Effects of Gravity on Supercritical Water Oxidation (SCWO) Processes

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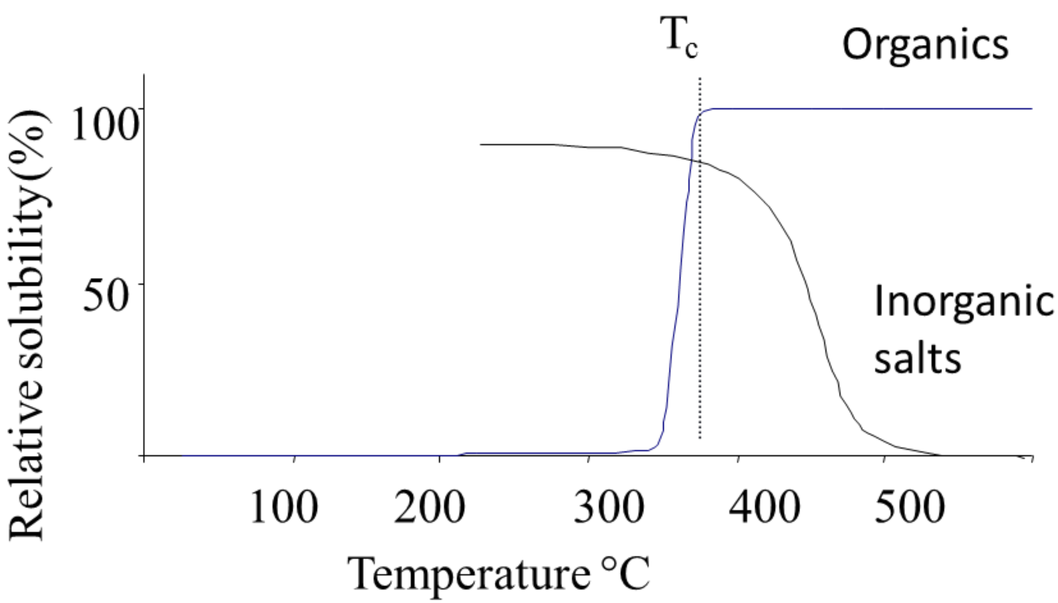
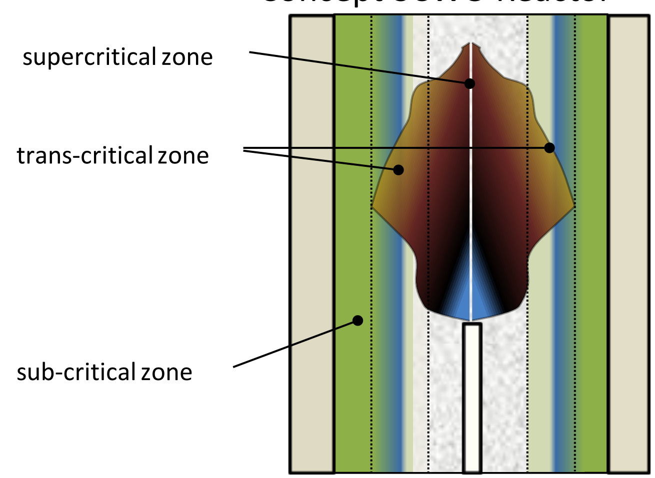
Motivation and Application

Precursor study to the investigation of supercritical water oxidation (SCWO)

Dissolve inorganic precipitates generated during SCWO in a subcritical shroud



Hydrothermal Flame Concept SCWO Reactor



Objectives

- Characterize the hydrodynamics of supercritical water jets
- Identify the jet injection conditions leading to laminar and turbulent regimes
- Assess the effects of buoyancy on the jet behavior

Re ~ Momentum/Viscous

$$Re = \frac{\rho U d}{\mu}$$

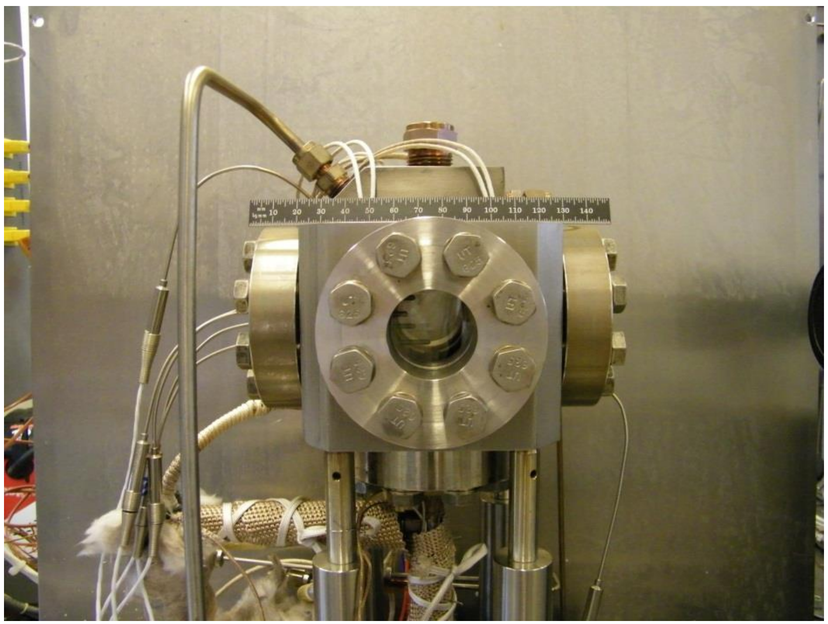
F ~ Momentum/Buoyancy

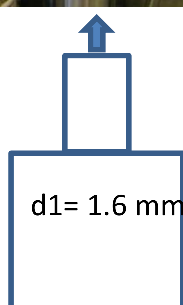
$$F = \frac{U}{(\frac{\Delta\rho}{\rho} g d)^{1/2}}$$

