Rayleigh-Benard Convection

Simulation vs. Experimental Results

Aaron Kaufman, Sarah Kintner, Dr. Paul Thomas | Physics and Astronomy

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Abstract

The Rayleigh- Benard convection model describes convection currents that organize in fluid that is heated from below; a regular pattern of convention cells, known as Benard cells, are characteristic of this model.

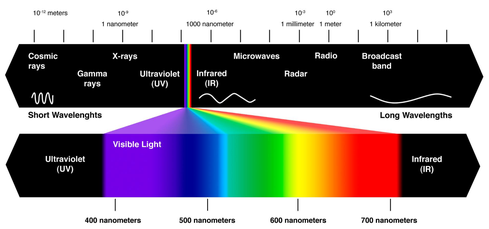
Warm water is less dense than cool water and consequently rises; as the warm water cools, its density increases and begins to sink.

The system self-organizes into multiple Benard cells, each driven by density currents of warm water rising and cool water sinking

This project is based on a 2-D model of Rayleigh-Benard convection. Use of an FLIR Exx infrared (IR) camera (λ= 7.5 µm to 13 µm) allows researchers to compare computer models with experimental data. Infrared radiation, part of the electromagnetic spectrum, is emitted from objects as a function of temperature.

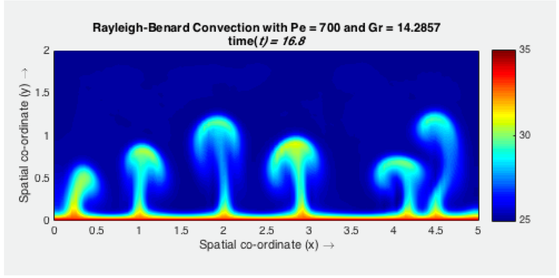
Introduction

- Heat convection transfers heat from one area to another as the heated medium moves away from the source and carries the heat with it.
- In a simple system, such as Raleigh-Benard Convection models, density current cells form.
- Computer simulations are used to model convection in a variety of systems
- IR cameras can be used to view heat convection in a 2-D scenario

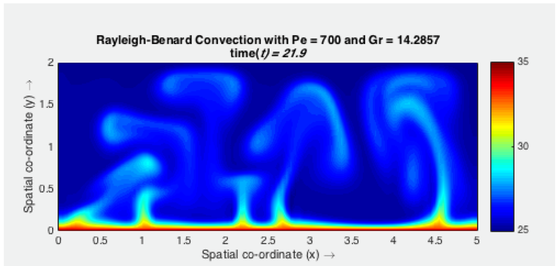


Computer Simulation

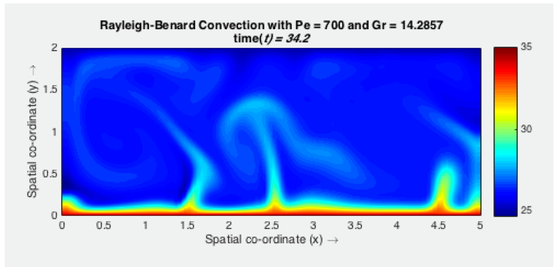
MatLab .m file supplied by MathWorks. 100 computational cells horizontal by 70 computational cells vertical.



Rising plumes

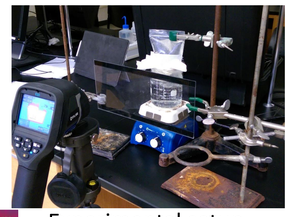


Rising and descending plumes
Visible convection currents

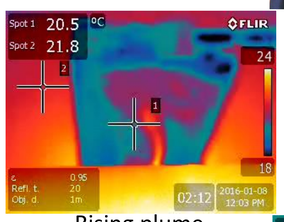


Decreasing intensity as the system approaches an equilibrium temperature

Experimentation

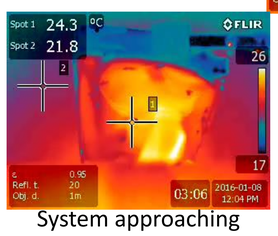


Experimental setup



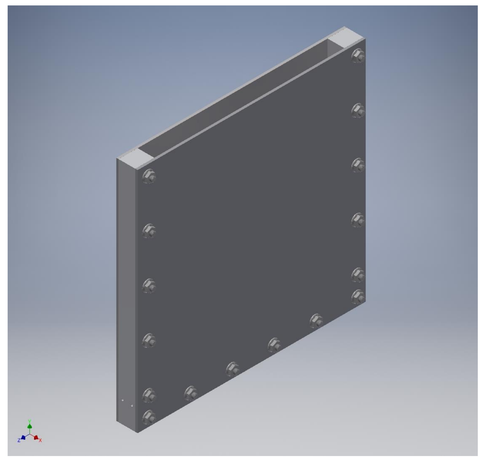
Rising plume

Rising and descending plume



System approaching equilibrium

- Preliminary tests displayed geometry similar to the computer simulation.
- Convections currents were driven as warmer) water (according to the color palette) rose and was replaced with cooler (darker) water.
- Proof-of-concept
- Polyethylene bag has a high percent transmittance of infrared.
- Plexi-glass (opaque to IR) shielded the IR camera from the heat source.
- A polyethylene bag partially submerged in a hot bath was the container for the heat convection.



Experimental tank design with one polyethylene face and a uniform heat source at the bottom.

Complications

- Uniform heat source location and design.
- Suitable material for IR transmittance and structural support.
- Polyethylene has low heat resilience.
  - Warping
  - Inconsistent seal
  - Thickness effects transmittance

Conclusion

We have demonstrated that we can, in principle, construct an experiment that permits an infrared movie to be made of a convecting cell that can be compared to a numerical Rayleigh-Benard model of the same situation. Problems that remain are the comparison between a two dimensional simulation and a three dimensional tank. Also, the infrared transparent material limits the design of the experiment because of physical properties like rigidity, heat resistance, and percent transmittance. Relationships between the Rayleigh-Benard model and the preliminary experiment can be seen in both the geometry and structure of rising and descending plumes.

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