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Research Article

Buoyant Heat Transport in Flow Calorimetry

Mitchell R. Swartz*

JET Energy Inc., Wellesley Hills, MA 02481, USA

Abstract

Reported 'excess heat' by flow calorimetric systems may be false positive or inflated, if the information was collected with temperature probes at two different heights or in the absence of confirmatory thermal Joule calibrations and η_B correction. This is especially true at higher temperatures. The non-dimensional number (η_B), which is the ratio of heat transported by the buoyant forces caused by any inhomogeneous temperature distribution to the heat transported by the expected solution convection, can yield an improved semiquantitative estimate of the actual gain: $\text{Power Gain}_{(\text{corrected})} = \text{Power Gain}_{(\text{indicated})} * (1 - \eta_B)$.

Keywords: Benard instability, Buoyancy correction, Buoyancy heat transport, Flow calorimetry, Flow calorimetry correction

1. Introduction – Overview of the Impact of the Buoyancy Effect

Although flow calorimetric systems are increasingly used to detect enthalpic changes (excess heat) secondary to putative CF/LANR/solid state nuclear reactions [l–6], there are serious potential problems when used with volumes passing unconstrained flow (that is, outside of simple pipes or arteries where there is no significant volume to enable buoyant heat flow). Flow calorimetry is simply not semiquantitative absent joule (ohmic) calibration and buoyancy correction. The equation(s) cannot be trusted to accurately derive the power output or putative excess heat if there are errors in the measured fluid flow, or the specific heat of the water, or absent buoyancy correction. Figure 1 shows this and the utterly huge amount of potential error.

Specifically, problems arise if uncalibrated outputs are taken from temperature probes at two different elevations (levels, heights), or with heat transported by buoyant forces between them. In those cases, the indicated values provide an inaccurate value. Figure 1 demonstrates that the indicated uncalibrated outputs area shown as a function of real, actual output power (from loss, through breakeven to circa 300%) and the non-dimensional number η_B which is the ratio of heat transported by the buoyant forces to the heat transported by the applied solution convection. Figure 1 saliently demonstrates that the temperature differential is only truly accurate and usable for a flow calorimetric equation IF the temperatures are taken at the same elevation. Simply put, even if all variables are correct, and although the equation may be dimensionally correct, it is not valid for low flow rates or where there is buoyancy instability of

*Mitchell R. Swartz ScD, MD, EE, E-mail: drswartz@nanortech.com.

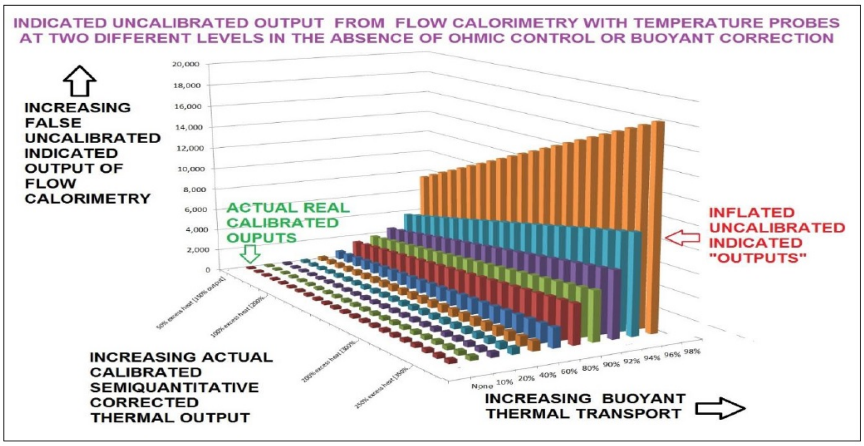

Figure 1. The indicated uncalibrated outputs from flow calorimetry with temperature probes at two different elevations (levels, heights) in the absence of ohmic controls or buoyant correction.

water (Benard instability). Instead, semiquantitative calibrated information is needed and it is achievable, as shown here using the non-dimensional number ($= \eta_B$) which is the ratio of heat transported by the buoyant forces to the heat transported by the applied solution convection.