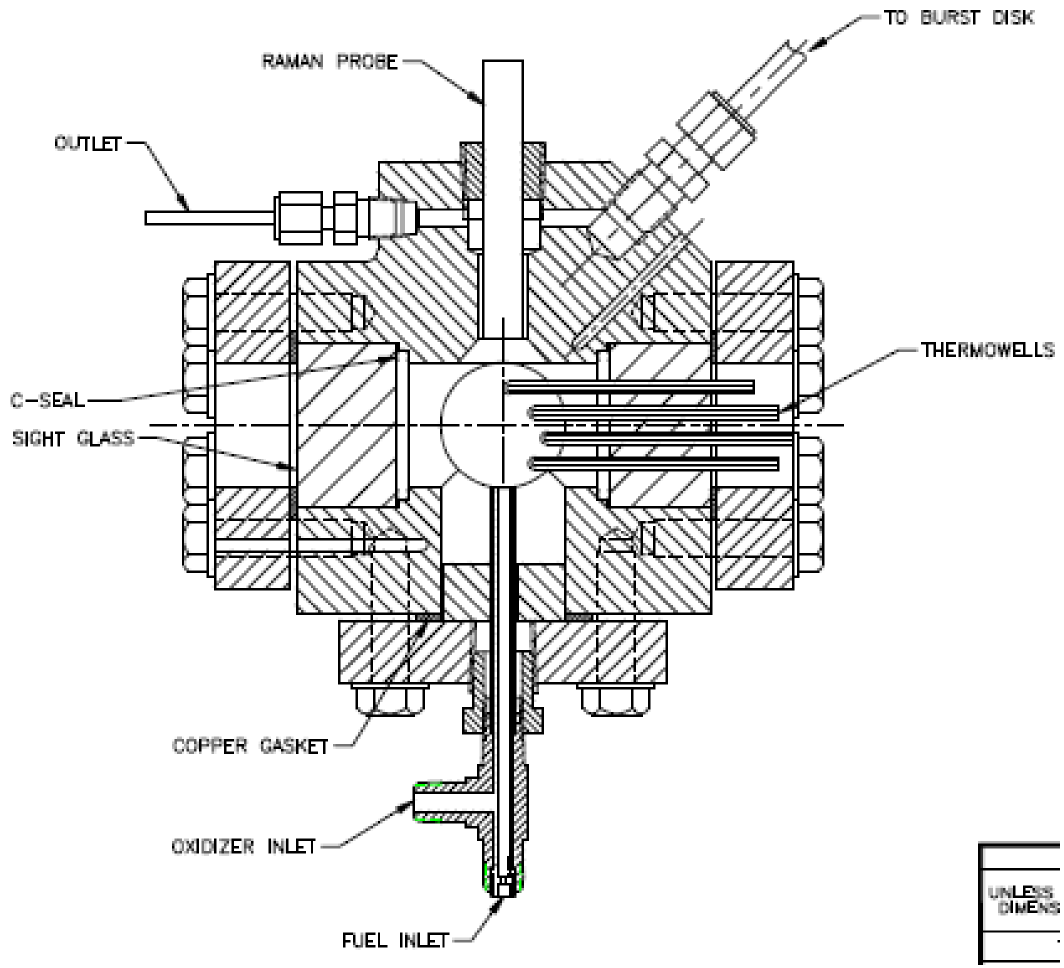
Gr ~ Buoyancy/Viscous

$$Gr = (\frac{Re}{F})^2$$

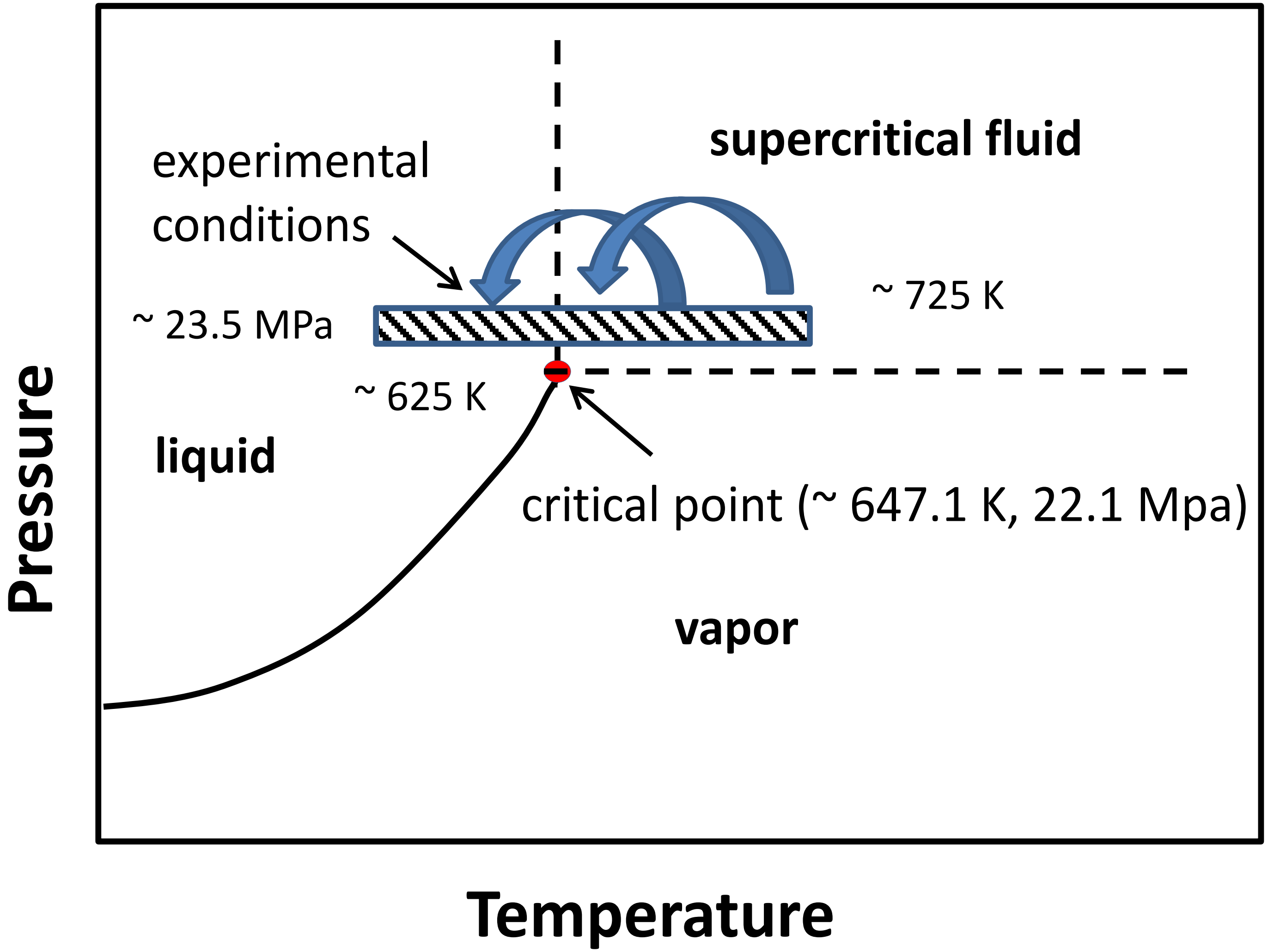
SUPERCRITICAL WATER TEST CELL



