MEASUREMENT OF ENTRAINMENT INTO AN AXISYMMETRIC JET USING TEMPERATURE AS A TRACER: A PILOT STUDY

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SUMMARY

The current extended abstract is a pilot study of an ongoing experimental and theoretical investigation of ambient entrainment of room air into an axisymmetric free jet using temperature as a tracer. The project aims to investigate, by revisiting the concepts and fundamentals of axisymmetric free Jets and entrainment in ventilation applications, particularly focusing on how to optimize performance of low mixing air distribution systems and to test methods of measuring entrainment in such systems. The study aims to explore a scalar field method using temperature as a tracer to estimate entrainment in axisymmetric free Jets. The results obtained show jet characteristics that slightly differ from what is reported in velocity field measurements and other scalar field studies. Thus, a call is made herein for further investigations to understand entrainment and appropriate methods to determine jet characteristics and its mixing effect. Additionally, more studies are needed to verify whether earlier results are representative of entrainment conditions for low mixing ventilation systems whose operation mode depend on near-filed characteristics of jets.

Keywords: Entrainment, jets, near-field, passive tracer, temperature, delivery capacity

1 INTRODUCTION

Over the past century empirical studies have demonstrated the fundamental characteristics of jet flow issuing from different engineering nozzles or geophysical flows like volcanic eruptions or rivulets etc. One interest characteristic of jet flows is entrainment. Depending on industrial applications, problems of entrainment can vary from requirements of high entrainment (e.g., to enhance mixing in chemical processes) to those requiring low entrainment (e.g., impingement cooling). Not limiting the issue to industrial processes, entrainment is a universal problem and particularly of high importance in ventilation applications. Sandberg et al. (2018) have discussed the basic concepts characterising ventilation flow and air distribution highlighting their differences and the role of entrainment in different air distribution systems.

Traditional air distribution systems have sought higher entrainment to increase the systems dilution capacity (Etheridge & Sandberg, 1996), and recently, with more research done perhaps in the last decade, systems have been proposed whose optimal operation depend on low entrainment i.e., personalized ventilation systems (Melikov, 2004). Many studies and research methods have been done and developed on ventilation requiring mixing or dilution due to increased entrainment, yet there is little done on ventilation systems that work with low entrainment. One reason could be that these systems are new and have not yet been commercialized (except in the sense used in vehicles and aeroplanes) compared to their counterpart systems which are widely used in ventilation. Thus, there is an opportunity to explore easier methods of determining entrainment rate and consequently testing system performance into low mixing requirements for ventilation jets.

The aim of the current pilot study, presented here as an extended abstract, is to explore the passive scalar method for determining entrainment, with temperature as a tracer at low Reynolds numbers (*Re*) in the near field ($\leq$10 nozzle diameters downstream from the nozzle exit) of an axisymmetric round jet.

2 METHODS/MATERIALS

The study was conducted in a climate chamber at the university of Gavle. The experimental setup is shown in Figure 1. Temperature measurements were performed with 18 T-type thermocouples spaced 10 mm apart and each had a tip diameter of 1 mm, configured on a test rig as shown in Fig. 1.C. The thermocouples were calibrated and had an accuracy of ± 0.03 ºC with measurements done at a sampling rate of 1 second. The test rig was connected to a traversing system which was controlled in two directions, radial (*r*) and the axial (*x*) planes of the jet flow. Measurements were done with a resolution of 2.5 mm for all points with $r/D \leq 1.85$ and with a resolution of 10 mm for $r/D \geq 1.85$ across the jet, while downstream resolution was 25 mm (0.5*D*) for $x/D \geq 1$.

A specially designed nozzle of diameter (*D*) = 50 mm was used, details of the nozzle are presented in (Todde, Linden, & Sandberg, 1998). The nozzle is of a 5th polynomial with the exit section coinciding with the point where the tangent is parallel to the nozzle axis. Two *Re* were investigated: 2540 and 4760. The Reynolds numbers were scaled with a constant kinematic viscosity of 14.8 x 10-6 m^2/s and the mean nominal exit velocities estimated by the airflow measurements with the orifice plate.

