TIME COURSE OF THERMAL STRATIFICATION AND ITS RELEVANCE TO FLOW CALORIMETERS

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ABSTRACT

Vertical flow calorimeters may be unreliable under some conditions. There have been many improvements in calorimetry [1-8], noise analysis [9], and definitions of input power [1,10], and other issues that can contribute to patterns of failure [11,12]. Although many aspects of calorimeters have been discussed, including issues of potential problems with the thermometry (i.e. thermocouples, thermistors and thermometers, including electrical grounding and crosstalk, thermal mixing and sensor positioning problems), the potential impact of positional effects of Benard instability upon the output of flow calorimeters was not initially considered. The positional orientation refers to the direction of the flow, and not to the orientation of any temperature probes therein.

Despite the reported advantages for flow calorimetry in detecting enthalpy from putative fusion reactions, these studies theoretically suggested, corrected for, and then measured, the effects from positional variation in the calorimetry of such flow systems [7,8]. Based upon the models, and the preliminary experiment discussed here, rather than 'ease of calibration' usually touted for such systems, it is suggested that calibration may be more complicated for vertical flow calorimetric systems. In the absence of additional calibration, it may be critical to keep semiquantitative calorimeters horizontal under some conditions. It is also important to avoid exogenous sources of heat which would further magnify these effects in such vertical flow systems. This mathematical analysis and observation of the time course of thermal stratification suggests why there may be erroneous measurements up to "kilowatt" levels if an improper vertical flow calorimetric system is used without adequate joule and other controls.

ANALYSIS OF A VERTICAL FLOW CALORIMETRY EXPERIMENT

One recent series of reports using vertical flow calorimetry [13,14,15,16] involves the CETI microspheres, reported to use a few percentage of the metal of other systems. The microspheres have multilayer metallic coats and are used as a distributed electrode bed. The cell is 10 cm long, 2.5 cm in diameter, and contains 1 to 40 ml of beads. Electrolyte percolates through, removing the heat, and exits from the top. The flow causes a temperature gradient. The observed delta-T, between the top and bottom, is in the range of 1.5 to 17C (flow rates to 1.0-1.5 liters per minute, with the water circulated by a magnetic impeller pump (aquarium type circa a reported 25 watts, total power consumption ~85 watts). At the ICCF5, the CETI cell was reported to have an input of 0.14 watts and a peak excess of 2.5 watts, a ratio of 1:18. At SOFE '95, the CETI cell had 0.06 watts input and 5 watts peak output, a ratio of 1:83. At Power-Gen, the ratio reportedly ranged from 1:1000 to 1:4000. There have been several complaints suggested regarding the CETI demonstrations concerning recombination, flow measurement, and inadequate heat ejection [15]. Mitchell Jones (mjones@jump.net) has reported ('98,'95; sci.physics.fusion) that he did an analysis of the pump motor used in the "Power Gen" demo and demonstrated a strong sensitivity of the flow rate to flow resistance.

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EXAMINATION OF MODEL - VF- CALORIMETERS MAY BE CORRECTED UNDER SOME CONDITIONS

The role of the Benard instability [17] has not been previously mentioned, even though it may have inadvertently impacted the calorimetry [7,8,16]. Even assuming the thermometry is correct, simple models demonstrate issues of the heat and mass transfer [7,8,17,18]. How much thermal stratification can come from the Benard instability? Dr. Merriman [19] has noted thermal stratification of ~0.2°C at 27°C. This is attributed to thermal stratification of air from the room because a temperature differential was also noted in the room, but both could result from Benard instability independantly.

EXPERIMENTAL DETERMINATION OF ACTUAL VERTICAL STRATIFICATION FROM BENARD INSTABILITY

A light water volume was used of cylindrical symmetry consisting of a container (polypropylene 10.0 cm diameter, 1.5 mm wall thickness, open, containing 300 ml and also containing six matched temperature probes (thermocouples Omega E type) stacked at 0.9 to 1.0 cm separations on a combed fenestrated polyethylene support. The cylindrical container itself was internally heated by a Medisonic ultrasonic irradiator which delivered 26.5 +/- 1.5 watts over a surface of 10 cm^2.

