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HEAT TRANSFER IN UNSATURATED, POROUS MEDIA

SUMMARY

During this period, a Christiansen cell has been designed and constructed. A calibration cell has also been designed and constructed. At the present time, the optical components are being configured into the final form to perform experiments. An additional apparatus to study a related configuration is also being designed.

BACKGROUND ON OPTICAL APPROACH

Compared with other measurement methods in the area of heat transfer it is well known that optical measurements possess considerable advantages. First the measurements do not disturb the temperature field, since in most cases the energy absorbed by the medium is small compared to energy exchange by heat transfer. There are also practically no internal errors in the optical methods so that rapidly changing processes can be accurately followed. This advantage arises from the possibility of recording the entire temperature fields on a single photograph. The information obtained from point by point measurement is instead deduced from an evaluation of the photograph. These measurements are frequently of greater sensitivity and accuracy than those using other methods for instance measurement of temperature using thermocouples.

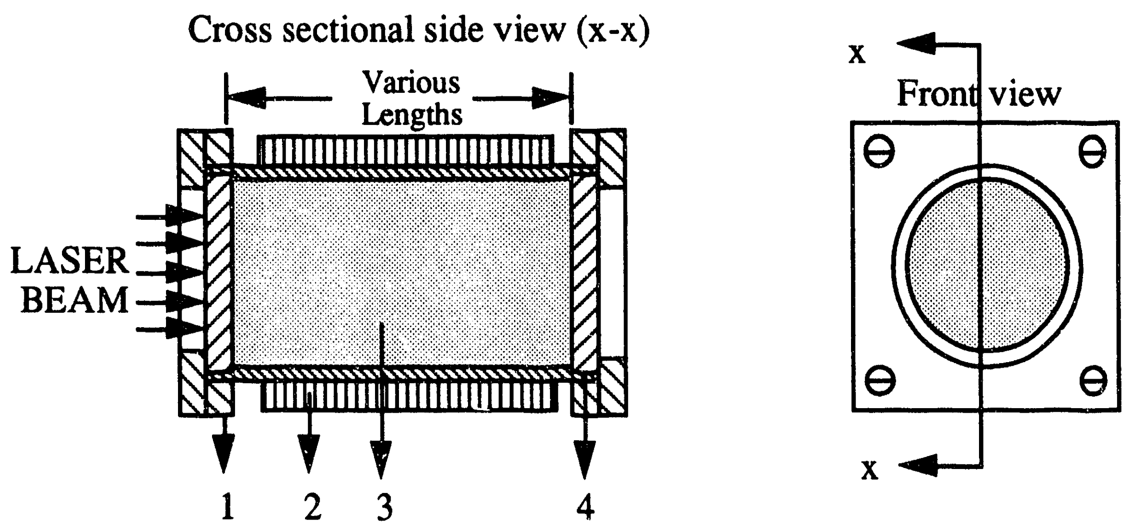
But there are also disadvantages in optical methods. The media under consideration must be transparent to radiation. For media other than ambient air the system must be enclosed. The optical methods basically yield a refractive index which requires subsequent calculation for interpretation as a temperature field. And finally, in order to obtain photographs suitable for accurate evaluation the physical dimensions of the system must be relatively small and, in many cases, two dimensional.

As was outlined in the previous quarterly report, a Christiansen cell is being designed to study heat transfer in unsaturated porous media. The unsaturation occurs because of phase change effects and generation of vapor. In what follows, the details of the work accomplished are summarized.

