FLOW VISUALIZATION OF LAMINAR MIXED CONVECTION IN TRANSPARENT 3D-PRINTED CHANNELS

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Introduction

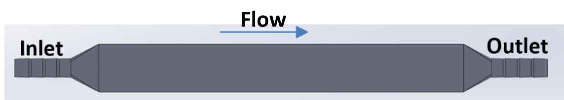
The investigation of mixed-convection flows are complicated due to the spatiotemporal instabilities of the flow. To precisely understand how the flow instabilities affect the flow pattern and heat transfer processes in a variety of fluid flow systems, flow visualization techniques are effective means. However, for the flow visualization, a challenge is to fabricate the device with a transparent material such as glass or clear plastic. A problem associated with plastic has been a high cost for lab-scale experiments, as customized plastic molds or extrusion systems are expensive. Alternatively, three-dimensional (3D) printing has recently been making a breakthrough in prototyping sophisticated and transparent fluid and heat-transfer devices.

Research Questions

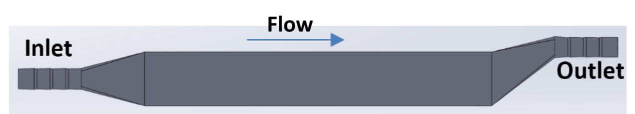
•Can a 3d printing technique be used to facilitate convection flow visualization?
•What are the flow patterns of laminar mixed convection at low Reynolds number (20 < Re < 200) and Rayleigh number range (3500 < Ra < 6000)?
•How does the aspect ratio of the channel affect the flow patterns?

Methodology

Design: Flow channels of diameter 15mm were created using CAD software. The two designs that were tested are shown.



Flow channel with co-axial outlet



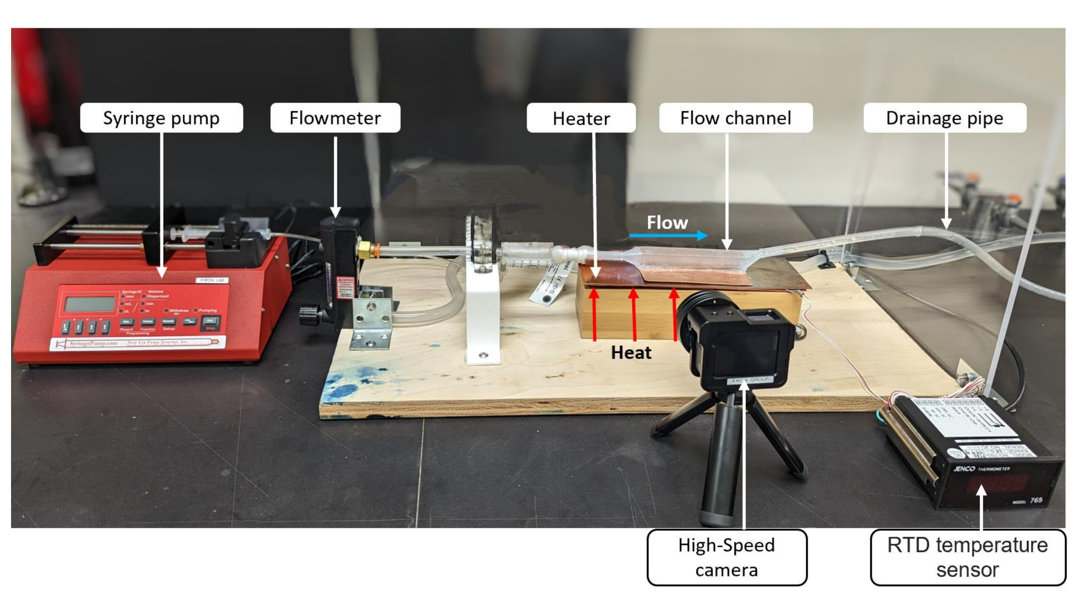
Flow channel with offset outlet

Printing & Polishing: The channels are printed using the EnvisionTec digital light processing 3D printer. This is a resin-based printer and for this study, two types of commercial EnvisionTec resin were tested: E-shell and E-clear. The goal was to have a transparent channel and E-clear was chosen as the better option since it had more transparent results after printing and polishing.

Flow channel printed with E-shell resin

Flow channel printed with E-shell resin

Experimental Setup: The flow visualization technique used is the dye injection method in which a high-speed camera records the dye flow patterns representing the flow fields in the channel.



Results and Discussion

Three dimensionless numbers are used to describe the flow properties.
Reynold's number (Re) helps predict flow patterns (e.g laminar or turbulent) in different fluid flow situations
Rayleigh's number (Ra) characterizes the fluid's flow regime (e.g laminar or turbulent) for natural convection processes
Richardson's number (Ri) represents the importance of natural convection relative to the forced convection

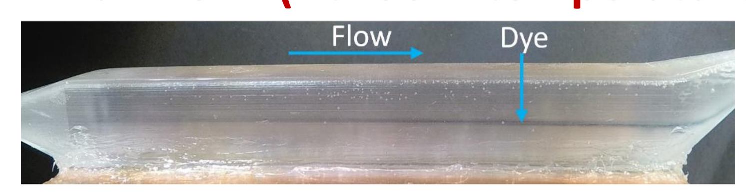
- Natural convection is negligible when Ri < 0.1
- Forced convection is negligible when Ri > 10
- Neither is negligible when 0.1 < Ri < 10.