There was significant heat loss from the monitored volume as it was surrounded by additional volume of ~3700 cc of water separated by the 1.5 mm polypropylene barrier (270 cm^2). The six matched probes, and two corroboratory temperature probes were inserted. Additional probes monitored the air, second (outer) cylinder temperature. The ultrasonic irradiator was activated for three 15-minutes periods. This raised the temperature during the irradiation, and evanescently thereafter, to examine for possible dynamic or temperature-related changes in thermal stratification of the cylinder. The temperature was plotted for each detector (Fig. 1), and the differential (Fig. 2) temperature was determined two ways. The first way involved T6-T1. The second way used [(T5+T6) - (T1+T2)]/2.

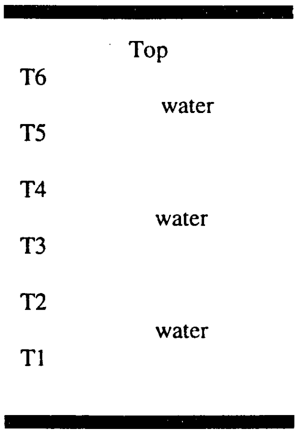

Fig. 1 Spaced temperature probes

The ASCII Schematic of the cell shows the location of the six temperature probes. The other sensors and irradiator are not shown.

RESULTS

Fig. 1 shows the results of six spaced temperature probes revealing the vertical temperature differential.

Fig. 2 shows the results of both methods of obtaining the temperature differential. There was a vertical differential consistent with the properties of water (warm less-dense water rising), and also consistent with reports [19]. After heating there was a much larger temperature stratification differential which decreased with time (Fig. 3). These differentials were in the range of 0.2-0.5 and 0.7-1.1 degree Centigrade respectively. After heating the time constant for the fall-off of the temperature differential was a fraction of an hour as shown in Fig. 3.

IMPLICATIONS

One implication of the lowest levels of observed stratification is that the "steady state" levels of circa 0.3 degrees is quantitatively consistent with other previous reports [19]. The larger temperature may have occurred because of greater heats available to incur the Benard instability which were noted this time because of the real-time monitoring of the profile which was not done in previous studies. These larger temperature differentials may herald considerable problems for vertical calorimetric systems with in-line heaters. So great may be the impact that since the generated thermal stratification here was considerable even at 25-29° Centigrade, that the cited reports of "kilowatts" using heaters to generate in-line input temperatures up to 10 degrees warmer might consider a reexamination.