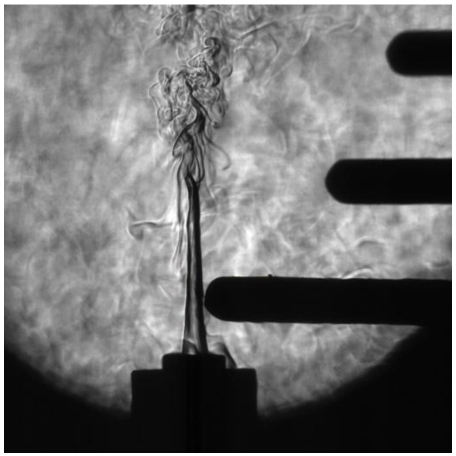




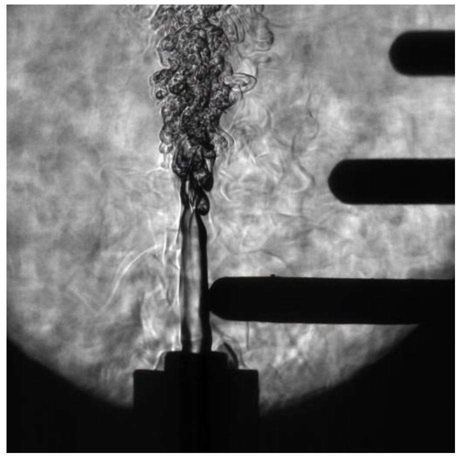
Experimental Conditions



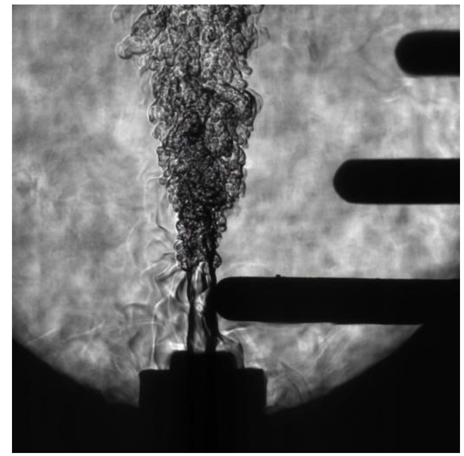
Supercritical Jet Injected into Supercritical Water