2. Background

2.1. The buoyancy effect is quite real and observable

Many aspects of calorimeters have been discussed, including issues of potential problems with the thermometry, electrical grounding and crosstalk, thermal mixing, sensor positioning problems, and recombination. Yet, the potential impact of the buoyancy error is usually not considered despite its demonstrated significance and relevance to heat and mass flow and Benard instability (Fig. 2). The amplification can be quite significant, making this an important potential false positive. Worse, these errors do not average out over successive measurements.

2.2. Heat driven flow interferes with accurate calorimetry

We first demonstrated the significance of this effect in a series of papers [7–12], beginning with Potential for Positional Variation in Flow Calorimetric Systems which discussed a theoretical examination of heat and mass flow [13] with inclusion of the Benard instability [14]. Therefore, as can be seen even in this early model of the impact of buoyancy movement in flow calorimetry, the indicated results are not semiquantitative without calibration and correction. The effect can yield the appearance of excess heat when there is none, and it can also magnify the real excess heat far beyond what is actually obtained in the absence of buoyancy instability of water. Such indicated values can deceive the experimenter and can be misused, or used by crafty individuals, in the absence of timely synchronous ohmic/joule controls. In either case, this can give everyone the wrong impression based on an indicated number rather than semiquantitative calibrated data.

2.3. Error increases with additional heat

The impact of buoyant velocity interfering with flow calorimetric indicated measurements increases and is especially true at higher temperatures. Figures 1 and 3 show typical examples of this. Large volumes of fluids, moving or not, can yield temperature differentials which are not excess heat, and must be accounted for, and corrected in all semiquantitative flow calorimetric calculations.

3. Results

3.1. Understanding the buoyancy effect

This error can be semiquantitatively corrected by continuum electromechanical/flow principles [13] and the Navier–Stokes equation. That equation is essentially an equation of energy flow, but to understand this continuum equation requires a closer look at heat capacity of a volume of mass and how heat can flow from that volume through a surface encompassing that volume (Fig. 6). Together the local heat increase ($\Delta T * \text{Heat capacity}$) and heat flux and the power input. Here, with electrical or other input (such as $V * I$) the local power and the other variables define Incremental Power Gain. Integrated over time this becomes the excess heat.

4. Methods

4.1. Derivation of Navier– Stokes equation, Benard instability

The Navier–Stokes equation is derived from $F = ma$, which is conservation of momentum and from the equations for conservation of mass and energy. Conservation of mass requires the continuity equation.

- Conservation of momentum

$$m\vec{a} = \sum \vec{F}. \tag{1}$$

where *m* is the mass, $\vec{a}$ the acceleration, and $\vec{F}$ is the sum of all forces acting on fluid.

- Conservation of mass (continuity equation)

$$\nabla \cdot \vec{u} = 0. \tag{2}$$

- Conservation of energy

$$\rho c \frac{\partial T}{\partial t} = k\nabla^2 T + \dot{q}. \tag{3}$$

The term on the left-hand side represents rate of change of local heat energy stored, the first term on the right-hand side represents heat conducted out and $\dot{q}$ is the heat generated.

The desired equations, therefore, add the forces on the right-hand side of Eq. (4), which here have forces which here arise from a pressure gradient, from gravity, and diffusion. Finally, because this is a Euler equation (a flow though a volume) rather than a Lagrangian (such as where is the ball as a $f\,(x, y, z)$ the convective derivative is needed and used on the left-hand side of Eq. (4).

- Navier–Stokes equation

$$\rho \left[\frac{\partial V}{\partial t} + (V.\nabla)V \right] = \rho \frac{D\vec{V}}{Dt} = -\nabla p + \rho\vec{g} + \mu\nabla^2\vec{V}. \tag{4}$$

where $\partial V/\partial t$ and $D\vec{v}/Dt$ represent convective derivatives, *p* the pressure, *g* the gravity, and ∇ is the diffusion.

