Initial Study of Supercritical Fluid Blowdown

Guillaume Mignot, Mark Anderson, Michael Corradini
University of Wisconsin-Madison, Department of Engineering Physics

Introduction:

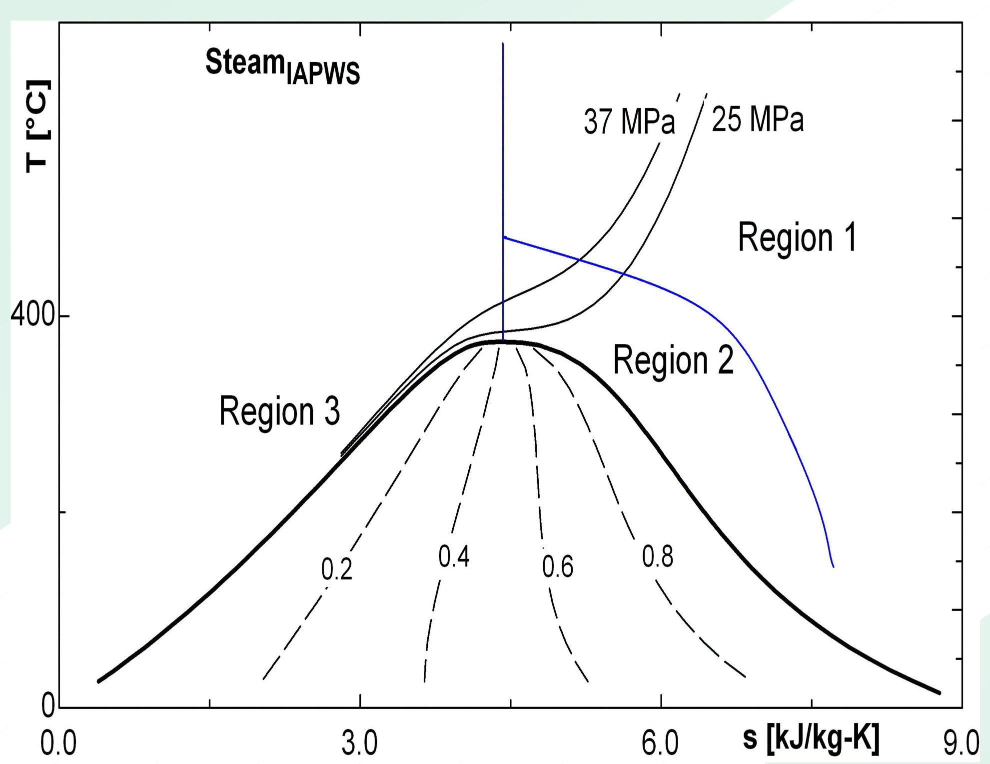
Advanced power cycles are investigating supercritical (SC) fluid as an optimal cooling fluid. The motivation of this work is based on three major reasons. First, by using a SC fluid, as a single-phase fluid, there is no concern about the heat transfer discontinuities. Secondly, it reduces the required mass flow substantially. Finally this simplifies the power cycle as fewer components are required (in particular phase separator). However those improvements do not come without any disadvantages. Effectively with the direct cycle design the loss of flow transient becomes the major concern in potential transients and accidents. This loss of flow can be caused by pump stoppage or a pipe rupture. In both cases the relevant parameter will be the time as it will specify the type of response to adopt to control the transient.

That is why the study of SC fluid blowdown has been initiated at the University of Wisconsin in order to characterize the critical mass flow rate of different supercritical fluid under a large range of temperature and pressure. An initial calculation has been done to evaluate the different behaviors of the supercritical fluid in a blowdown event and to design the experiments which are going to be run.

Initial calculation:

As an initial study, calculations have been done to estimate the mass flow rate of the fluid during a blowdown transient using a homogeneous equilibrium model when a two-phase flow appears in the model. They were conducted under both isentropic and friction conditions. These first calculations enabled us to map the behavior of the supercritical fluid during a blowdown in function of the initial temperature and pressure in the vessel.

