RESEARCH NOTE

The influence of an abrupt convergence on heat transfer in circular ducts: a theoretical assessment

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This is a theoretical assessment of the postulation made by Barozzi *et al*, of separation in laminar flow in a circular duct caused by an abrupt entry. Using sets of data supplied by Barozzi, predictions have been made using a program developed by Collins. The effects of viscosity variation with temperature, and of natural convection, are quantified for the flow of water in a vertical tube. The results are consistent with the discussion of Barozzi *et al*, and tend to confirm the presence of a definite abrupt entry effect

Key words: *laminar flow, entry effects, separation, heat transfer*

In an earlier study by the author[1], it was suggested that the presence of an abrupt, as opposed to a smoothed, entry to a circular duct, could affect a laminar flow-field. The recent experiments of Barozzi *et al*[2] indicate that heat transfer could also be affected over some distance from entry, and they postulate that separation has probably occurred. In reaching this conclusion, however, they compare their heat transfer values with analytical predictions of Churchill and Ozoe[3] which assume constant properties. For vertical flow of water, both viscosity variation with temperature and natural convection may be significant, and Barozzi *et al* make informed assessments of these effects on heat transfer. Both the effects, however, are accommodated within the laminar flow treatment of Collins[4]. This permits the separation hypothesis to be assessed with more confidence by accurately quantifying these effects. To this end typical experimental data were supplied by Barozzi[5], so that corresponding sets of theoretical predictions could be made.

Theoretical assessment

Seven sets of data (runs) were supplied by Barozzi[5] and defined† as in Table 1 in order of increasing *Re*.

Using the program developed by Collins[1,4], predictive runs were made for each experimental run, assuming a uniform inlet velocity profile. The following schemes were used:

(A) Constant properties, with *Re* and *Pr* set at their inlet values,

(B) As (A), but allowing μ to vary with temperature,

(C) As (B), but allowing ρ to vary in addition, ie a combined convection case.

Results for selected runs 1, 3, 4 and 7, and all schemes, are plotted in Figs 1(a)–(d) respectively, in the same manner as Barozzi *et al*'s[2] Figs 3–6. The experimental data are also shown. The comparisons are increasingly consistent at downstream distances and serve to confirm and clarify several points discussed in the paper.

As shown in Table 2, the predicted effect of viscosity variation is to increase *Nu* at the end of the

Table 1 Definition of sets of experimental data

Run	Mean *Re*	Mean *Pr*	Inlet temp, °C	Heat flux, W/m^2
1	768	4.236	37.31	5.578×10^3
2	845	5.848	25.07	3.604×10^3
3	1234	6.216	20.7	1.081×10^4
4	1308	4.606	35.18	5.538×10^3
5	1601	6.447	20.23	1.081×10^4
6	1705	6.471	20.28	1.081×10^4
7	1796	4.258	37.73	1.074×10^4

Table 2 Predicted effect of viscosity and density on heat transfer at 80 diameters

Run	Predicted increase in *Nu* %	
	Due to μ	Due to ρ
1	3.93	39.48
2	2.78	7.35
3	6.76	10.70
4	3.29	11.77
5	6.38	6.35
6	6.28	5.64
7	5.20	18.55

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† The notation is consistent with that of Barozzi *et al* on page 46 of this issue

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heated length by between about 3 and 7%. Again as shown in Table 2, the predicted effect of free convection is similarly to increase *Nu* by between about 6 and 18%. Run 1, with an increase of about 40% is an exception with a strong buoyancy effect, and Fig 1(a) shows that both experiment and prediction 'level off' in a very similar manner.

The analysis allows for axial conduction, which under these conditions is negligible (see Collins[6]). Finally, and perhaps to be expected, the above effects are indeed negligible near the inlet.

Now for a constant wall heat flux, the only variable determining *Nu* is the wall temperature, and Table 3 gives a comparison of these, three-quarters of the distance along the duct. The predictions overestimate the temperatures by only about 2.5 °C maximum and this (particularly Run 1) is completely comparable to results in Collins *et al*[4] for upward flow of oil with a sharp-edged entry. These relate to experimental data of Kemeny and Somers[7], and are given in Table 4. Initially, there is an underprediction (*Nu* higher), followed by a consistent, but small, overprediction of temperature.