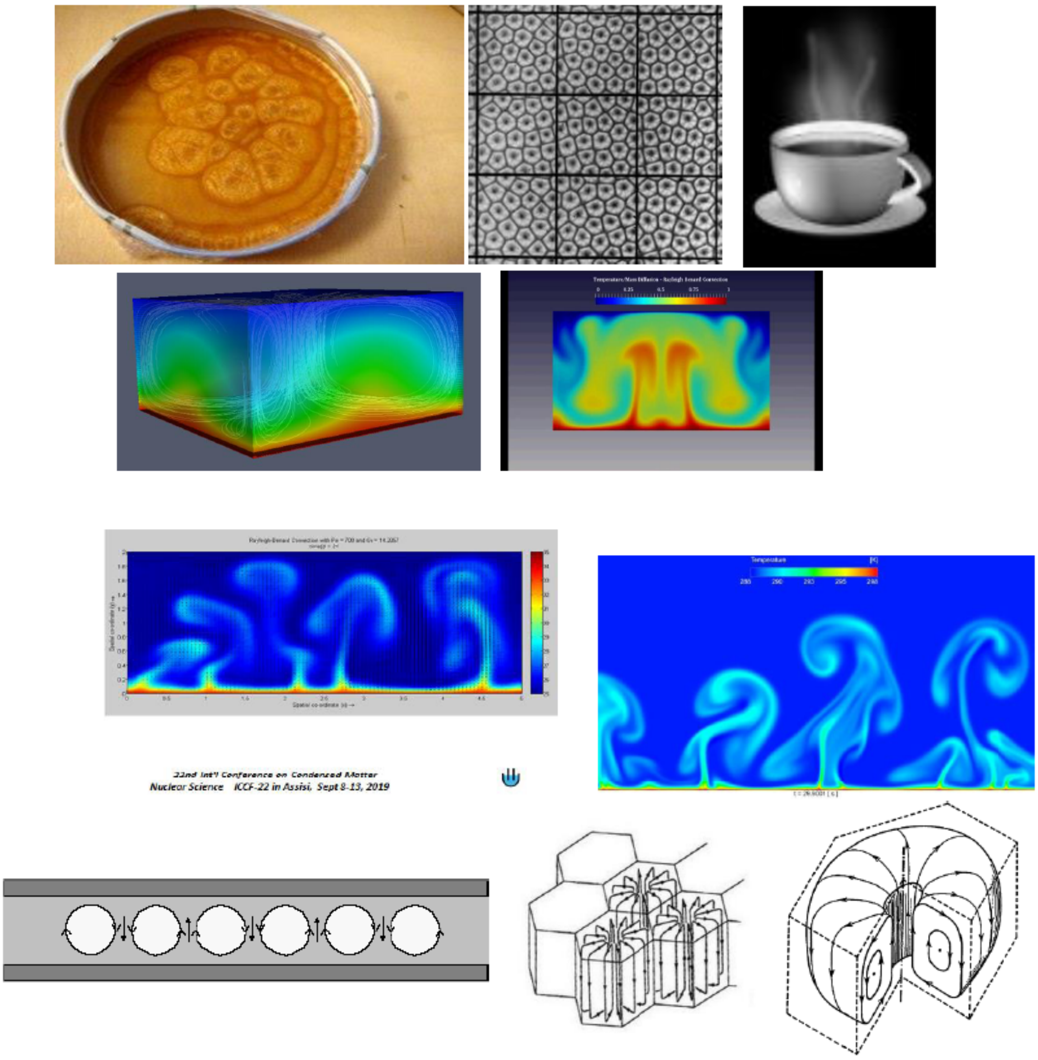

Figure 2. Examples of Benard–Rayleigh instability range from both the aqueous and gaseous regions in/near a cup of coffee, to the circulation cells which result from the uplift of fluid (and heat) arising from the difference of density. Shown are cells such as observed by Benard, and computer simulations and thermography and a cartoon schematic further showing the buoyancy effect and the induced circulations.

5. Results

5.1. Thermal expansion, Boussinesq approximation

In these cases, the thermal expansion must next be addressed. The key problem is that water and air and other fluids used in flow calorimetry suffer from thermal expansion. Their density is a function of temperature. Thus, water when