Blow down map depicted in a Temperature-Entropy diagram



Three domains are defined depending on the scenario occurring during the blowdown proceeding.Considering the first region the fluid remains in a single phase flow during the transition from the supercritical fluid to superheated steam.No second phase is expected in the area of the break. Region 2 is characterized by a transition from SC to subcritical condition with the appearance of a second phase in the pipe or at the exit; that is condensation is expected.Finally,in the third and last region the transition into the subcritical region leads to the formation of a second phase through a vaporization process.

Abstract:

The behavior of supercritical fluid (SC) during a blowdown has been investigated. A model based on a steady state Homogeneous Equilibrium Model (HEM) and conditions with and without friction is presented. Calculations indicating three different possible regimes in a blow down scenario are calculated with this model. The single-phase flow in the supercritical region and the transition either in to sub-cooled water, a two-phase fluid or a superheated gas near the critical point results in an interesting flow with a wide range of behavior. Indeed depending on the initial conditions and the geometry either vaporization or condensation can occur either in the pipe or at the exit.

Moreover those results are attempted to be extended to other fluids like CO_2, R22 or R134a by comparing its thermodynamic properties and dynamic evolution to dimensionless SCW results. Finally the design of an experiment with the depressurization of a supercritical water system is presented.

Chart of behavior for SC fluid blowdown

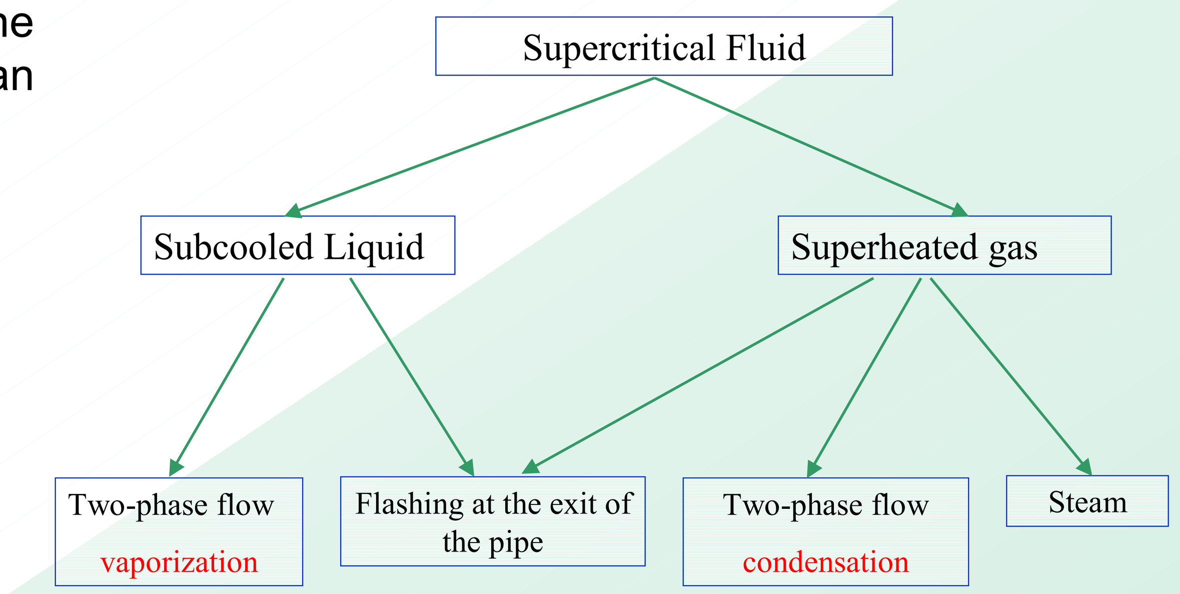
Here is a schematic view of the different behaviors which can occur during a blowdown.