EXPERIMENTAL APPARATUS

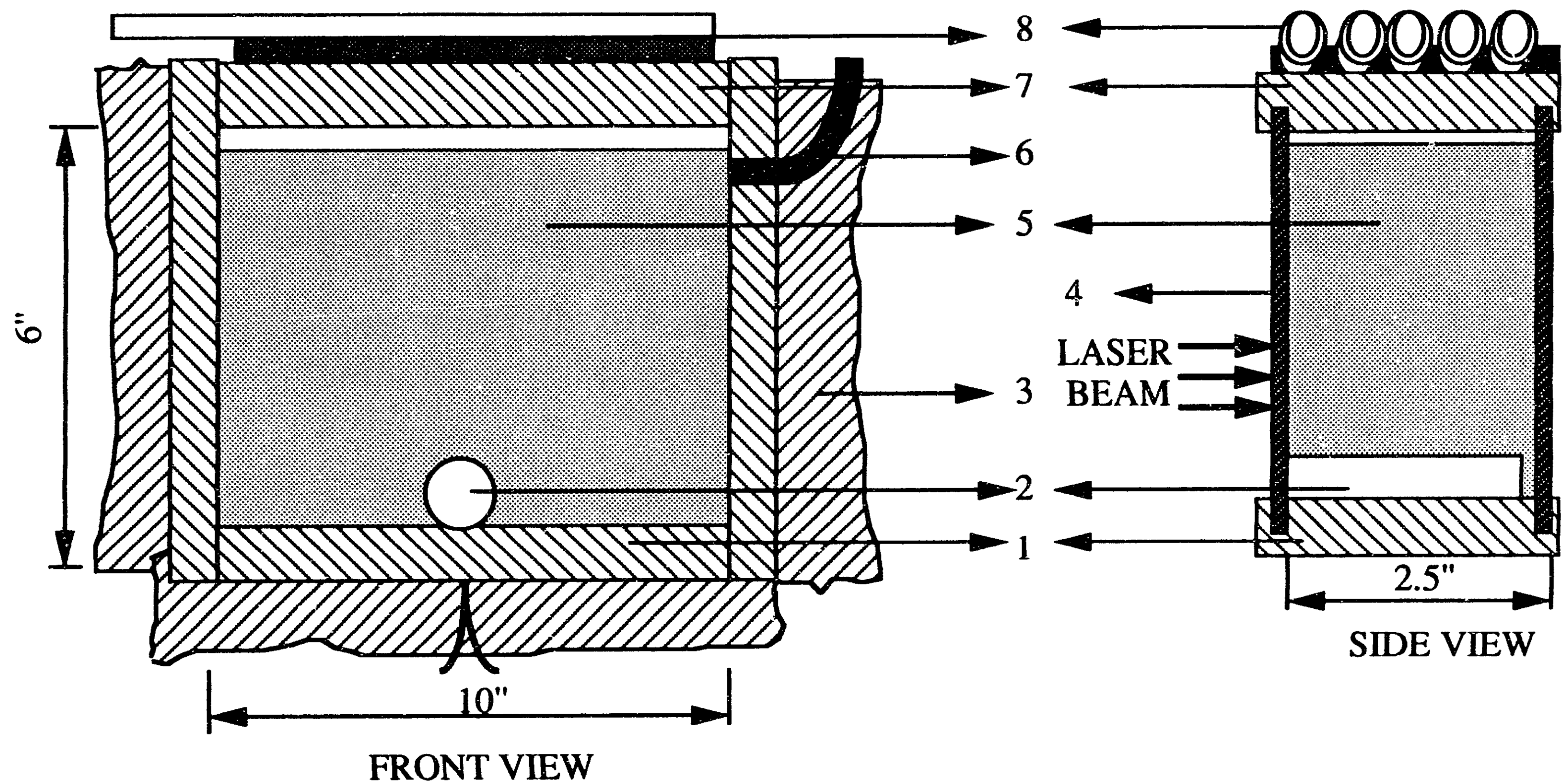
A. Optical Studies

To demonstrate the important parameters of the Christiansen cell, some experimental cells are constructed. A schematic sketch of a calibration cell of variable length is shown in Fig.1. The primary purpose of this cell is to determine the effects of heat transfer through the porous media for different lengths of the cell and the size of the porous media being used in the experiment. The cell lengths chosen are 2 in., 4 in., and 6 in. The diameter of the beads chosen for the experiment are 2 mm., 3 mm. and 10 mm. All of these configurations are heated from the outside by expandable band heaters mounted there. The rated power of the band heaters is 40 W/in^2. This cell is made from 1 in. inner diameter aluminium pipe with both ends of the pipe sealed by sapphire windows.



1) Aluminium end plates welded to the pipe section
2) Expandable mica band heaters
3) Porous media (Soda lime beads & ethyl salicyclate solution)
4) Sapphire windows glued inside the pipe.

Figure 1. The test cell to be used for initial evaluations in its present configuration.



1) Bottom plate - 0.75 in. thick aluminium plate
2) Cartridge heater - 2 in. length, 500 W
3) Thermal insulation
4) Pyrex glass - 0.25 in. thick
5) Soda lime beads in ethyl salicyclate solution - 3 mm beads
6) Overflow valve - To maintain atmospheric pressure.
7) Top plate - 0.75 in. thick aluminium plate
8) Cooling coils soldered on to top plate.