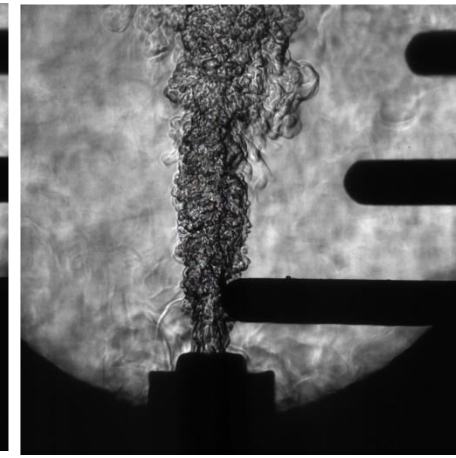
Re = 448
F = 1.37



Re = 1330
F = 3.81



Re = 1780
F = 5.03

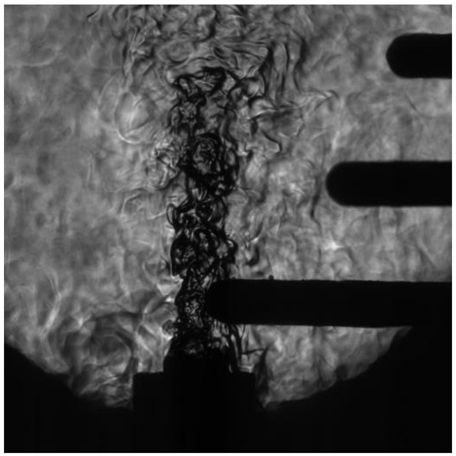


Re = 2680
F = 7.31

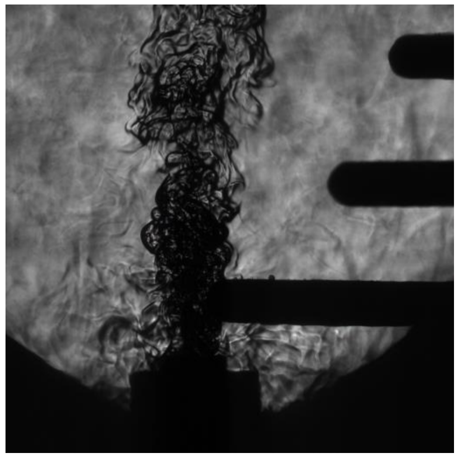
As Re increases, jet transitions from mostly laminar to turbulent

Classical Reynolds number transition to turbulence of jets

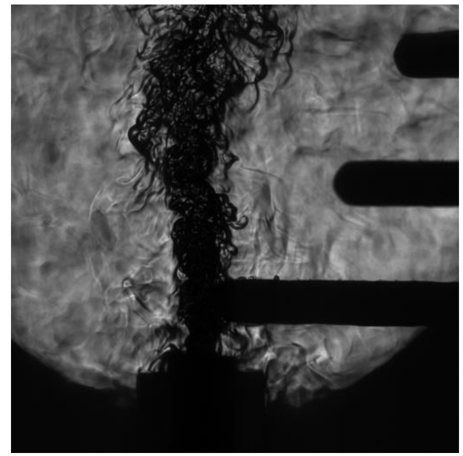
Supercritical Jet Injected into Subcritical Water