Calculation parameters for steam IAPWS:

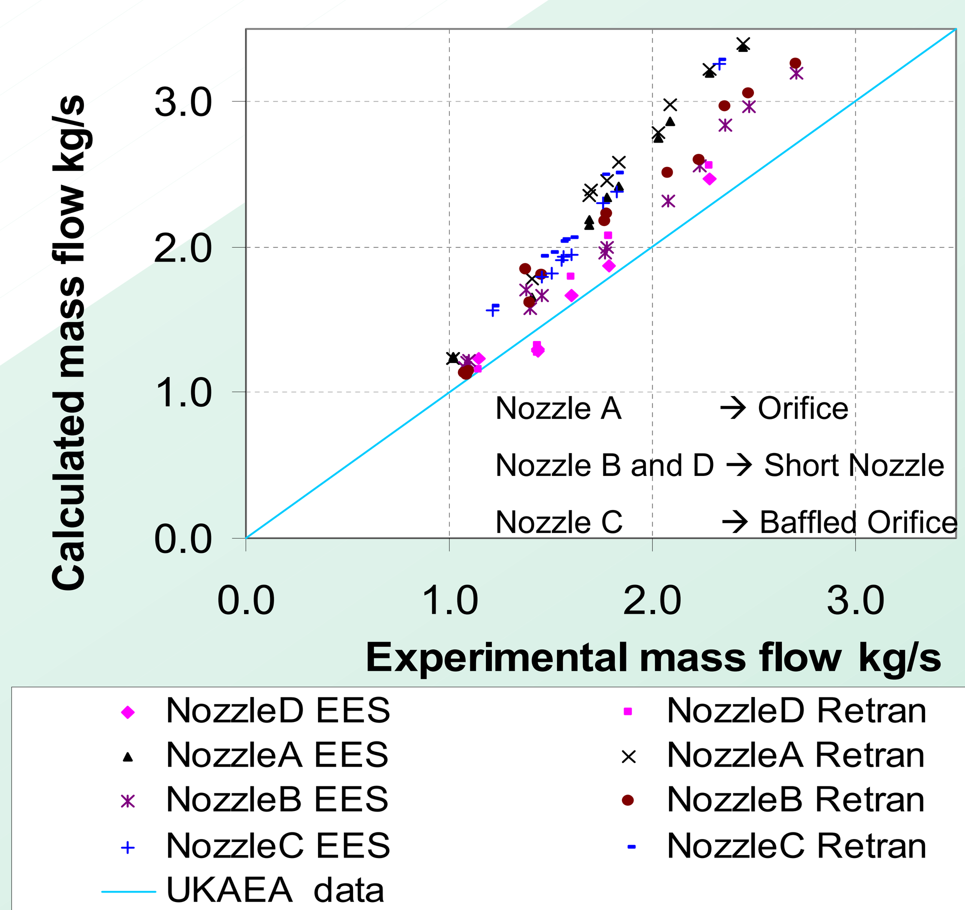
Pressure range: 25-37 MPa

Temperature range: 400-600 °C

Diameter : 0.25''



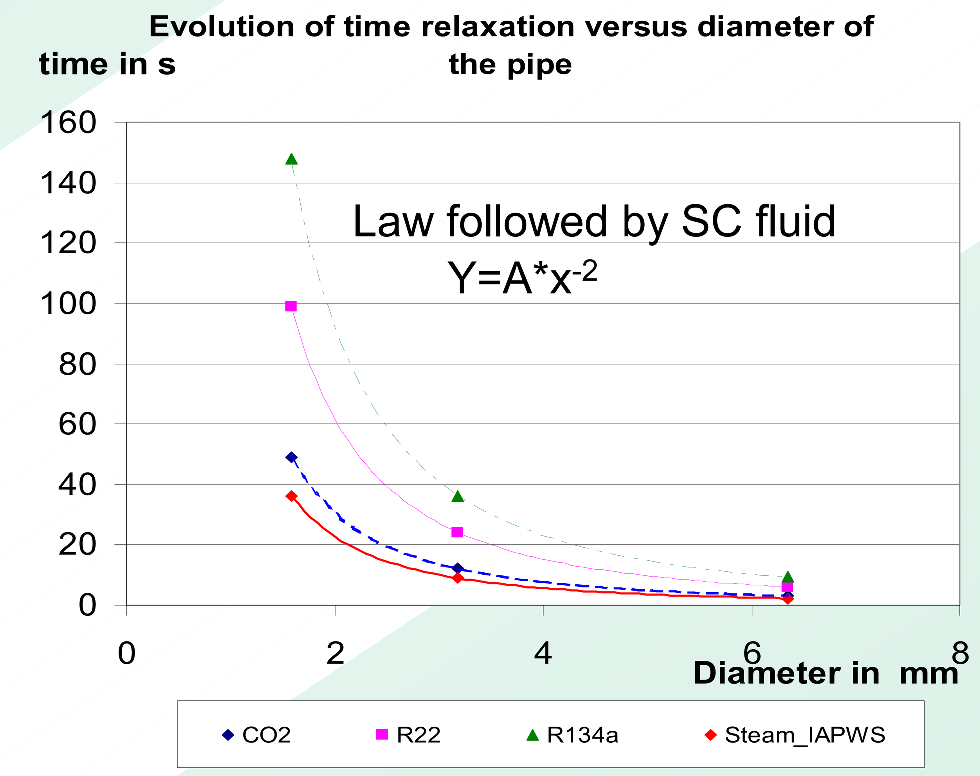
Comparison between UKAEA Data and Calculations

