Int. J. Heat Mass Transfer. Vol. 26, No. 8, pp. 1263–1264, 1983
Printed in Great Britain

0017-9310/83 $3.00 + 0.00
Pergamon Press Ltd.

LETTER TO THE EDITORS

COMMENTS ON "A STUDY OF LAMINAR BUOYANT JETS DISCHARGED AT AN INCLINATION TO THE VERTICAL BUOYANCY FORCE"

IN THEIR recently published paper [1], Satyanarayana and Jaluria claim to have studied *laminar* jets. They note that the "flow rates were kept small so that laminar flow in the inlet tube was obtained" and, furthermore, that "the buoyant jet flow entering the tank is laminar because of the low value of the Reynolds number" ([1], p. 1571). However, there are several points which indicate that the jet flows observed in [1] were mainly turbulent. First of all, the Reynolds numbers in the experiments (530.6, 904 and 1376, respectively) were too large for laminar jet flow (cf. the observations reported in [2] and in [3]) as well as theoretical predictions of the critical Reynolds number [4]. Furthermore, it is noted several times in [1] that the results are well correlated in terms of the parameter Gr/Re^2 (Grashof number Gr, Reynolds number Re). As this combined parameter is independent of the molecular viscosity, it provides further evidence of a turbulent jet flow. Finally, the authors of [1] also noted that the measured temperature profiles were Gaussian in form (p. 1571), and they used this type of profile, which is characteristic of turbulent jet flow, together with a turbulent entrainment model (cf. p. 1575 and ref. 16 of [1]) to analyze the flow.

Investigations on the influence of buoyancy on *turbulent*, non-vertical jets are already available in the literature [5–8] for horizontally discharged jets, and [9] for arbitrary angles of inclination including the horizontal discharge.

In order to avoid the uncertainties of an entrainment model related with the increase of buoyancy effects along the jet axis, the integral method given in [9] involves differential equations at the jet axis. This may account for good results even in cases where the success of the method has been found surprising by some authors [11]. Results due to various authors are most conveniently compared by making use of dimensional analysis [10] which shows that, at large distances from the nozzle, the axes of all buoyant turbulent jets with the same discharge angle reduce to one curve if the length coordinates are referred to the characteristic length $L = B^{-1/2} M_0^{3/4}$ (where $2\pi B$ is the buoyancy flux, and $2\pi M_0$ is the kinematic momentum flux at the jet origin). This similarity law has been tested in ref. [9] for horizontal discharge with a variety of nozzle diameters, discharge velocities, and discharge temperatures. Figure 1 shows that the measurements due to Satyanarayana and Jaluria [1] are also consistent with the similarity law and, furthermore, agree quite well with the theoretical predictions by the integral method [9] for turbulent jets. In the light of the above discussion, the agreement should not be surprising. However, some experimental results given in [1] for non-horizontal discharge are neither in accord with the similarity law nor with the analytical and experimental results of [9] (Fig. 2). Unfortunately, Satyanarayana and Jaluria do not provide quantitative comparisons of their measurements with their own predictions for the non-horizontal discharge. This could have helped to unveil the source of the discrepancies.

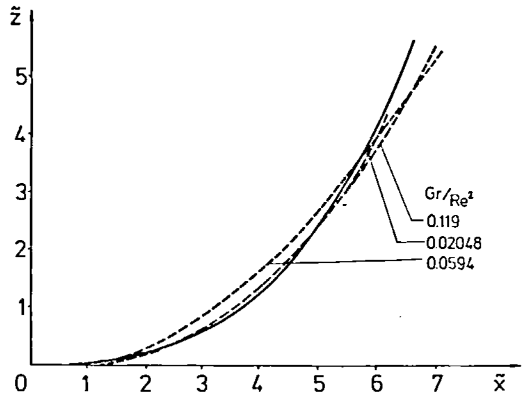

FIG. 1. Axes of horizontally discharged, buoyant, turbulent jets in the reduced coordinate system $\tilde{x} = x/L$, $\tilde{z} = z/L$, with $L = B^{-1/2} M_0^{3/4}$ ($2\pi B$, buoyancy flux; $2\pi M_0$, kinematic momentum flux at jet origin) [9]. Solid line: theoretical prediction [9] (experimental results of ref. [9] not shown). Broken lines: experimental results [1] (virtual jet origin located 2.2 nozzle diameters upstream of exit plane [5]).

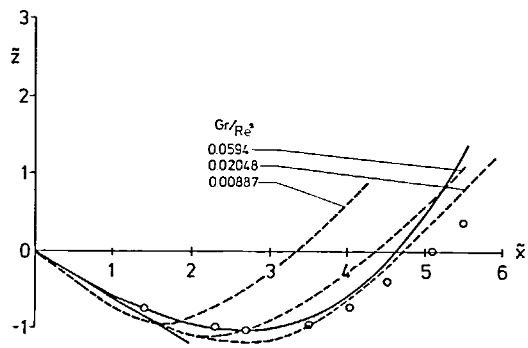

FIG. 2. Axes of buoyant turbulent jets discharged downwards at an inclination of 30°. (Reduced coordinates as in Fig. 1.) Solid line: theoretical prediction [9]. Circles: experiments [9]. Broken lines: experiments [1]. (Virtual origin as in Fig. 1.)

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REFERENCES

1. S. Satyanarayana and Y. Jaluria, A study of laminar buoyant jets discharged at an inclination to the vertical buoyancy force, *Int. J. Heat Mass Transfer* **25**, 1569–1577 (1982).
2. A. J. Reynolds, Observations of a liquid-into-liquid jet, *J. Fluid Mech.* **14**, 552–556 (1962).
3. B. Hanel und E. Richter, Das Verhalten von Freistrahlen in verschiedenen Reynolds-Zahlbereichen, *Luft- und Kältetechnik* **15**, 12–17 (1979).
4. J. C. Mollendorf and B. Gebhart, An experimental and numerical study of the viscous stability of a round laminar vertical jet with and without thermal buoyancy for symmetric and asymmetric disturbances, *J. Fluid Mech.* **61**, 367–399 (1973).

5. G. N. Abramovich, *The Theory of Turbulent Jets*, p. 585. MIT Press (1963).
6. B. Regenscheit, Die Luftbewegung in klimatisierten Räumen, *Kältetechnik* **11**, 3–11 (1959).
7. A. Koestel, Paths of horizontally projected heated and chilled air jets, in *Heating, Piping and Air Conditioning*, pp. 221–226 (1955).
8. K. Madni and H. Pletcher, Buoyant jets discharging nonvertically into a uniform, quiescent ambient—a finite difference analysis and turbulence modeling, *J. Heat Transfer* 99, 641–647 (1977).
9. G. Fleischhacker und W. Schneider, Experimentelle und theoretische Untersuchungen über den Einfluß der Schwerkraft auf anisotherme, turbulente Freistrahlen, *Gesundheits-Ingenieur* **101**, 129–140 (1980) [Corrigendum: *Gesundheits-Ingenieur* **104**, 56 (1983)].
10. W. Schneider, Über den Einfluß der Schwerkraft auf anisotherme, turbulente Freistrahlen, *Abhandl. Aerodyn. Inst. T. H. Aachen* **22**, 59–65 (1975).
11. T. Mizushina, F. Ogino, H. Takeuchi and H. Ikawa, An experimental study of vertical turbulent jet with negative buoyancy, *Wärme- und Stoffübertragung* **16**, 15–21 (1982).