$$\mathrm{Ra}_x = \frac{g\beta}{\nu\alpha}(T_s - T_\infty)x^3$$

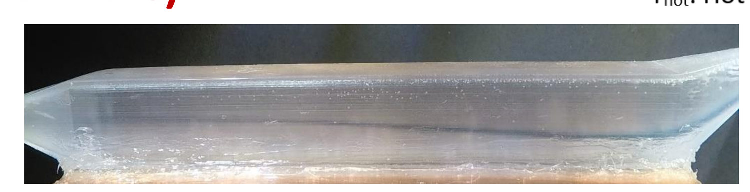
$$\mathrm{Ri} = \frac{g\beta(T_{\mathrm{hot}} - T_{\mathrm{ref}})L}{V^2}$$

x: characteristic length
g: acceleration due to gravity
β: Thermal expansion coefficient
μ: is the kinematic viscosity
α: thermal diffusivity
Ts: Surface temperature
T_∞: Fluid temperature far from the surface
Gr: Grashof number
Pr: Prandtl number
T_{ref}: Reference temperature
T_{hot}: Hot wall temperature

1. Laminar Flow (At room temperature T=24°C)



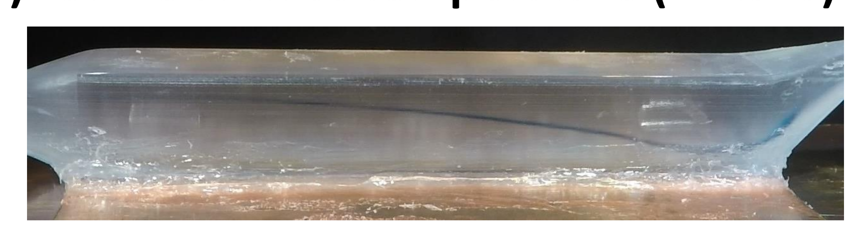
Flow pattern at Re = 35.6



Flow pattern at Re=133.3

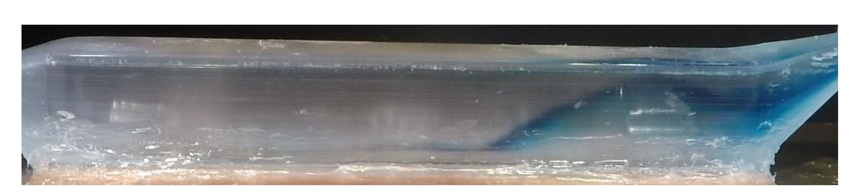
2. Mixed Laminar Flow (With Heating)

a) Same surface temperature (T=45°C)



Re = 35.6 Ra = 3.05x10^6 Ri = 7.4
Both forced and natural convection since 0.1<Ri<7.4

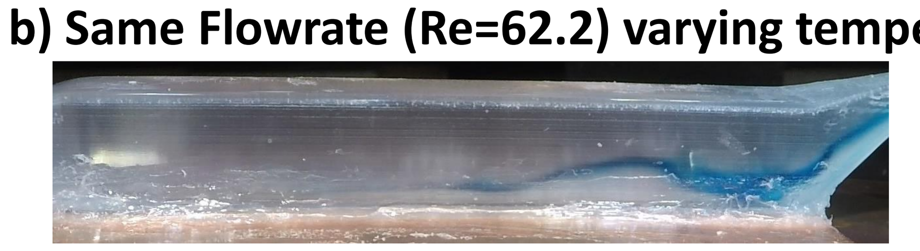
Re = 62.2 Ra = 3.05x10^6 Ri = 2.6
Both forced and natural convection since 0.1<Ri<7.4



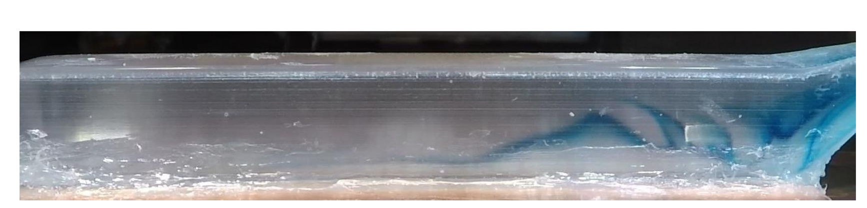
Re = 106.7 Ra = 3.05x10^6 Ri = 0.87
Both forced and natural convection since 0.1<Ri<7.4

When Ra is small (3.05x10^6), the dye patterns are highly ordered at lower Re while the dye pattern became slightly disordered at higher Re. Thus, Re determines the flow pattern more than the Ri

b) Same Flowrate (Re=62.2) varying temperatures



T = 50.4°C Ra = 4.49x10^6 Ri = 4.8
Both forced and natural convection since 0.1<Ri<7.4



T = 60°C Ra = 8.07x10^6 Ri = 7.5
Both forced and natural convection since 0.1<Ri<7.4

When Ra is large (> 4x10^6), the dye patterns become disordered as Ri increased. This experimental result shows the importance of Ri

Conclusion

- We created transparent 3D printed channels for the flow visualization experiment by determining the appropriate wall thickness, 3D printing resin, and polishing process.
- A dye solution was prepared with a similar density to the working fluid.
- The channel was used to visualize the mixed convection flow as a function of the bottom wall temperature and the Rayleigh number which is a dimensionless number associated with the buoyancy-driven flow.
- The spatiotemporal instabilities of mixed convection in horizontal channels are investigated by capturing the flow patterns using a high-speed camera.

Future Work

- Explore the effect of changes in channel aspect ratio on the flow patterns observed.
- Use Computational Fluid Dynamics software to compare numerical data with the experimental data obtained and understand the effects of surface roughness on the flow patterns

Acknowledgement

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