The following explore super-critical steam generation and what is of interest?

Building an efficient small high output steam generator is of interest to anyone building and automotive steam system. Harry Schoell has built a small high output steam system. It has utilized several new innovative ideas. Maybe not so new but, according to him, has made them work. Water lubrication has been proposed and tried before. Harry clames to have it working. One of the more intriguing ideas is the use of close to super critical pressure. By increasing the operating pressure the power plant size can be substantially reduced. Going above critical pressure two phase boiling is avoided. Below the critical pressure of 3200.116 PSIA there exists a separation, difference in heat content, enthalpy, density etc, between the liquid and gas phases at the same temperature along the saturation line. Along the saturation line for any given temperature there can exist a mixture of liquid and gas. It is this two phase region that causes problems. There is substantial expansion as the liquid vaporizes into a gas. The force of this expansion acts in all directions. It displaces a volume of water equal to the vaporized gas volume. Acceleration of fluid by that expansion creates back pressure opposing flow. In the ext ream case this expansion forces liquid out of the boiler known as carry over.

You can find many references that define the critical temperature of a substance to be a temperature below which no liquid can exist. But if one looks at the definitions of gas and liquid we find the distinctive difference to be compressibility. A liquid is a non-compressible fluid. A gas is compressible fluid. Looking at the compressibility graph one can see that above the critical pressure there a change in compressibility with temperature. If one finds the like compressibility values of gas and liquid below and above the critical pressure could we not say they are liquid and gas states. For example at 3100PSIA we find the compressibility of the liquid to be \(0.0000421371022588\) cuft/lb/psi and the vapor to be \(0.00002853018320962\) cuft/lb/psi. If we find the same compressibility factors for 3500 PSIA could we not say the same compressibility values indicate the same states. We find at 3500 PSIA, 714.703679995797 F a compressibility of \(0.00000421371022588\) cuft/lb/psi and at 789.7927082516071 F a compressibility of \(0.00002853018320962\) cuft/lb/psi. Would not these also gas and liquid states. Thoes compressibilities exist at 5000 PSIA as well if we consider thoes compressibilities liquid and gas states below the saturation pressure. Would not they also be liquid and gas states above. A method of finding phase change temperature is be looking at the derivative of a property of the substance. The phase change occurs at max or min point. The second order derivative equal to 0. In graph 3 “Specific Volume change per degree F” we see that where the specific volume change per degree F peeks (max point) coincides with the phase change point along the saturation line. W also that continuing on above the critical pressure. The function PhaseT finds that point and returns the temperature given the pressure. After graph 6 there some specific examples for the above compressibility values. Note PhaseT temperature lays between thoes compressibilities. They are peak points of the rate of change of compressibility with respect to enthalpy for that pressure as well.

What is of interest is how heat conductivity, density, and the rate of volume change per degree F as the fluid is heated at constant pressure. The graphs were generated with MathCad using Mr. Eds IFC-67 steam properties plug in. A line on the graphs shows the relation of the property to temperature changes at a specific constant pressure. The blue lines are sub-critical pressures 1000 PSIA, 1500 PSIA, 2000 PSIA, 2500 PSIA and 3000 PSIA. The black line 3200.116 PSIA (critical pressure) shows an animally close to critical temperature. That is a problem with the IFC-formulations. The 3500 line also shows a similar animally. The red lines are super-critical pressures 3500PSIA, 4000 PSIA, 4500 PSIA,5000 PSIA ... 8000 PSIA. There some anomalies in \(\frac{d}{dt}v\) (specific volume change per degree F) graph.

Thros are occurring at region boundaries of the IFC-67 formulation where different formula are used in different regions and may have slightly different values at the boundary. The horizontal axis is temperature and the vertical axis the property of interest. On each graph there 16 constant pressure lines from 1000 PSIA to 8000 PSIA. Sub-critical to super-critical in increments of 500 PSI. The first graph is of heat conductivity vs temperature. Observing the sub-critical pressure lines you can see that there is an abrupt drop in heat conductivity as liquid changes to a vapor at constant saturation temperature. While at and above the critical pressure it becomes more and more of a gradual change. The density plots are much the same. Making an abrupt change below the critical pressure and more and more gradual change as pressure is increased above the critical pressure.

As I said before there is a liquid and gas phase above the critical pressure. In the last graph that can defiantly be seen. The liquid phase is characterized by an increasing rate of volume change as temperature approaches the phase change temperature. At the phase change point the rate of change of specific volume with respect to temperature \(\frac{d}{dt}v\) peaks. A maxima point. Above the phase change temperature \(\frac{d}{dt}v\) is decreasing. Below the critical pressure there is an abrupt change in \(\frac{d}{dt}v\) as liquid changes into vapor. while at and above the critical pressure it is a gradual change right up to it's maxima. Interesting to note is the (over all) max \(\frac{d}{dt}v\) occurs at the critical point.
Heat conductivity at sub-critical pressures makes a stepped drop at the saturation temperature. The **black** critical pressure and following 3500 PSIA plots have anomalies probably because of the IFC-67 formulations having problem at computation boundaries and critical point discontinuities.
In this graph the rate of change of specific volume with respect to temperature at constant pressure plots illustrates how the phase change occurs at a maxima.

NOTE. liquid has an increasing rate of change while gas has a decreasing rate of change. Calculated as $\text{cuft/lb/F} = \frac{d}{dt} \left( \frac{ST_{\text{pdata}}(p,t,1,1)}{p=\text{constant}} \right)$. 
This graph illustrates that at super-critical pressure the liquid and gas phase do both exist. The liquid has nearly zero compressibility.
5. Isentropic Compressibility Log Scale

\[ \delta v_{\delta p}(3200.116, 705.1028) = 0.00001136367092678 \]

Critical point compressibility

\[ ST_{ptdata}(3100, 0, -1, 1) = 700.2767350560773 \]

Saturation temperature at 3100 PSIA  \( PhaseT(3100) = 700.2767350560773 \)

\[ \delta v_{\delta p}(3100, 700.2767350560773) = 0.00002853018320962 \]

Compressibility if vapor

\[ \delta v_{\delta p}(3100, 700.2600000000000) = 0.00000421371022588 \]

Compressibility if liquid

Find same compressibility at 3500 PSIA  \( tt := PhaseT(3500) = 719.5506814236438 \)

\[ \text{root}(\delta v_{\delta p}(3500, tt) - 0.00002853018320962, tt) = 789.79420995217 \]

Find same compressibility at 4500 PSIA  \( tt := PhaseT(4500) = 770.1069223846789 \)

\[ \text{root}(\delta v_{\delta p}(4500, tt) - 0.00002853018320962, tt) = 1086.4956080301986 \]

Find same compressibility at 5000 PSIA  \( tt := PhaseT(5000) = 795.0965551499106 \)

\[ \text{root}(\delta v_{\delta p}(5000, tt) - 0.00002853018320962, tt) = 1286.4400323110265 \]