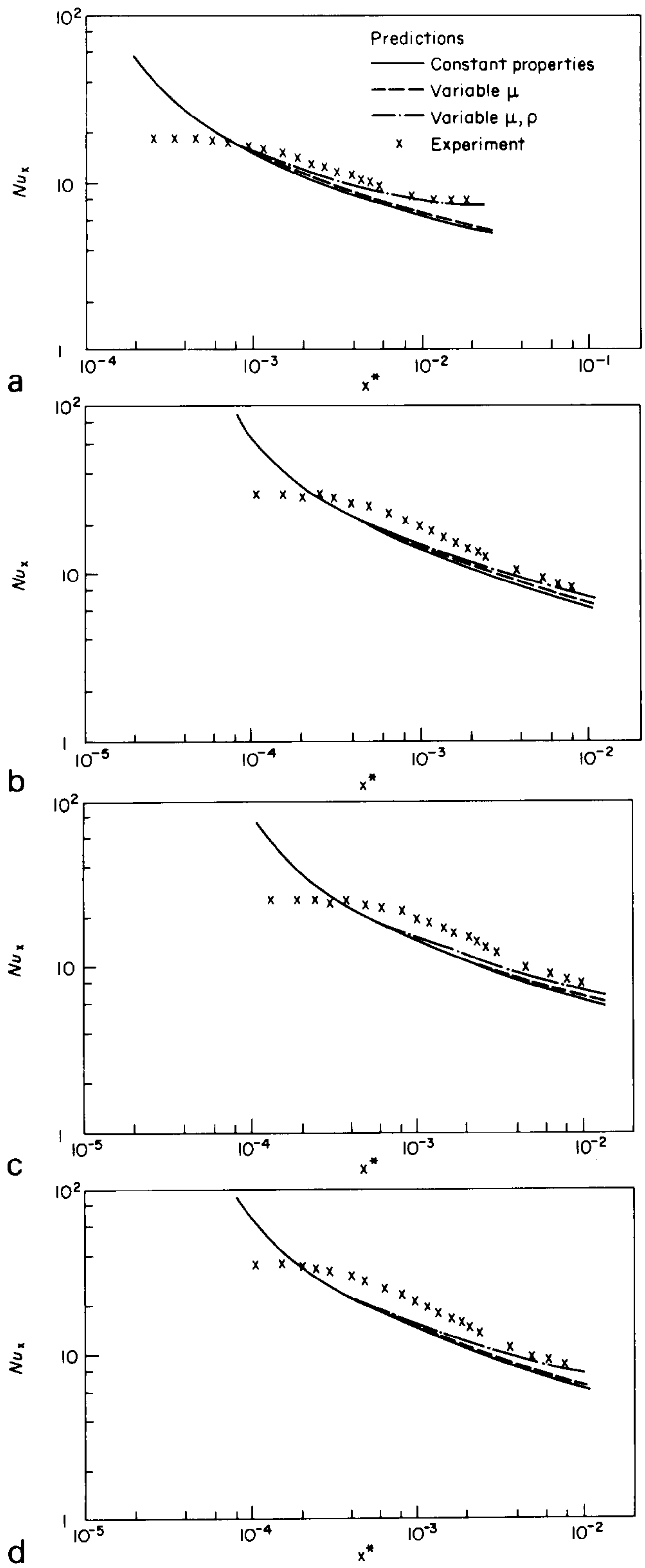

Fig 1 Heat transfer comparisons (a) Run 1—Re: *768,* Pr: *4.2355; (b) Run 3*—Re: *1234,* Pr: *6.2158; (c) Run 4*—Re: *1308,* Pr: *4.6061; and (d) Run 7*—Re: *1796,* Pr: *4.2583*

Conclusions

The results presented here confirm the assessment of the effects of viscosity variation and natural convection made by Barozzi *et al.* They thus confirm the basic premise of a definite sharp-edged entry effect on heat transfer under the experimental conditions. Also, such an effect may be quantified more accurately by comparing experimental data with scheme (C) type predictions.