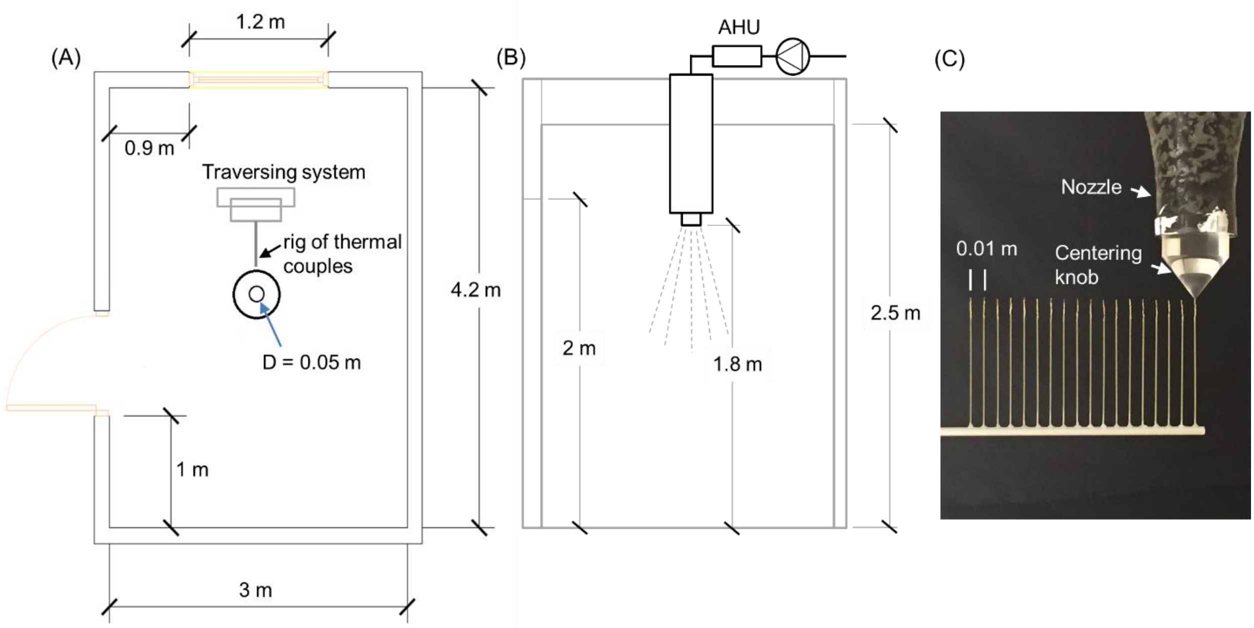

Figure 1. Experimental setup: (A)plan view (B)side view (C)Thermocouple's test rig being centred to the nozzles axis.

The system was setup to work with a nominal temperature difference(ΔT) of about 4 ºC between the jet centreline exit temperature and the average room temperature outside the jet (measured at about $r/D = 5.3$). This was to minimize the differences on the influence of buoyance between the considered *Re*. This was achieved by lowering the supply temperature relative to the room temperature. The resulting experimental temperature difference across conditions was 4±0.3 ºC.

3 RESULTS

3.1 Mean scalar field

Figure 2 show the radial profiles of the normalized temperature distribution for both *Re* at different axial distances up to $x/D = 5$, beyond which the jets behaviour begins to show similarity. The axial temperature difference $\Delta T(x)$, difference between the axial station (x) and the average room temperature measured outside the jet at a radial distance ($r = 5.3D$). $\Delta T(x)$ is normalized by jet maximum centreline temperature difference $\Delta T(max)$. The cross-sectional profiles differ with those observed in velocity measurements and the top-hat profile is not observed although profiles up to *x/D* = 1 suggests that the flow is laminar. At *x/D* ≥ 2, the profiles begin to wobble in such a way that it deviates from the parabolic profile dominant in velocity measurements. We speculate that this happens due to the mixing effect at the shear layers of the potential core region. This appeared in both cases of *Re* but the wobbling effect was much wider in the higher *Re* because the effect of shear stresses increases with *Re*, thus the mixing effect is higher (Viggiano et al., 2018). Additionally, Fig. 2. also show that for *Re* = 2540 the normalized centreline temperature difference shows signs of decaying *x/D*= 3.5 while this is observed much earlier (at *x/D* = 2.5D) with *Re* = 4760. This is confirmed in Figure 3 which shows the centreline decay of normalized temperature difference