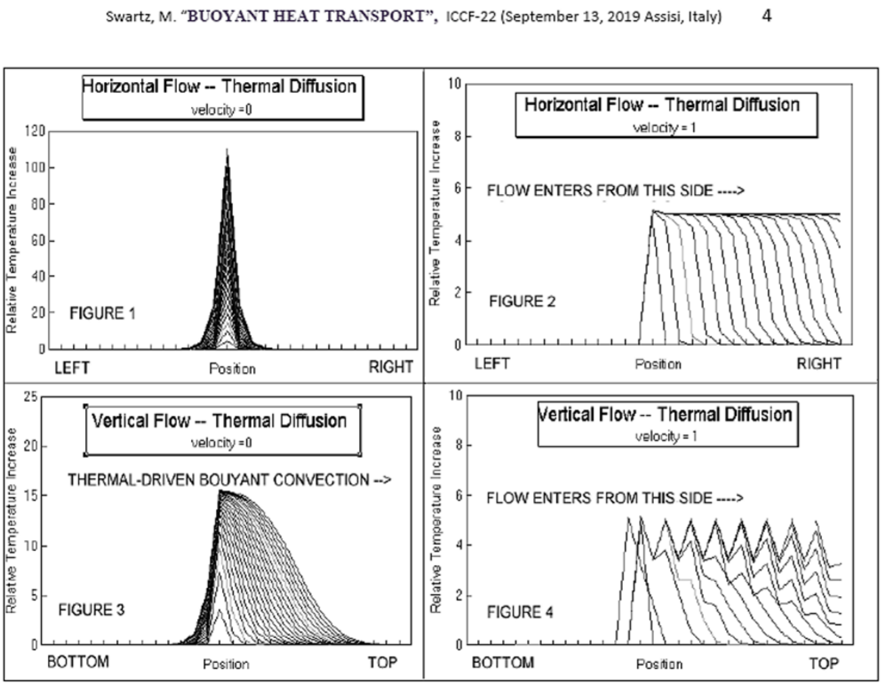

Figure 3. Impact of the direction of fluid velocity in flow calorimetry. Figure 3 from the Potential for Positional Variation in Flow Calorimetric Systems first discussed these theoretical issues/errors of heat and mass flow. The direction of the flow (horizontal with the input and output being measured at the same height) are shown on the top. The bottom shows vertical flow, although the curve itself remains horizontal for easy comparison.

it freezes floats on top, as one example, thereby fortunately saving all of the life below in the pond during the Winter.

For simplicity, the Boussinesq approximation is used, which only considers the thermal expansion in any term of Eq. (4) involving gravity (such as on the right hand side). Solution leads to Benard instability, the Rayleigh Taylor wavelength, and what is universally observed (Fig. 2). This equation is generally ignored in simplistic flow calorimetric systems/calculations.

5.2. η_{B} evaluates impact of buoyancy effect

We derived a non-dimensional number ($= \eta_{\mathrm{B}}$) which can determine if flow calorimetry is defective when it is significantly greater than zero, and can be used to correct the flow calorimetry to the first order [7–10]. η_{B} is the ratio of heat transported by the buoyant forces to the heat transported by the applied solution convection.

η_{B} is also derivable from other non-dimensional factors including the Archimedes non-dimensional number (which is the ratio of the buoyant force to the viscous force), and the Rayleigh non-dimensional number (which is the ratio of gravity to thermal conductivity).

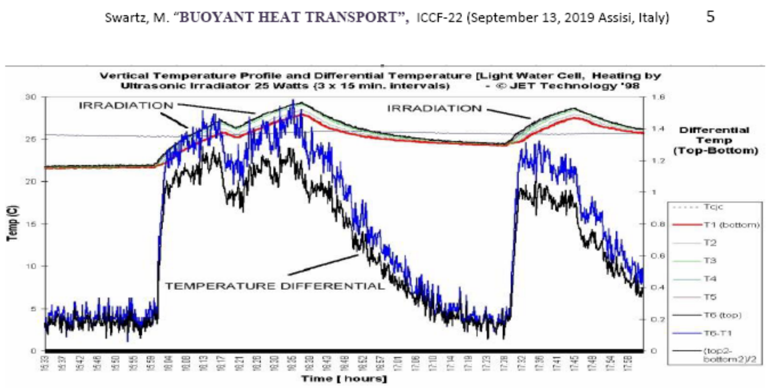

Figure 4. False indicated differential masquerading as excess heat. Examples of higher temperature Benard instability effect are seen during ultrasonic irradiation of palladium loaded cathode located in a simple tank (aquarium) of ordinary water. There is an initial ΔT between the top and the bottom (left hand y-axis) of several degrees. THIS IS NOT EXCESS HEAT prior to the irradiation, and that proves the entire issue. This temperature differential increases markedly to 20°C, and more, after initiation of the ultrasonic irradiation. Note that the time for fall off is significant.