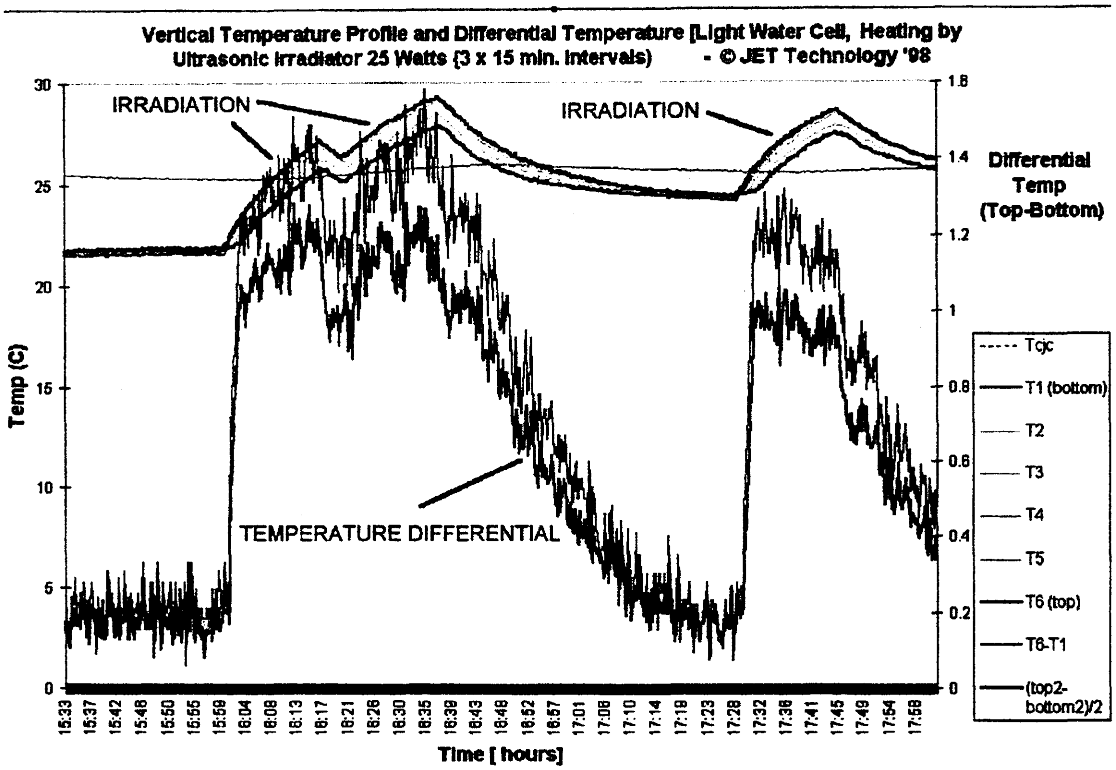
Vertical Temperature Profile and Differential Temperature [Light Water Cell, Heating by Ultrasonic Irradiator 25 Watts {3 x 15 min. Intervals} - © JET Technology '98
IRRADIATION
IRRADIATION
TEMPERATURE DIFFERENTIAL
Temp (C)
30
25
20
15
10
5
0
Differential Temp (Top-Bottom)
1.8
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Tcjc
T1 (bottom)
T2
T3
T4
T5
T6 (top)
T6-T1
(top2-bottom2)/2
15:33
15:37
15:42
15:46
15:50
15:55
15:59
16:04
16:08
16:13
16:17
16:21
16:26
16:30
16:35
16:39
16:43
16:48
16:52
16:57
17:01
17:06
17:10
17:14
17:18
17:23
17:28
17:32
17:36
17:41
17:45
17:49
17:54
17:58
Time [hours]