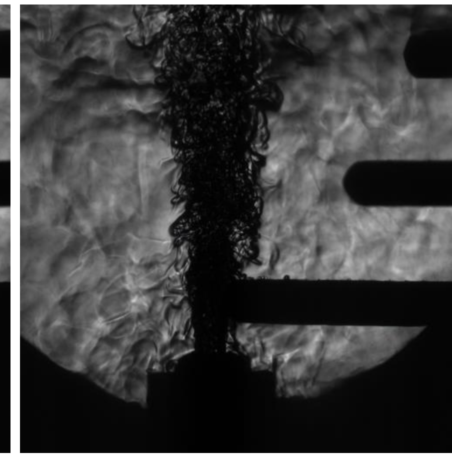
Re = 471
F= 0.5



Re = 943
F= 1.0



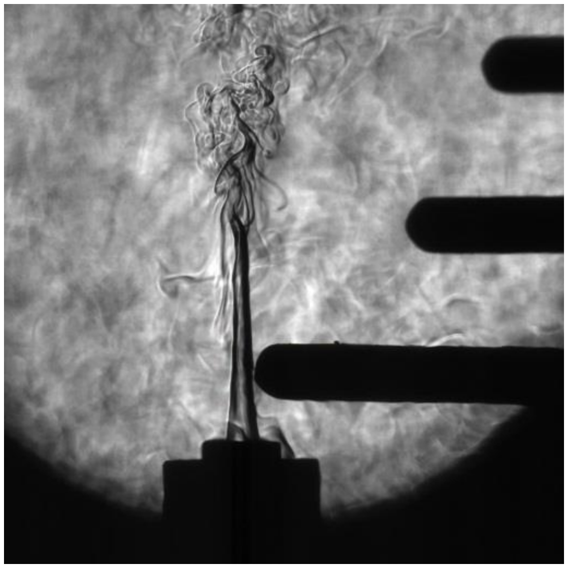
Re = 1890
F= 2.0



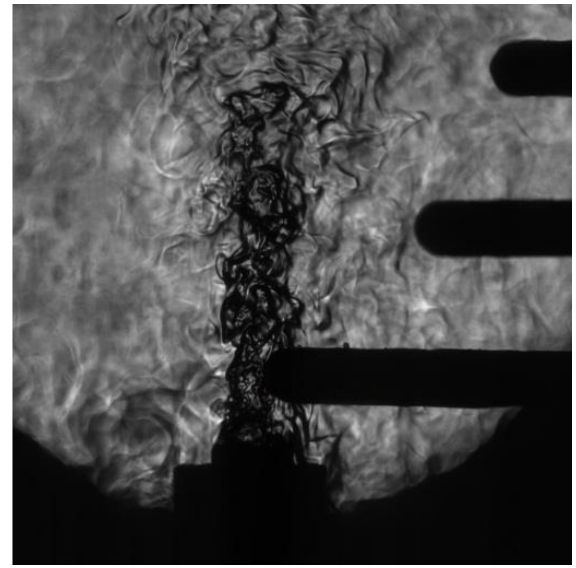
Re = 2830
F= 3.0

Transition appears to be from turbulent buoyant plume to turbulent buoyant jet

Jet Comparison



Supercritical into supercritical
Re = 448
F = 1.37



Supercritical into subcritical
Re = 471
F= 0.5

For similar Reynolds and Froude numbers the character of the two jets is strikingly different.

Property Variations near Critical Point

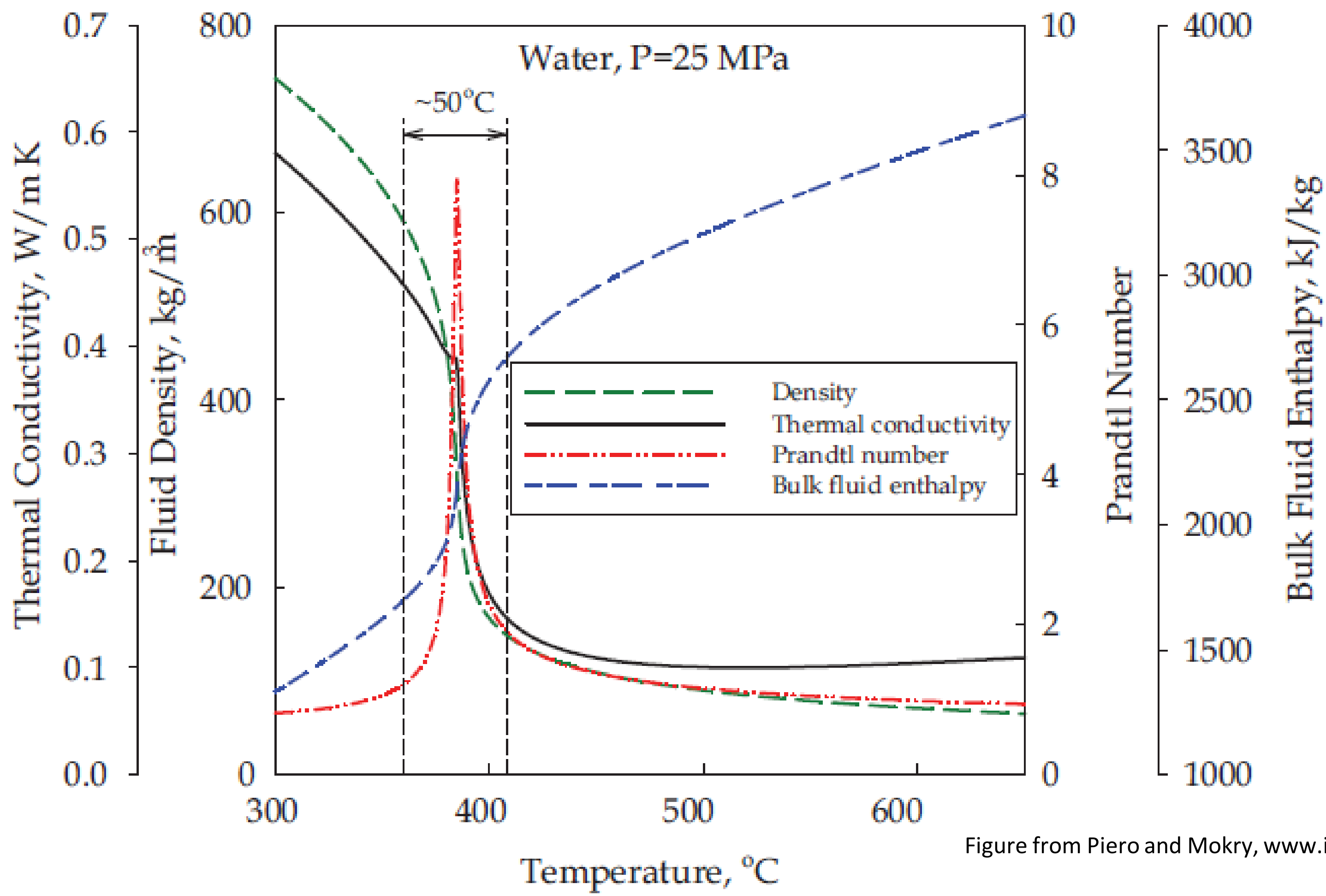
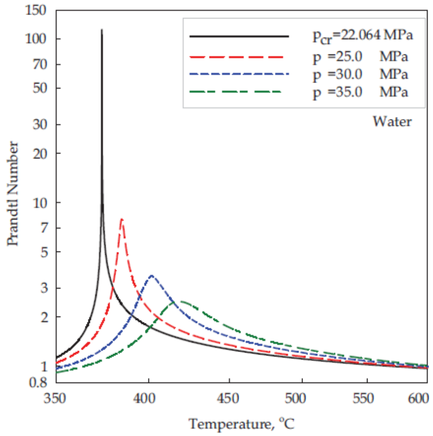


