EVIDENCE OF STABLE AND REPRODUCIBLE STRUCTURED CONVECTION

INTRODUCTION

Structured convection refers to a family of convection current structures that may be used for controlling heat transfer and mass transport by means described under patent application 08/224,431. Copies are available for research purposes. In simple terms structured convection develops a draw like of a flue, but on a heated or cooled surface without an enclosure. The following is a discussion of temperature recordings made on a full day operation of a structured convection test cell.

The direct demonstration that structured convection is present and stable is the sudden change in the behavior of the cell when the energy storage mass became saturated and the structured current broke down. This is evidenced by an abnormal sharp increase in collector surface and air temperatures and sharp widening of the convection layer near the surface, indicating the onset of normal turbulent convection. The data also indicate the range of conditions in which structured convection was stable and suggests control variables which would extend its range. The test cell is described in some detail as figures 3a, 3b, and 3c in the referenced patent application and in figure A.1 herein. The main components of the cell were a solar collector chamber connected top and bottom to a passive thermal mass chamber, with specially designed control veins at the top of the collector chamber which induce a structured convection current to form over the full area of the heat absorber surface under suitable conditions.

OPERATING CONDITIONS

The day of the recording was a bright sunny Dec 28. The test cell glazing was oriented south at 60° from horizontal and exposed to the sun from about 9:00 AM to about 5:00 PM. The cell was sealed and no mechanical device was used to effect its operation until late afternoon when a fan was turned on to relieve the stagnation that developed when the structured current became unstable and broke down. All energy transfers to that time were the result of passive absorption, conduction, radiation and convection. Temperature records were made with an Esterline 24 point chart recorder making temperature recordings on each point once every 5 minutes, using thermocouples placed in various locations in and around the test cell. Solar gain was calculated by the method of Kreith and Kreider for a 60°F surface oriented south on Dec. 21 in Denver.

DATA ANALYSIS METHODS

The data record was hand digitized with a magnifying glass using a Sumagraphics digitizing tablet with AutoCad, and adjusted for scales. The chart recorder's calibration method included the use of non-liner scale graph paper. The scale distortion is noted in figure A.2 but not otherwise incorporated in this analysis. Software developed for general application to time-series data (CURVE) was used to calculate temperature differences and to construct centroid derivative curves from the sequential differences between data points. The curves presented display various patterns of temperature change that the reader may evaluate in conjunction with their knowledge of the basic relationships of heat transfer. A mathematical analysis of the heat transfer coefficients is not presented here because of having only imprecise measurements for the solar gain and thermal storage capacity, and because of having only single point measures for the distributed field variables involved.

SUMMARY OF OBSERVATIONS

It can not be too heavily emphasized that the basic questions regarding structured convection are far more easily answered by direct physical observation of air currents than by the analysis of temperature data.   Unfortunately these simple physical observations are quite difficult to record. What is found by physical observation of smoke tracers is an air mass that drifts slowly and steadily toward the absorber surface where small parcels of air suddenly dart into the surface and are then drawn up and out of the collector within a rapidly moving surface current, on the order of 1/4" thick, traveling at a rate of ~15 ft/sec.   These conditions are found uniformly throughout the collector space and over the full absorber surface, with minor exception in edge conditions. What is convincing by physical observation is that the collector air mass is definitively calm, and that the rising surface current does not mix turbulently with the collector air mass, even at the top.

Figures A.2 to A.6 show the temperatures recorded. Three periods of operation are labeled:

Period I. A 41/2 hr period showing structured convection in operation

Period II. A 30 min anomaly starting at about 1:40 PM during which structured convection appears to have collapsed

Period III. The remainder of the day.

Some of the events and relationships observed could not reasonably have occurred without there being a confined convection current near the absorber surface with a highly organized state.   This evidence principally concerns the following:

1) The sudden increase in collector temperature in the mid-afternoon.
2) The 120°F/in temperature gradient near the surface and 4°F/in gradient between 1/2” and 3” from the surface until mid-plot

the surface to 80°F/in and rise to 16°F/in in the next three inches

3) The temperature in the collector space being nearly constant while other temperatures follow the trends of solar gain.
4) The temperature in the middle of the storage mass rising significantly higher than the temperature in the middle of the collector.

DISCUSSION

Some additional notes on these and other subjects are incorporated into the figures. Particular attention is paid to the thermal anomaly that appears in the middle of the afternoon. During this anomaly the absorber surface temperature, collector air space and top storage temperatures rise sharply, and the temperatures in the middle and bottom of the storage mass decline. The temperature at the top of the storage mass increases almost as much as the collector space air temperature. The conclusion one has to draw is that the storage is still open to the collector space, but that convective heat transfer has dramatically decreased. Considering that the storage mass had actually been warmer than the collector space for over an hour when the anomaly began, as shown in figure A.3, a stalling of convection should have been expected long before. However, it didn't happen for an extended period and then happened suddenly.

If the stalling of structured convection in period II had to do with some fundamental instability of the phenomenon it is not apparent from the stable temperatures and temperature gradients during period I, as shown in figures A.4 and A.5. Further insight into what occurred is found in figures A.6. Here the rate of change of temperature in the storage mass is compared to the rate of energy input from the sun. The derivative curve of temperature should be directly proportional to the rate of energy gain, and serves as a relative (not absolute) measure of the overall system efficiency. If the collector has a constant rate of efficiency, the derivative of the storage temperature would have exactly matched the shape of the solar gain. What is observed is that the rate of change of temperature in storage was declining sharply just before the thermal anomaly. This suggests what directly caused the collapse of the structured convection, the reduced extraction efficiency by the thermal mass. It also shows that structured convection was stable in a wide range

CONCLUSIONS

Accepting these observations, it would seem demonstrated that structured convection can operate in a very stable manner over a range of conditions and that others who use a combination of physical observation and appropriate instrumentation should be able to reproduce and control the results. A variety of ways to extend these conditions seem evident, including providing either a mechanical means to assure energy extraction or an energy storage system of adequate capacity.