Fig. 2

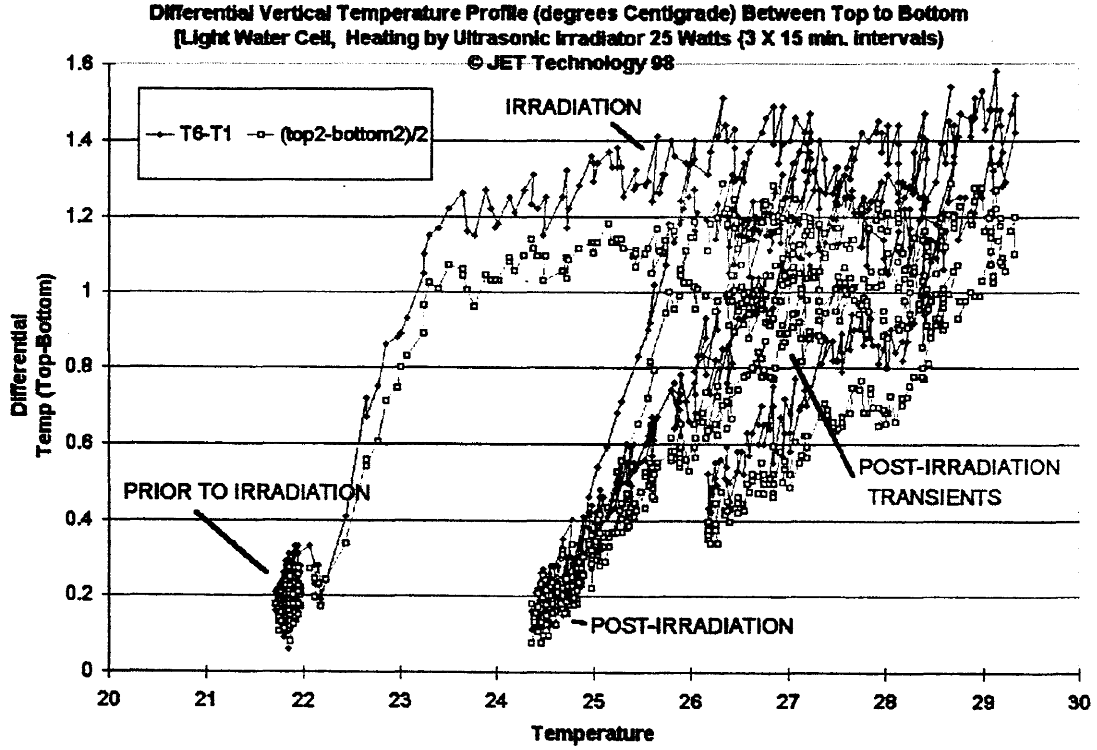
Differential Vertical Temperature Profile (degrees Centigrade) Between Top to Bottom [Light Water Cell, Heating by Ultrasonic Irradiator 25 Watts {3 X 15 min. intervals} © JET Technology 98
T6-T1
(top2-bottom2)/2
IRRADIATION
PRIOR TO IRRADIATION
POST-IRRADIATION
POST-IRRADIATION TRANSIENTS
Differential Temp (Top-Bottom)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
20
21
22
23
24
25
26
27
28
29
30
Temperature

Fig. 3

The equation used to derive the output, and therefore the presence of any excess heat involves the flow, the specific heat of the water, and the temperature differential. Although this equation may be dimensionally correct, it may not be valid for low flow rates in certain cases discussed below. A quasi-one-dimensional (Q1D) analysis [7,8,17,18] further examined the impact of the flow orientation with respect to the gravitational field during flow calorimetry with consideration of convection, conduction, and gravity-thermal instabilities. The analysis begins with the definition of η_B which is the ratio of heat transported by the buoyant forces to the heat transported by solution convection.