Figure from Piero and Mokry, www.intechopen.com

Influence of compressibility, C_p, λ ?

Vorticity Equation

Consider azimuthal vorticity equation for axisymmetric, variable density with buoyancy flow.
Viscous effects not shown



$$V = \nabla \boldsymbol{x}\, \psi + \nabla \varphi$$

$$\omega = \nabla \boldsymbol{x}\, V = \nabla \boldsymbol{x}\, (\nabla \boldsymbol{x}\, \psi)$$

$$\nabla . \mathrm{V} = \nabla^2 \varphi$$

$$\frac{D\omega}{Dt} - \omega \frac{v_r}{r} + \omega(\nabla . \mathrm{V}) = \frac{1}{\rho^2}\left(\frac{\partial \rho}{\partial r}\frac{\partial p}{\partial x} - \frac{\partial p}{\partial r}\frac{\partial \rho}{\partial x}\right) - \frac{g}{\rho}\frac{\partial \rho}{\partial r}$$

Vortex Stretching

Compressibility $\sim M^2$

Baroclinic $\sim Pr$

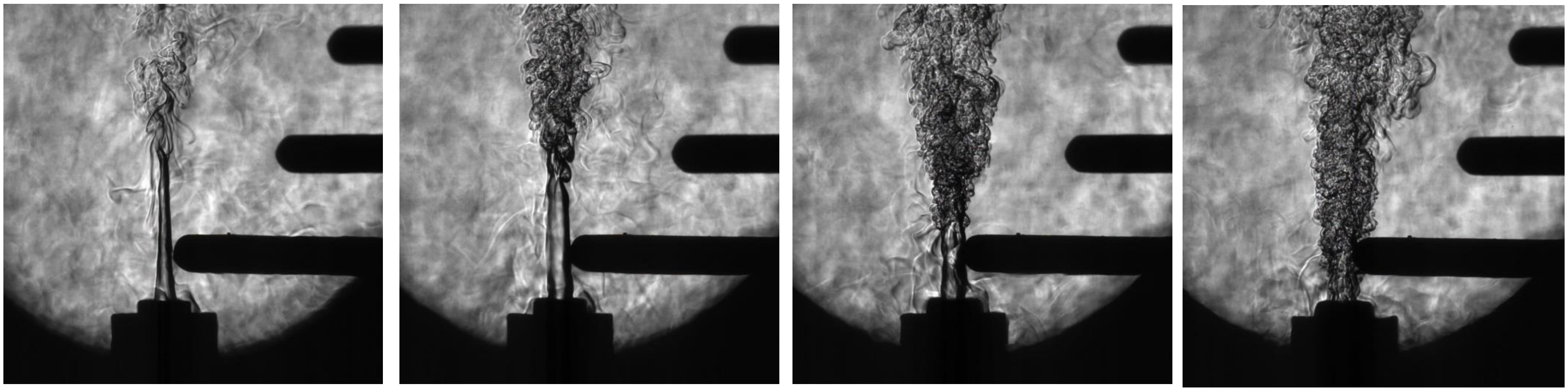
Buoyancy $\sim Pr/F^2$

- Prandtl number ($Pr = \mu C_p/\lambda = \delta_V/\delta_T$) comes in because thermal mixing layer thickness can be much different (thinner) than velocity shear layer

  Note $Pr/F^2 \sim Ra/Re^2$
- $M^2 << 1$ for the conditions of the experiment. It can be large very close to the critical point (speed of sound -> 0)