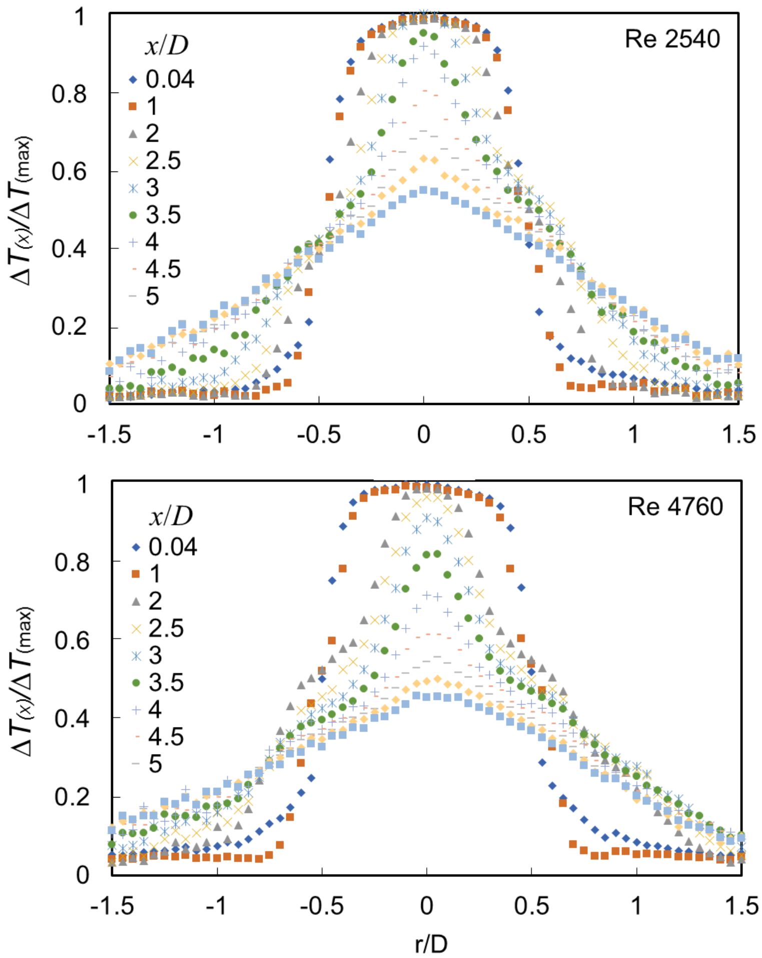

Figure 2. Radial profiles of the normalized mean temperature difference

In Figure 3, we see that *Re* = 4670 begins to decay much earlier than *Re* = 2540, however at about *x/D* = 7.5 they attain similarity. Earlier studies (Pitts, 1991) had suggested that the local entrainment rate of surrounding fluid into an axisymmetric jet can be correlated with the centreline mixing behaviour. Further studies with more Reynold number variations are required to substantiate this deduction with passive scalar entrainment measurements.

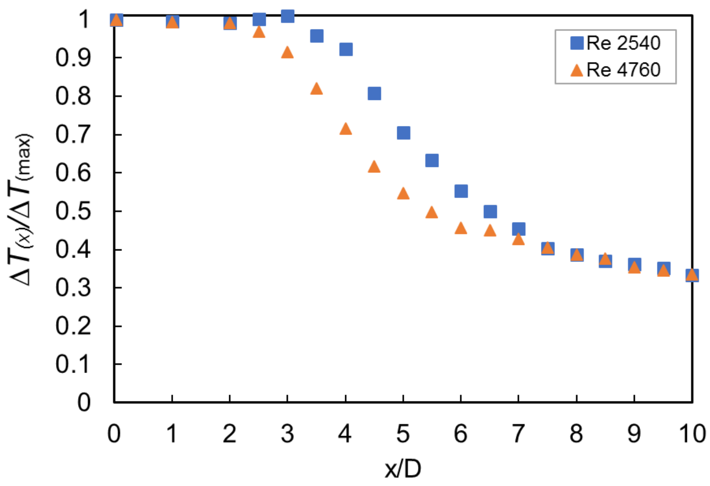

Figure 3. Centreline decay of normalized temperature difference

A detailed qualitative demonstration of the potential core and dilution of the jet temperature into the ambient is shown in Figure 4 with the contour plot of the normalized mean temperature difference across the 2-dimensional measurement plane. No distinctive differences were noticed between the two cases considered although there is a suggestion that shows a slightly longer potential core for *Re* = 2540.