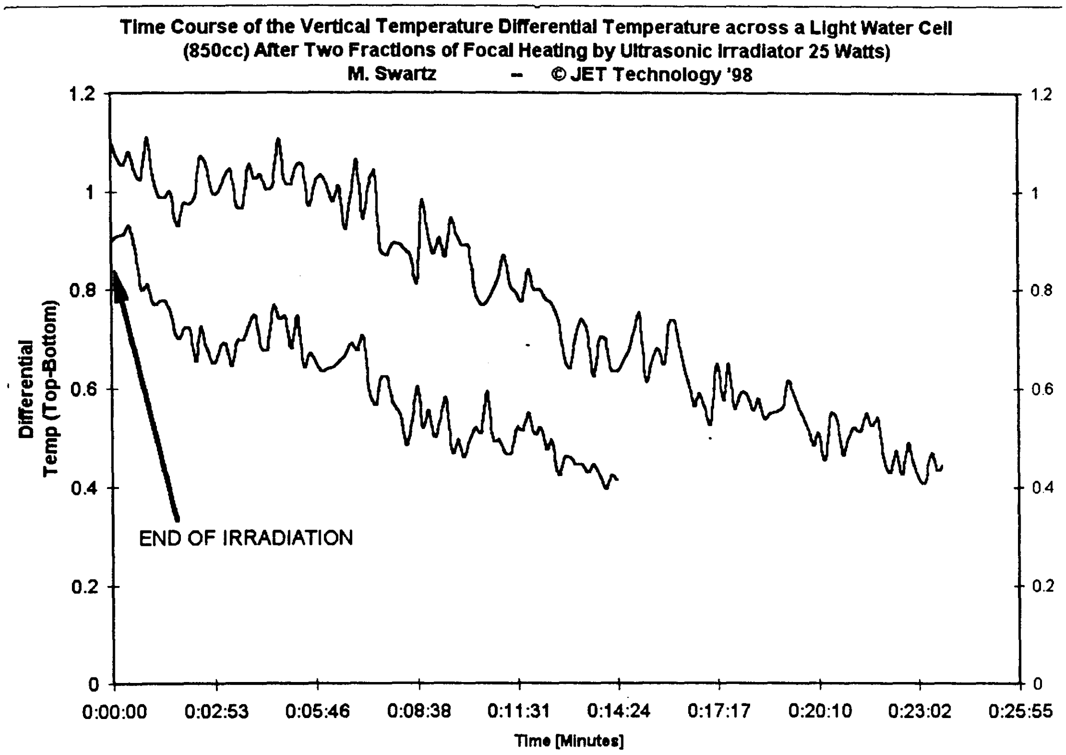

Fig. 4

$$\eta_B = \frac{\text{heat transported by buoyant forces}}{\text{heat transferred by solution convection}}$$

This model of heat and mass transfer has indicated that what is generally correct for horizontal calorimetric systems, may not be correct for vertical systems, when the non-dimensional number (= η_B) is significantly greater than zero. The vertical flow calorimetry (VFC) amplification effect may occur when Benard instability can create additional mass transport (see data above) which adds to total heat transport, thereby yielding false derivations of the "excess heat" generated. Any apparent amplification of the 'excess heat' (if any, and there does appear to be some) would be greatest at the low flow levels. Increased flow makes the positional error less important. As a corollary, any false excess heat, or excess heat magnification, should also reduce with increased flow.

The analysis suggests corrections of the apparent "gain" of a sample derived by such vertical flow calorimetry (VFC) may be correctable to first order.

Apparent gain = Real Gain/ (1-[fraction of heat transported by Benard instability])

SUMMARY

In summary, thermometry may not be the only rate-limiting factor for obtaining high-quality information from flow calorimeters. Problems can occur if the non-dimensional number, η_B (which is defined as the ratio of heat transfer by buoyancy to the heat transfer by convection) is greater than zero.

η_B may be time-variant in a real system where viscosity, turbulence, and other parameters play a role or where there is a heat source of any type (as shown here). Furthermore, the actual mass and heat flow kinetics depend upon other non-dimensional factors including the Archimides non-dimensional number which is the ratio of the buoyant force to the viscous force, and possibly the Rayleigh non-dimensional number, which is the ratio of gravity to thermal conductivity.

With vertical flow calorimetric systems, errors appear as stratified vertical temperature differentials which may not necessarily result from flow. These vertical temperature differentials arising from Benard instability may be in the range of 0.2-0.5 degrees or more. In this preliminary study, effects up to 0.7 to 1.1 degrees Centigrade were observed after heaters were activated and then turned off (up to 25-29 degrees Centigrade).

The larger vertical temperature differentials in the post-heating phase heralds considerable potential problems for vertical calorimetric systems with in-line heaters. Such systems should consider the use of controls and correction techniques [8] since the generated thermal stratification can be considerable. These controls should examine thermal stratification in the absence of the prime experiment at all temperature ranges and should examine the dynamic changes after a joule control.

This hypothesis of Potential for Positional Variation in Flow Calorimetric Systems [7,8] appears to again be important. The model of heat and mass transfer by inadvertant Benard instability in vertical flow calorimeters is demonstrated to be further important. These experiments and mathematical models do not imply that such systems do not necessarily exhibit 'excess heat'. But rather that any such reported 'excess heat' parameters may be inflated, if the information was indeed collected with a vertical flow calorimetric system, in the absence of confirmatory calibrations under low to moderate flow conditions where the non-dimensional number (η_B) is not trivial.

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