

Analysis: theoretical expansion of steam compared to ideal gas

Recently I read an experimental analysis of an engine. <http://www.modeleng.org/articles/hall01.pdf> Making steam consumption and efficiency comparisons of superheated steam v saturated steam and common inlet - exhaust valve v separate inlet and exhaust valve. In that analysis there were charts showing the actual steam pressure in the engine. Ideal gas expansion lines were also included. That perked my interest. The author W. B. Hall did some great work in collecting and processing the experimental data. The analysis presented here is the ideal isentropic expansion curves of steam compared to the ideal gas formula using $n=1.35$ and $n=1.30$.

First is to set up approximate expansion parameters to those used in the Hall analysis: From the charts the cutoff pressure and ending pressures were approximated. I then figured the expansion ratio producing the ending pressure.

The first analysis if for saturated steam:

The approximated cutoff parameters. $P_c := 40$ from Fig 4 effects of superheat 0° F superheat.

$P_{t_c} := ST_ptdata(P_c, 1, -1, 1)$ cutoff steam properties state point saturated state.

$P_{t_{c_1}} = 267.249$ cutoff temperature saturated steam temp at P_c

$xr := 2.87$ expansion ratio

$V_c := P_{t_{c_2}}$ specific volume at cutoff $V_c = 10.497 \text{ ft}^3/\text{lb}$

$V_e := P_{t_{c_2}} \cdot xr$ specific volume at end of expansion $V_e = 30.125 \text{ ft}^3/\text{lb}$

$Pig(v, n) := P_c \cdot \left(\frac{V_c}{v}\right)^n$ Ideal gas formula for pressure given specific volume and k.

Set up to produce plot points. The number of points is $1 + \text{steps}$ set below. The iteration variable i is used to generate a volume array v . The volume array values are then used to generate the corresponding pressure arrays Pst , $Pig135$ and $Pig130$. The 135 and 130 corresponding to the k factor of 1.35 and 1.30.

$\text{steps} := 100$ $i := 0.. \text{steps}$ $\text{step} := \frac{V_c \cdot (xr - 1)}{\text{steps}}$ $v_i := V_c + i \cdot \text{step}$

$p := 15$ initial pressure guess needed for the root function. The variable p has no significance other in the root solving of the steam property point below

$Pst_i := \text{root}(ST_ptdata(p, P_{t_{c_5}}, 5, 1) - v_i, p)$ Generate the pressure line of isentropic steam expansion.

$Pig130_i := Pig(v_i, 1.30)$

$Pig135_i := Pig(v_i, 1.35)$

$P_{t_{shc}} := ST_ptdata(P_c, P_{t_{c_1}} + 93.1, 1, 1)$ cutoff steam properties state point superheated state. $P_{t_{shc_1}} = 360.349$

$V_e := P_{t_{shc_2}} \cdot xr$ $\text{step} := \frac{P_{t_{shc_2}} \cdot (xr - 1)}{\text{steps}}$ $v_i := P_{t_{shc_2}} + i \cdot \text{step}$ $P_{t_{shc_2}} = 12.002$ $V_e = 28.318$

$Pht_i := \text{root}(ST_ptdata(p, P_{t_{shc_5}}, 5, 1) - v_i, p)$ Generate the pressure line of isentropic steam expansion.

After doing the above I saw some interesting facts of saturated steam expansion: My theoretical expansion lines showed similar results with Hall's saturated steam line except for the closeness through the first part of expansion. I figured that was due to throttling. The saturated steam may have become slightly super heated dropping to the 42 PSI from

$\text{inlet} := \text{ST_pdata}(60, 1, -1, 1)$ $\text{cutoff} := \text{ST_pdata}(P_c, \text{inlet}_4, 4, 1)$ $\text{cutoff}_1 = 282.433$ $\text{cutoff}_1 - P_{t_{c_1}} = 15.184$ super heat

$$V_e := \text{cutoff}_2 \cdot \text{xr} \quad \text{step} := \frac{\text{cutoff}_2 \cdot (\text{xr} - 1)}{\text{steps}} \quad v_i := \text{cutoff}_2 + i \cdot \text{step} \quad \text{cutoff}_2 = 10.748 \quad V_e = 30.847$$

$\text{Pth}_1 := \text{root}(\text{ST_pdata}(p, \text{cutoff}_5, 5, 1)_2 - v_i, p)$ Generate the pressure line of isentropic steam expansion.

$\text{super} := \text{ST_pdata}(60, \text{inlet}_1 + 93.1, 1, 1)$ $\text{super}_c := \text{ST_pdata}(P_c, \text{super}_4, 4, 1)$

$$\text{step} := \frac{\text{super}_{c_2} \cdot (\text{xr} - 1)}{\text{steps}} \quad v_i := \text{super}_{c_2} + i \cdot \text{step}$$

$\text{Psth}_1 := \text{root}(\text{ST_pdata}(p, \text{super}_{c_5}, 5, 1)_2 - v_i, p)$ Generate the pressure line of isentropic steam expansion.