5.3. First order correction using buoyancy factor

To zeroth order one can write using the specific heat capacity, the temperature differential, and the rate of mass transfer caused by both the expected convection and the buoyancy movement secondary to the temperature inhomogeneity.

$$P_{\text{observed}} = P_{\text{out}} + P_{\text{error}} = C_{\text{p}} * \Delta T * V_{\text{total}} = C_{\text{p}} * \Delta T * \left(V_{\text{convection}} + V_{\text{buoyancy}}\right) \tag{5}$$

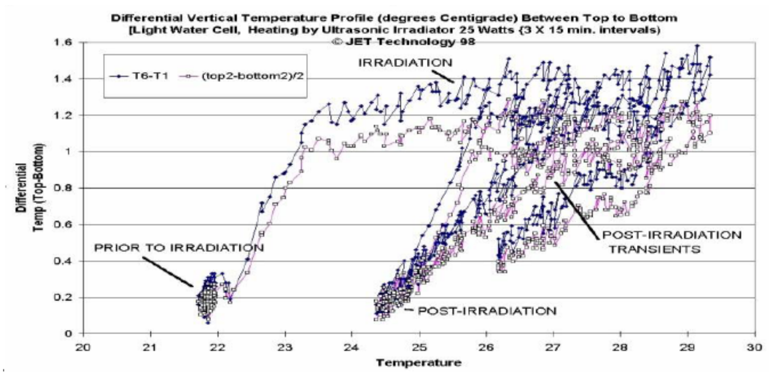

Figure 5. Second false indicated differential masquerading as excess heat. A second example of higher temperature Benard instability effects which were seen during ultrasonic irradiation of a cathode in a simple tank of ordinary water. The x-axis shows the temperatures recorded, and the y-axis is the differential (ΔT) between top and bottom. Notice a clear differential of 0.2°C, before and after the experimental run. There is an initial Δt between the top and the bottom (left hand y-axis). This increases markedly to 20°C differential and more after initiation of the ultrasonic irradiation.

Figure 6. Scientific heroes of buoyant heat flow. The concept of specific heat originated with Dr. Joseph Black (1728–1799; left top), a Scottish physician and chemist who reported on the latent heat and heat capacity of ice and water. In 1761, Black reported of these findings in melting ice and boiling water, and realized that different materials have different specific heats. The heat flow issues were developed by Jean Baptiste Joseph Fourier (1768–1830; mid top), French mathematician and physicist, while with Napoleon Bonaparte on his 1798 Egyptian expedition, became governor of Lower Egypt and secretary of the Institut d'Égypte. It focused his attention to heat propagation. After the British victories, in 1822, he presented his equation on heat flow now used [15,16]. George Gabriel Stokes (1819–1903; top right), a mathematician and physicist, put the continuum flow equation together incorporating both heat conduction {from his research of crystals (1851) and incompressible fluid flow (1843)}. Henri Claude Bénard (1874–1939; bottom left), a French physicist, became known for his experiments on convection in liquid including the buoyancy circulations, which were analyzed by John William Strutt, the third Baron Rayleigh (1842–1919; bottom right).

The chain rule in calculus and consideration of coolant redistribution reveal the higher order terms from the impact of the buoyant flow.

$$\frac{\partial P_{\text{error}}}{\partial \eta_{\text{B}}} = \left(C_{\text{p}} * \Delta T * V_{\text{convection}}\right) + \left(C_{\text{p}} * V_{\text{convection}}\right) * \eta_{\text{B}} * \frac{\partial \Delta T}{\partial \eta_{\text{B}}}) \tag{6}$$

The term containing $\partial \Delta T / \partial \eta_{\text{B}}$ depends upon many factors including the total tank volume just outside the reactor (or thermal control) and the actual input temperature boundary condition. However, that term appears to be higher order, and so the linear correction to the observed power becomes

$$P_{\text{corrected}} = P_{\text{observed}} - (C_{\text{p}} * \Delta T * V_{\text{convection}} * \eta_{\text{B}}). \tag{7}$$