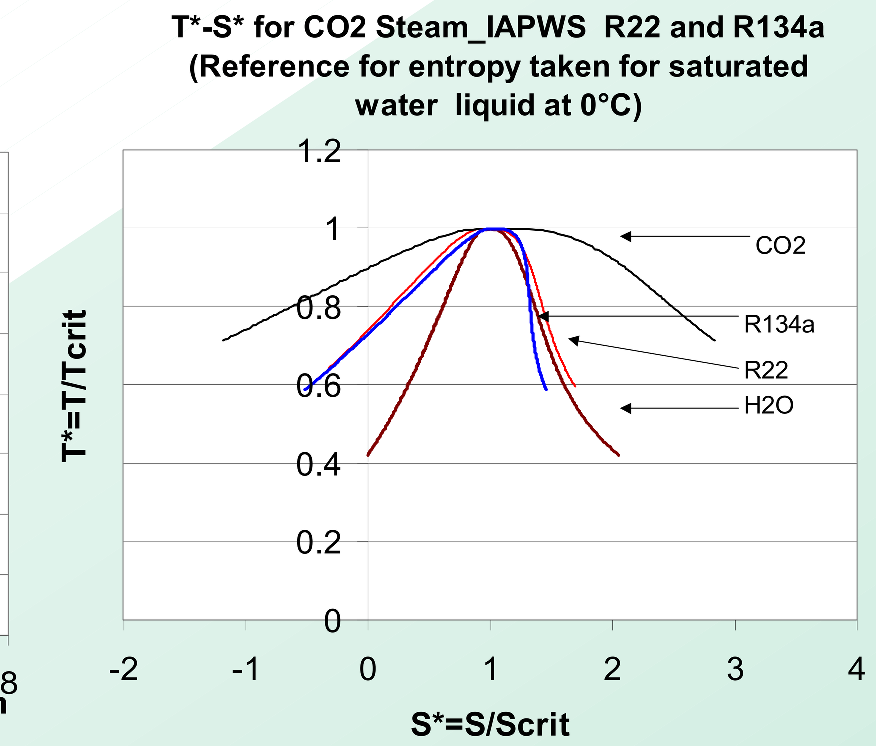


Comparison of UKAEA data and calculated mass flow rates with RETRAN and HEM-EES code

As a matter of validation of our code, calculations were done at the same conditions as those of the UKAEA experimental data. Considering the dimension of the nozzles (9 mm long 2mm diameter) the calculation were made assuming an isentropic flow without taking the geometry of the nozzles into account. The results are in accordance with RETRAN calculations and the experimental mass flow at low mass flow. However, at high mass flow corresponding to conditions of high pressure and low temperature the results show that the calculations diverge from the data line. This divergence is more pronounced for orifices than for nozzles. This is due to the contraction of the flow at the location of the orifice.

