow is assumed radially and from one end of the ice core, e.g., the bottom of the core before the core is broken and extracted. In the finite

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[1]Kelley, J. J. and B. Koci, 1990, "The Polar Ice Coring Office (PICO): Development of Shallow and Deep Ice Coring " The 5th International Conference on Sea Ice and the Okhotskt Sea, Mombetsu, Japan, Conference Proceedings, pp. 129-132.

cylinder model, heat conduction is assumed both radially and axially from both ends. Using these models one can perform parametric studies to determine minimum core sizes that are obtainable for different surface temperatures in thermo-mechanical drills without jeopardizing the interior region of the cores due to excessive heat penetration.

RESULTS: Das *et al.* (1991) have presented results of their computations by taking examples of ice cores of various sizes and calculating their temperatures. Here we present the results of their calculations for a finite cylinder in Figure 2. Among the three models, this one gives the maximum heating effect within the core. Figure 2 presents nondimensional temperature profiles within ice cores subjected to different boundary temperature as time progresses. To demonstrate how one can get meaningful results from these curves, consider an ice core 20 cm (8 in) in diameter and 3 m long, initially at -40°C. Suppose the surface of the core was heated to O°C during drilling due to the conduction of heat from the circulating hot water in the annulus shown in Figure 1. We wish to determine the temperature at a radial location of 8 cm and a height of 1.5 m after 375 seconds of drilling. As described in Das *et al.*, these values correspond to a nondimensional radius 0.8 and a nondimensional time 0.05. Using these two parameters, we read a nondimensional temperature of 0.32 from Figure 2 which yields a temperature of -12.8°C at the desired location. This temperature is well below melting; therefore, the core will retain its structural integrity.

CONCLUSIONS: The methods developed during the first phase of this study can predict the thermal state of ice cores, whereby it can give us upper bounds of the temperatures of hot water in the annulus, so we can exert some control to avoid overheating the core. However, these analytical techniques are based on many simplifying assumptions which are not necessarily valid under actual field conditions. For example, for these theories to apply a constant surface temperature around the core must prevail, which may not be a realistic boundary condition. Therefore, improvements in these modeling techniques are necessary and we are presently working on a general finite element model that can overcome the limitations of the present analytical models.

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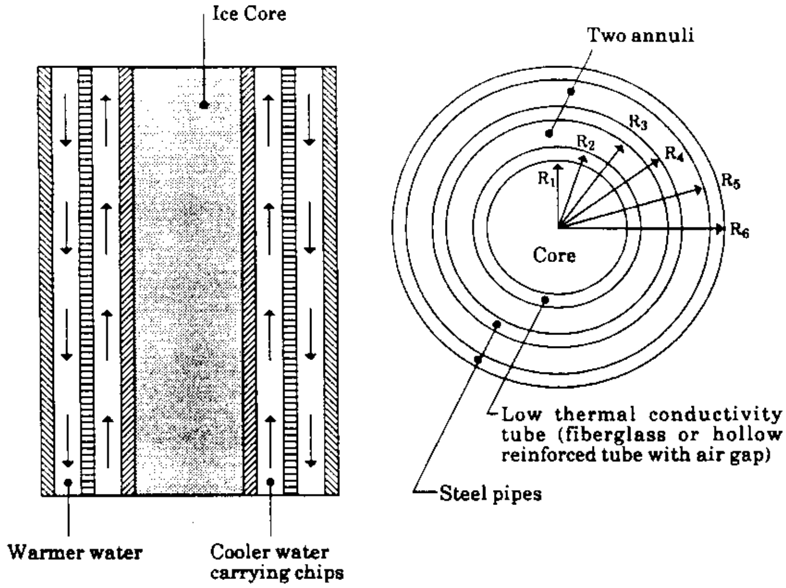

Figure 1. Internal flow geometry of a thermo-mechanical coring drill.

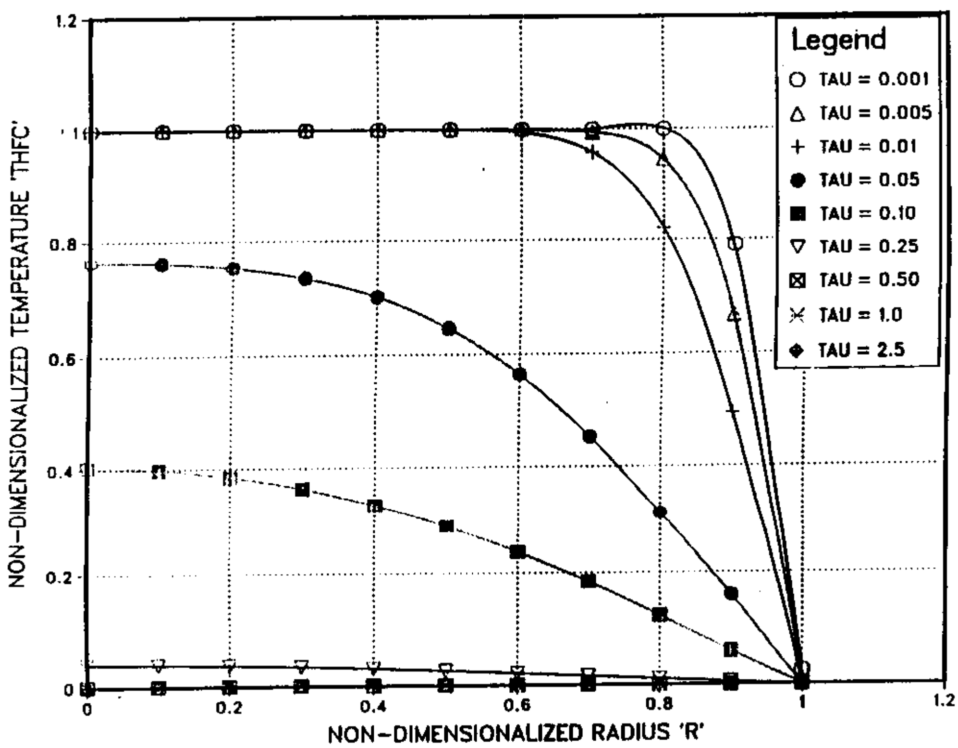

Figure 2. Temperature distribution in finite cylinder. Tau represents nondimensionalized time.