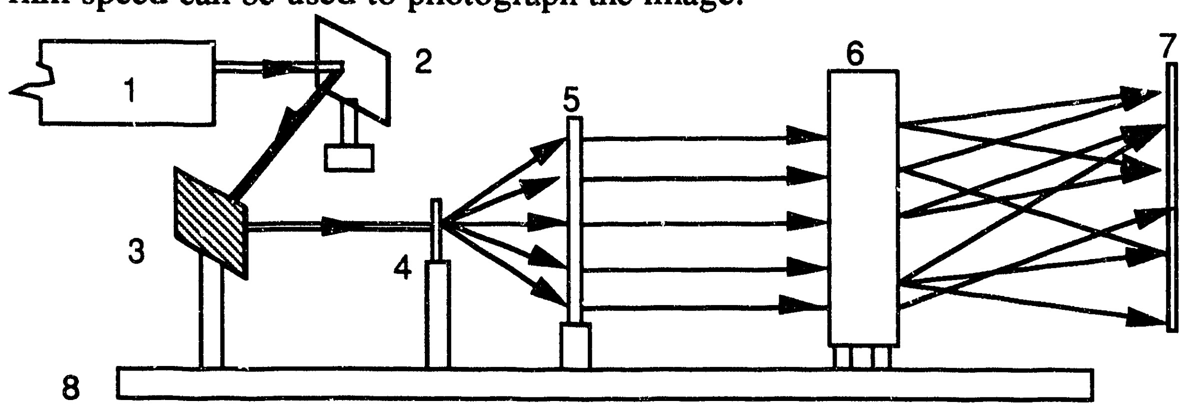
Figure 2. The primary Christiansen cell apparatus to be used in this work.

A schematic sketch of the Christiansen cell is shown in Fig. 2. The cell, whose major components are the top plate, bottom plate, and side walls is designed to permit investigation of heat transfer in fluid saturated porous media heated from below by a uniform volume heat source. To heat the mixture inside the cell, a cartridge electrical heater is used. The selection of the heater plays a major role in determining the dimensions of the cell. To assure the possibility of achieving the boiling point in the assembly in a 2 in. length, a cartridge heater with a rated power of 500 W is chosen. The test section facilitates the use of suitable insulation so that undesirable heat losses are minimized.

The two side walls of the cell are made of Pyrex glass 6 in. high and 10 in. width with 0.25 in. thickness. To reduce heat conduction from the test section the side, the top and bottom plates are to be made of a material of low thermal conductivity. However, in addition the material must resist attack by the organic fluid used at higher temperatures. So, aluminium plates which are 0.75 in. thick are used for the two sides and top and bottom plates. The dimensions of the top and bottom plates are 10 in. x 2.5 in., and dimensions of the side plates are 6 in. x 2.5 in. The top plate is cooled by cold water from a constant temperature circulating bath. The cooling coils are soldered on to the top plate and these circulate cold water (5°C). The organic fluid used is ethyl salicyclate which has an index of refraction of 1.51 at room temperature and a boiling point of 148°C. Soda lime beads are used as the porous medium, the diameter of the beads considered for the experiment is 3 mm. Silicone cement is used to seal all edges to prevent the leakage of the organic fluid from the cell.

An argon ion laser is operated in a multi-wavelength mode, with two dominant wavelengths: 5145 Å (Green) and 4880 Å (Blue). Using the wavelength alternator and carefully tuning the prism table, wavelengths from 5680 Å to 6600 Å can be achieved. These wavelengths are required to track the refractive index of the media in the cell as the temperature of the cell rises. The optical set up is shown in Fig. 3.

The beam coming from the 5 W argon-ion laser is reflected on to the optical rails using a front surface mirror. The reflected light from the front surface mirror is further adjusted to be parallel to the axis of the optical rails using a second mirror. The laser beam which is now parallel with the optical rails is passed through a pinhole to cutoff the extraneous light. The selection of the aperture plays an important role in the quality of the image obtained. Smaller apertures result in a cleaner beam, but there is a tremendous loss of power with smaller apertures. The aperture of the pin hole is selected to be 80 μm (0.003 in). This beam is expanded to 1 in. diameter parallel beam when using the smaller experimental cells and is expanded to 4 in. in diameter for the actual cell. A double convex lens with a focal length of 0.2 m. is used. This expanded beam is allowed to pass through the test section, whereby refraction takes place at different layers in the cell. The angle of refraction of the beam is a function of the refractive index of the media, which is the function of the temperature of the cell. Calibrated thermocouples are used for the temperature measurement and temperature monitoring within the cell. The image of the refracted light from the cell is obtained on a screen. A camera with a very slow film speed can be used to photograph the image.



1) 5 W Ar-Ion Laser
2) Front surface mirror reflecting light off the laser bench
3) Front surface mirror reflecting light parallel to the optical rails
4) Pinhole with 80 μm aperture
5) Double convex lens, focal length 20 cm.
6) Christiansen cell (experimental cell)
7) Ground glass screen
8) Optical rails, 1 m length.

Figure 3. Layout of the optical system used in the present experiment.

B. Related Work

An additional apparatus is currently being conceived that will allow us to study unsaturated flows in thermal fields. This device will be a box filled with granular materials and a heater located in the bottom of the box. The temperature of the heater will be maintained at temperatures above the 100°C. Water will then be allowed to flow into the top in a flow that is quickly started and stopped. Thermocouples and moisture detection devices will be located throughout the porous material, and the output of these devices will be be tracked as function of time.

END

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