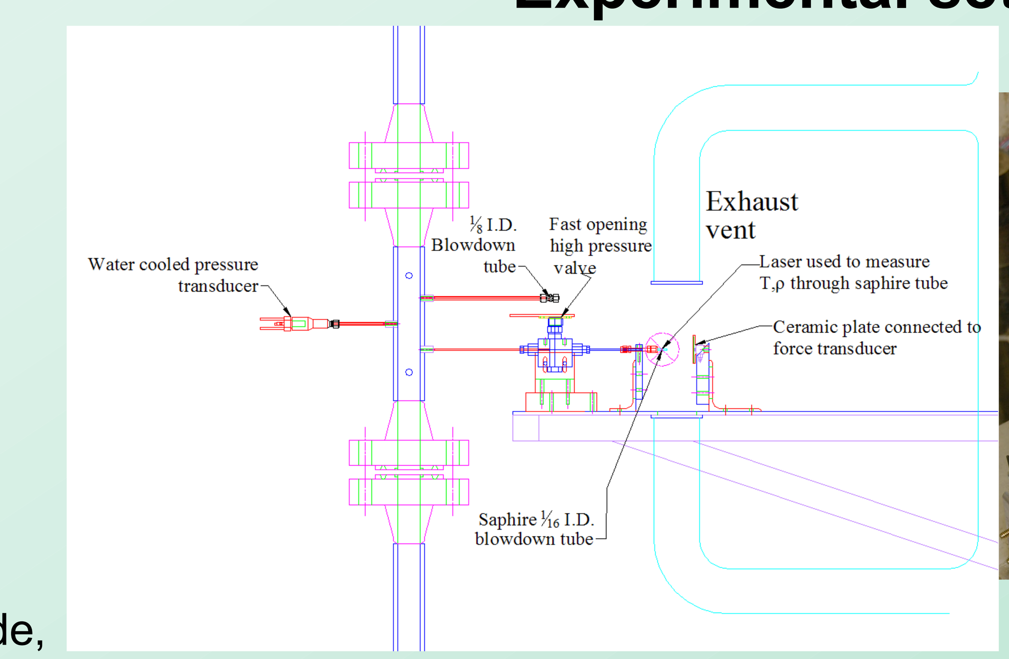
Generalization to other SC fluids

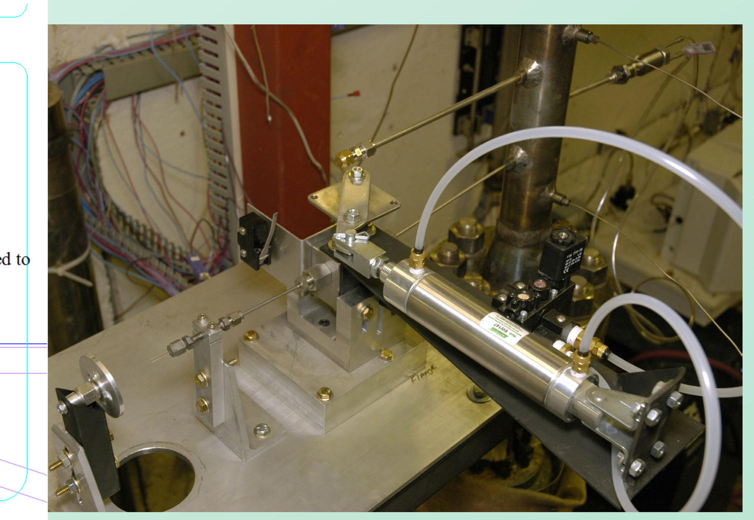




In order to extend our work to other SC fluid calculations have been done based on dimensionless numbers to compare the thermodynamic properties and the dynamic behaviors for a vessel blowdown simulation. All those fluids have the same initial conditions considering their own critical point. Despite its disparity with water, CO_2 is the fluid which behaves the most like water.

Experimental set up





The UW supercritical fluid facility located at our Tantalus Lab allows us to observe the transient depressurization for a large range of pressure and temperature. The reaction force on a plate will be used in addition to the pressure of the loop to determine the mass flow. In addition a laser instrumentation based on absorption wave length will give us the temperature and density of the fluid just before the shock occurs at the exit of the pipe.

Current observations:

- A HEM code was developed to predict the behavior of SC fluid
- A large range of behaviors was shown. They are characterized by the initial conditions at the location of pipe rupture.
- The extension of our result for water to other fluids shows good consistency; for example CO_2 data from University of Hamburg correlate our pressure transient calculations
- Experiments are being developed for Water and other SC fluids