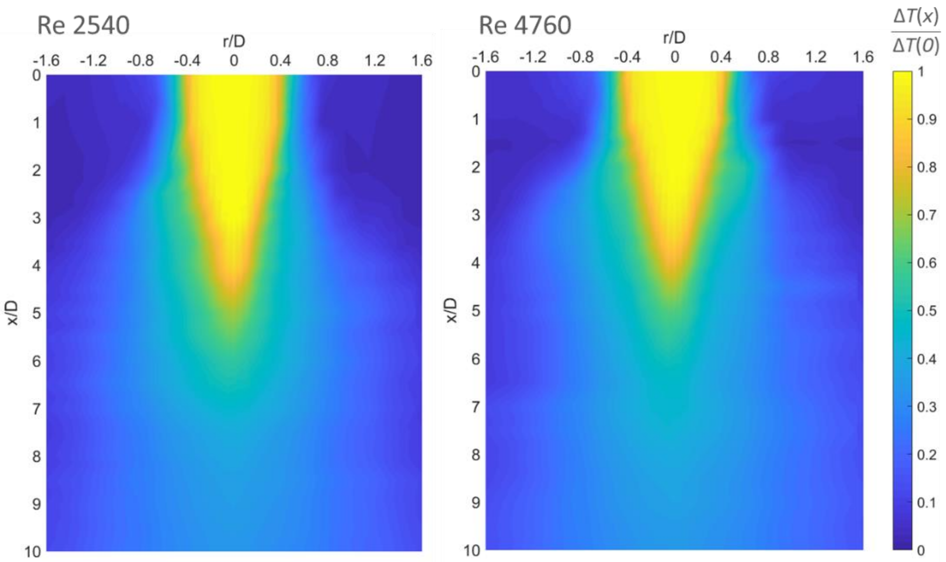

Figure 3. Contour plot of the normalized mean temperature difference across the 2-dimensional measurement plane.

4 DISCUSSION

The results obtained here, especially for the passive scalar cross-sectional profiles differ substantially from those reported in early research regarding velocity fields and temperature measurements, both in the shape of the profiles and the level of entrainment(Mi, Nathan, & Nobes, 2001). Some researchers (Mi et al., 2001; Trabold, Esen, & Obot, 1987) had shown that entrainment is independent of Reynolds number in the initial region but the effect is observed in the zone of established flow. The results herein for the two Reynolds numbers suggest that there might be a dependence particularly in the transformational downstream region of a Reynolds numbers. This calls for further near-field investigation to verify the findings reported in earlier studies and to check if the observations made herein are general and valid for other Reynolds numbers. This is important because ventilation applications like personalized ventilation have an optimal mode of operation in the near-field of turbulent jets.

The methods of using a scalar field like temperature to test the air delivery capacity for proposed low missing air distribution holds potential as it differentiates the method from those used in dilution capacities, e.g., tracer gas decay methods, which may not entirely be representative of the measure of the delivery of supply air but rather dilution of room ambient air. With such systems shown to have higher performance (Arsen Krikor Melikov, 2016; Yang, Melikov, & Sekhar, 2009), perhaps it is time we revisited the concepts of ventilation and jet characteristics so as to optimize air distribution with low mixing systems. This will also help introduce testing methods and guidelines for practice when implementing low mixing air distribution systems such as personalized ventilation in buildings.

5 CONCLUSIONS

The current study has investigated temperature as a passive scalar tracer in jets at two low Reynolds numbers. It is shown that although Literature suggests that entrainment maybe independent of Reynolds numbers in the near field, the results reported here shows a level of dependence and more interestingly that cross-sectional scalar profiles may differ from those observed in velocity field measurements. Further work is required to understand whether the observations are general and apply to various Reynolds numbers. This understanding will help establish guidelines, performance testing methods and limits of air distribution with low mixing systems.

REFERENCES

Etheridge, DW, & Sandberg, M. (1996). Building ventilation: theory and measurement. John Wiley & Sons.

Sandberg, M, Wigö, H, Kabanshi, A. (2018), Is building ventilation a process of diluting contaminants or delivering clean air? To be presented at *Roomvent 2018, 2-5 June*. helsinki, Finland

Melikov, AK. (2004). Personalized ventilation. *Indoor Air*, *14*, 157–167.

Melikov, AK. (2016). Advanced air distribution: improving health and comfort while reducing energy use. *Indoor Air*, *26*(1), 112–124.

Mi, J, Nathan, GJ, & Nobes, DS. (2001). Influence of jet exit conditions on the passive scalar field of an axisymmetric free jet. *J. Fluid Mech.*, *432*(4), 878. https://doi.org/10.1115/1.1412460

Pitts, WM. (1991). Reynolds number effects on the mixing behavior of axisymmetric turbulent jets. *Experiments in Fluids*, *11*(2–3), 135–141. https://doi.org/10.1007/BF00190289

Todde, V, Linden, E, & Sandberg, M. (1998). Indoor Low Speed Air Jet Flow: Fibre Film Probe Measurements. In *ROOMVENT'98, Stockholm, Sweden, June 14-17, 1998*.

Trabold, TA, Esen, EB, & Obot, NT. (1987). Entrainment by Turbulent Jets Issuing from Sharp-Edged Inlet Round Nozzles. *Journal of Fluids Engineering-Transactions of the Asme*, *109*(September 1987), 248–254. https://doi.org/10.1115/1.3242655

Viggiano, B, Dib, T, Ali, N, Mastin, LG, Cal, RB, & Solovitz, SA. (2018). Turbulence, entrainment and low-order description of a transitional variable-density jet. *Journal of Fluid Mechanics*, *836*, 1009–1049. https://doi.org/10.1017/jfm.2017.822

Yang, B, Melikov, A, & Sekhar, C. (2009). Performance Evaluation of Ceiling Mounted Personalized Ventilation System. *ASHRAE Transactions*, *115*, 395–406.