Supercritical Jet Injected into Supercritical Water

Transition from Buoyant Laminar Jet to Buoyant Turbulent Jet



Re = 448
Pr/F^2= 1.4

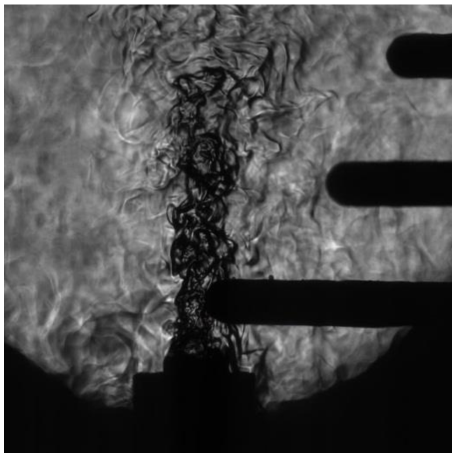
Re = 1330
Pr/F^2= 0.2

Re = 1780
Pr/F^2= 0.11

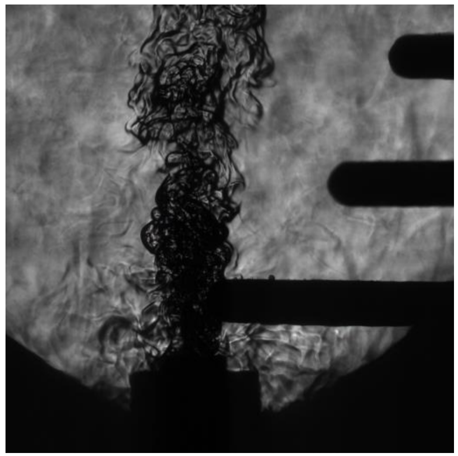
Re = 2680
Pr/F^2= 0.05

Supercritical Jet into Subcritical Water

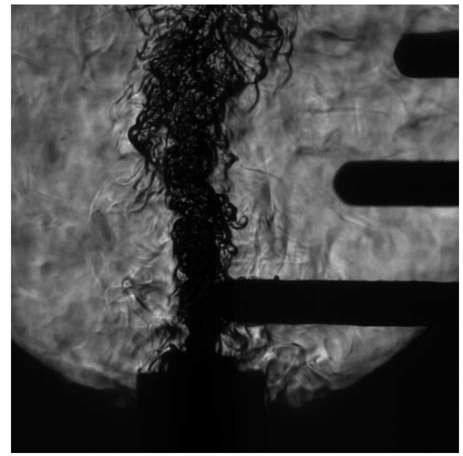
Transition from Buoyant Turbulent Plume to Buoyant Turbulent Jet