Acknowledgement

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Table 3 Comparison of wall temperature and *Nu*

Run	Experiment‡		Predictions‡	
	Wall temp, °C	*Nu*	Wall temp, °C	*Nu*
1	55.3	7.52	56.05	7.206
2	36.3	6.96	37.15	6.384
3	47.3	8.06	49.51	7.638
4	49.9	7.73	51.30	7.024
5	44.0	8.73	46.38	8.099
6	43.2	8.99	45.87	8.227
7	62.2	8.59	64.19	8.042

‡ *Experiment,* 59.56 *dia; prediction,* 60 *dia*

Table 4 Wall temperature comparison

Distance from entry, dia.	Wall temperature, °C	
	Experiment[7]	Prediction[4]
2.67	52.61	51.67
10.00	62.06	62.36
17.35	66.39	67.22
24.67	69.28	70.50
32.00	71.81	73.22

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CALENDAR

Practical Applications of Heat Transfer	31 March 1982 London, UK	Conference Department, The Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, UK, SW1H 9JJ
The Jubilee Chemical Engineering Symposium	5–7 April 1982 London, UK	Fiona Dendy, IChemE, 165–171 Railway Terrace, Rugby, Warwicks, UK, CV21 3HQ
Conference on Stirling Engines: Progress Towards Reality	6–7 April 1982 Reading, UK	Conference Department, Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, UK, SW1 9JJ
6th International Symposium on Jet Cutting Technology	6–8 April 1982 Surrey, UK	Conference Organiser, 6th Jet Cutting, BHRA Fluid Engineering, Cranfield, Bedford, UK, MK 43 0AJ
International Energy Technology Exhibition	6–9 April 1982 Tokyo, Japan	Industrial and Trade Fairs International, Radcliffe House, Blenheim Court, Solihull, West Midlands, UK, B91 2BG
27th International Gas Turbine Conference and Exhibition	19–22 April 1982 London, UK	International Gas Turbine Center, ASME Gas Turbine Division, 6065 Barfield Road, Suite 218, Atlanta, GA 30328, USA
Steady and Transient Performance of Pipe and Duct Systems (Short Course)	19–23 April 1982 Cranfield, UK	John Hanson, CIT Fluid Engineering Unit, Cranfield, Bedford, UK, MK43 0AL
Turbocharging and Turbochargers 1982	26–28 April 1982 London, UK	Conference Department, The Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, UK, SW1H 9JJ
European Conference on Mixing	27–29 April 1982 Noordwijkerhout, The Netherlands	Organising Secretary, 4th Mixing Conference, BHRA Fluid Engineering, Cranfield, Bedford, UK, MK43 0AJ
Condensers and Vapor Generators (Short Course)	May 1982 Amsterdam, Netherlands	Mollie Meyer, Hemisphere Publishing Corporation, 19 West 44th Street, New York, NY 10036, USA
Compressor and Steam Turbine Technology	11–14 May Geneva, Switzerland	The Center for Professional Advancement, Postbus 19865, 1000 GW Amsterdam, The Netherlands
Gas Turbine Conference and Products Show	23–27 May 1982 Amsterdam, Netherlands	Technical Affairs Department, ASME, 345 East 47th Street, New York, NY 10017, USA
World Energy Congress	23–27 May 1982 Knoxville, TN, USA	Dr S. McCullough, Energy Opportunities Consortium, PO Box 2229, Knoxville, TN 37901, USA
Pump Hydraulic Design	27 May 1982 London, UK	Conference Department, The Institution of Mechanical Engineers, 1 Birdcage Walk, Westminster, London, UK, SW1H 9JJ
International Conference on Fouling of Heat Exchange Surfaces	May/June 1982	Engineering Foundation, 345 East 47th Street, New York, NY 10017, USA
Heat and Mass Transfer in the Cooling and Freezing of Foodstuffs and Biological Products	June 1982 Trondheim, Norway	International Institute of Refrigeration, 177 bd Malesherbes, 75017 Paris, France