An improved estimate of the purported gain (or over-unity gain) then becomes, corrected to first order,

$$P_{\text{corrected}} = P_{\text{observed}} - \left(C_{\text{p}} * \Delta T * V_{\text{convection}} * \eta_{\text{B}}\right) P_{\text{corrected}} = P_{\text{observed}} * \left(1 - \eta_{\text{B}}\right) \tag{8a}$$

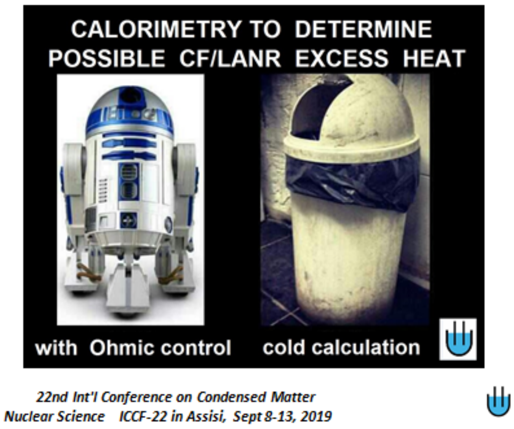

Figure 7. *Sine qua non* for good calorimetry. Good calorimetry absolutely requires an ohmic control at the same location as the heat source being examined. This and correction for buoyancy error will markedly improve the accuracy and reliability of flow calorimetry.

$$\text{Incremental Power Gain}_{\text{corrected}} = \text{Incremental Power Gain}_{\text{indicated}} * \left(1 - \eta_{\mathrm{B}}\right). \tag{8b}$$

6. Conclusion

Buoyancy error exists, as does the means to correct it.

(1) In summary, reported excess heat by flow calorimetric system may be false positive or inflated, if the information was indeed collected with temperature probes at two different heights, in the absence of confirmatory thermal Joule calibrations, and especially under low to moderate flow conditions where the non-dimensional number (η_{B}) is not trivial.

(2) Flow calorimetry is not semiquantitative absent calibration and buoyant correction. Uncalibrated outputs from flow calorimetry with temperature probes at two different elevations (levels, heights), or with heat transported buoyant forces, may be inaccurate in the absence of ohmic controls and buoyant correction. This was corroborated at ICCF-22 by Dr. Jacques Ruer [18]. It is important to consider that alternative methods of calorimetry are not sensitive to this type of error, including multiring systems [19,20].

(3) The effect can yield the appearance of excess heat when there is none, and it can also magnify the real excess heat far beyond what is actually obtained in the absence of buoyancy instability of water. Such would provide the wrong impression based on the indicated numbers rather than semiquantitative calibrated information.

(4) This is especially true at higher temperatures.

(5) The non-dimensional number (η_{B}) is important. For more accurate measurements, semiquantitative correction can be made even in the presence of buoyant flow by use of the linear correction based on the indicated values of data and the measured, or estimated, values of η_{B}.

(6) The buoyancy effect can be misused, or misunderstood, in the absence of timely synchronous iso-located ohmic/joule controls and correction for buoyancy. By failing to use ohmic/joule controls and then succumbing to the siren of buoyant heat's contribution to obtain an elevated, uncalibrated number is not accurate, is wrong, is risky and should not be repeated.

6.1. Failure to correct buoyancy error has risk

There is a substantial risk to the reputation of the entire field, if individuals within it take advantage of the error of thermal-induced buoyancy instability of water, and if it is for the wrong reason, such as without correction, without ohmic controls, and perhaps not even indicating by figure where the temperature measurements for the flow calorimetry are made. Are they made at the same level?

The science and engineering of cold fusion/LANR are still under unwarranted scrutiny and attack by outside powers that ignore discoveries, achievements, and the entire literature of the field. In that light, we must as scientists and engineers continue our research unabated for as was said at Waterloo: *"La Garde meurt, elle ne se rend pas"*! (*"The Guard dies, it does not surrender"*!). The loss in that battle, as might happen in this field which has worked uphill for 30 years, resulted from failure to admit huge mistakes, sheer recklessness, and, above all, overreaching ambition that exceeded all realistic possibilities [17].

By failing to use ohmic/joule controls and then succumbing to the siren of buoyant heat's contribution to obtain an elevated, uncalibrated number is wrong and should not be repeated.

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