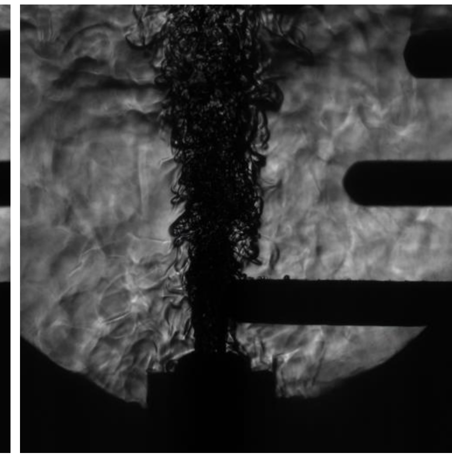
Re = 471
$Pr/F^2 = 56$



Re = 943
$Pr/F^2 = 14$

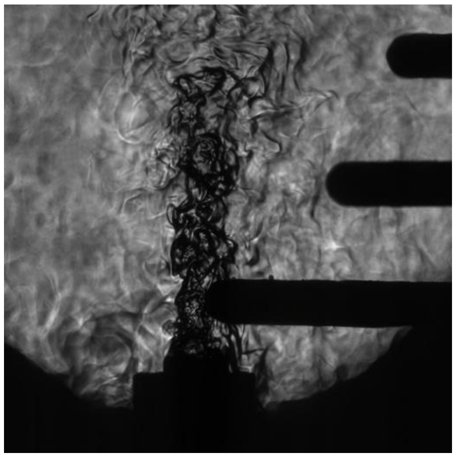


Re = 1890
$Pr/F^2 = 3.5$

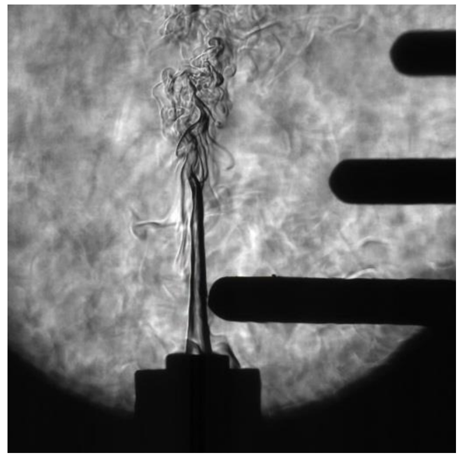


Re = 2830
$Pr/F^2 = 1.6$

Findings



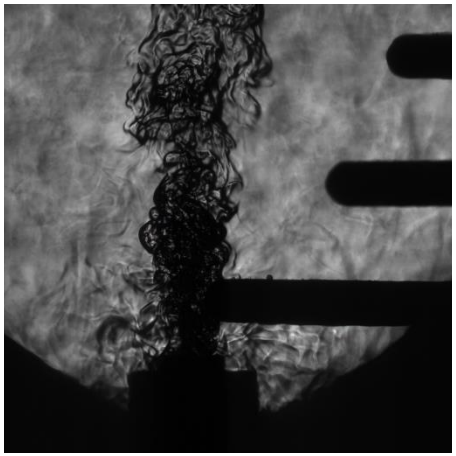
Re = 471
Pr/F^2= 56



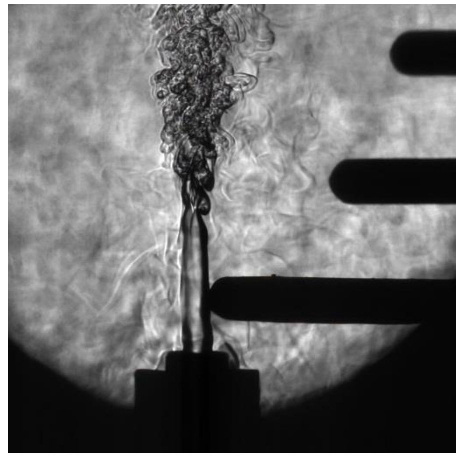
Re = 448
Pr/F^2= 1.4

At low Reynolds number, the parameter Pr/F^2 controls the laminar/turbulent nature of the jet . For values of the parameter >>1, the jet is turbulent due to strong buoyancy effect.

Findings (contd)



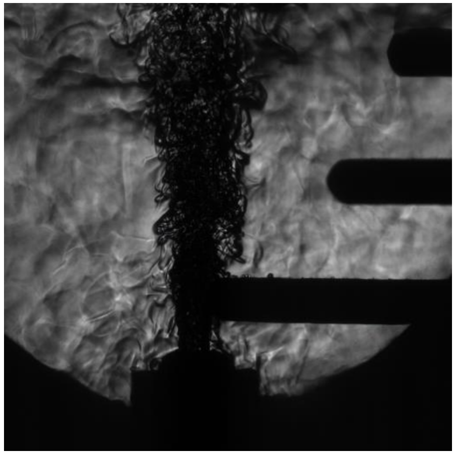
Re = 943
Pr/F^2= 14



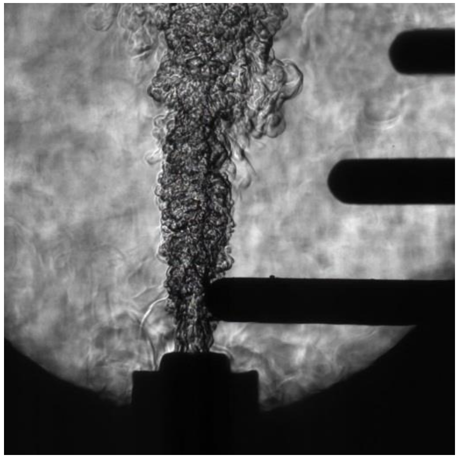
Re = 1330
Pr/F^2= 0.2

At intermediate Reynolds number the situation is similar to the low Reynolds number case.

Findings (contd 2)



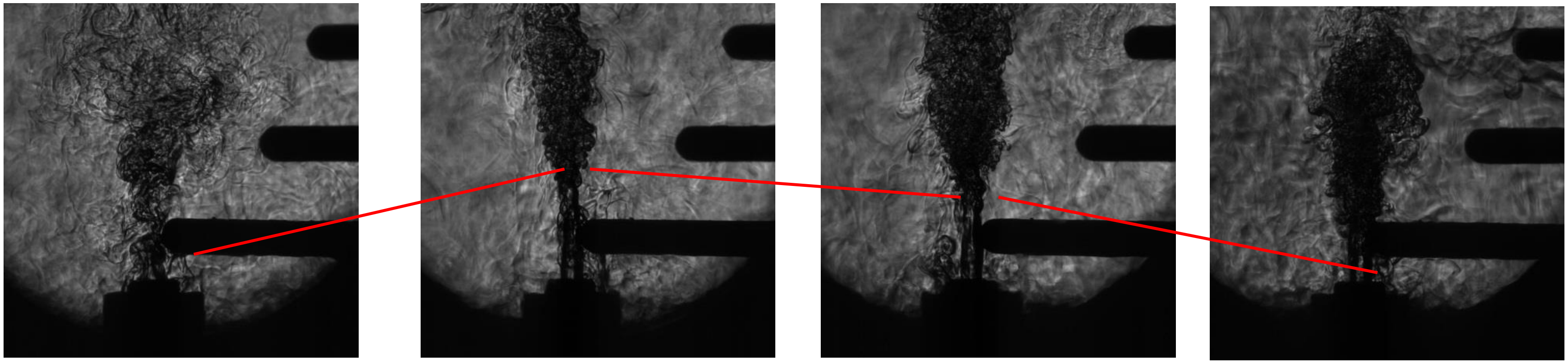
Re = 2830
Pr/F^2= 1.6



Re = 2680
Pr/F^2= 0.05

At large Reynolds numbers (> 2000), the jet is turbulent.

Supercritical Jet (~450 C) Injected into Transcritical Water (~380 C)



Re = 466
Pr/F^2 = 7

Re = 935
Pr/F^2 = 1.2

Re = 1400
Pr/F^2 = 0.6

Re = 1880
Pr/F^2 = 0.4

Note appearance of laminar length as flow transitions from plume to jet behavior

Summary

- Behavior of supercritical water jets injected into subcritical and supercritical was studied
- The laminar/turbulent nature of the jet under gravitational conditions depends upon the Reynolds number of injection and the parameter Prandtl number/(Froude number)^2
- Compressibility may be important near the critical point but it is not clear it can be separated from gravity effects on the ground

Acknowledgements

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