

ASTEM97

**Based on the
IAPWS IF-97**

Water and Steam Properties for Industrial Use

Implementation by

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Appendix B

Region 3 Saturation Properties

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Saturation Pressure

The saturation pressure (in Pa) at temperature (in K) is calculated with
FUNCTION PSAT97(TIN)

and is valid in the range 273.15 K to 647.096 K (T_{crt}). For numerical considerations in **ASTEM97**, if the input temperature is greater than $T_{crt}-1.188D-9 = 647.095999998812$ K PSAT97 returns 22,064,000 Pa, as the function returns 22,064,000.0003206 Pa at 647.096 K.

Saturation Temperature

The saturation temperature (in K) at pressure (Pa) is calculated with
FUNCTION TSAT97(PIN)

and is valid in the range 611.213 Pa (P_{min}) to 22.064 MPa (P_{crt}). For numerical considerations in **ASTEM97**, if the input pressure is greater than $P_{crt}-1.7D-7 = 22,063,999.9999999$ Pa TSAT97 returns 647.096 K, as the function returns 647.095999998812 K.

Saturation Properties in IF-97 Region 3

SUBROUTINE ROOT3MAX(TIN,RHOF,RHOG)

In IF-97 region 3 (function of temperature and density - ρ) the saturation properties may be obtained by one of two methods. The simple method is to iterate on ρ_{f-sat} and on ρ_{g-sat} separately until the computed pressure is within a predefined tolerance to P_{sat} at T_{sat} . The alternate method, the default in **ASTEM97**, is to use the Maxwell criteria to determine ρ_{f-sat} and ρ_{g-sat} at the same time. The method described by Kretzschmar, et al. (1998a) is used for this method. The starting points are obtained from the simple method. The simple method calculation appears to be consistent with the ASME (ASME) implementation.

The difference in the calculated latent heat of vaporization from these calculations are compared to Wagner (Wagner) in Figure 1. (The bar from -0.01 to +0.01 kJ/kg represents the number of digits in Wagner.) The Maxwell criteria calculations compare favorably with Wagner up to about 369 °C.

The default ROOT3MAX calculation in **ASTEM97** is based on the Maxwell criteria without the correction (curves labeled “W/O rhog correction”, solid line). A flag is available to the user to apply a correction to the saturated vapor density to be consistent with Wagner’s results. A flag is also available to the user to perform the calculation with the simple method, to be consistent with the ASME implementation. The default method is recommended.

The simple and alternative methods are used up to a temperature of 647.06599 K (PSAT97 returns a value of 22,063,997.3189269 Pa). A linear interpolation is used from this point to the critical point at 647.096 K (22.064 MPa).

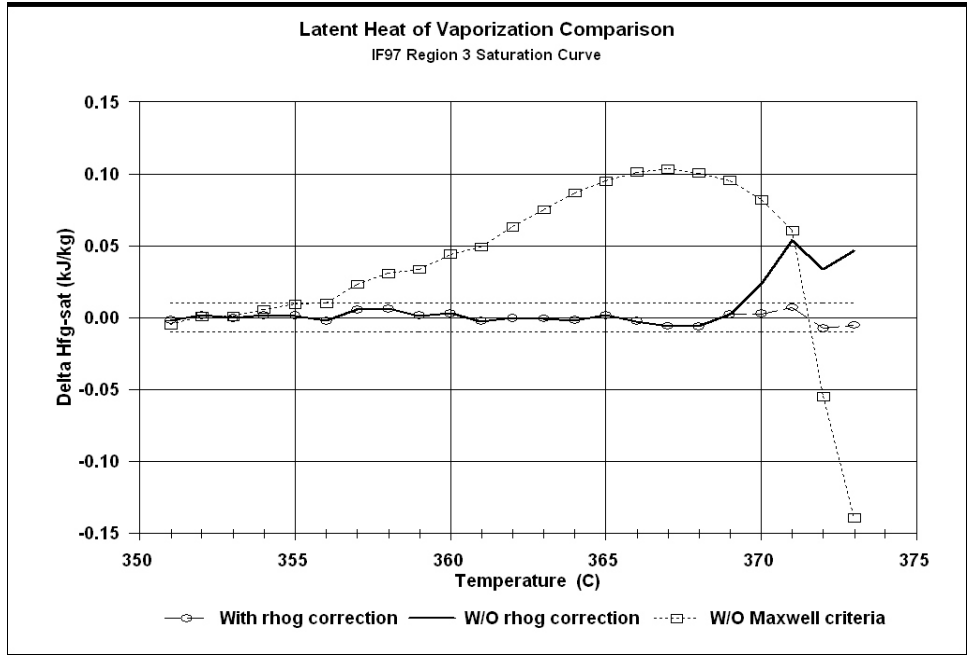


Figure 1 - Comparison of Δh_{fg} calculations

Comparisons of v_{f-sat} and v_{g-sat} are provided in Figures 2 and 3. (The bar from -1.0×10^{-6} to $+1.0 \times 10^{-6} \text{ m}^3/\text{kg}$ represents the number of digits in Wagner.)

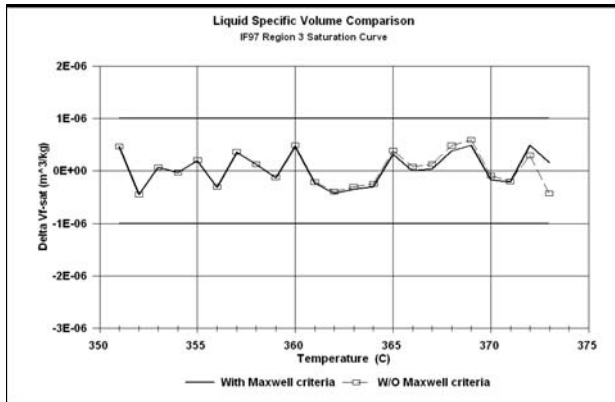


Figure 2 - Comparison of Δv_f calculations

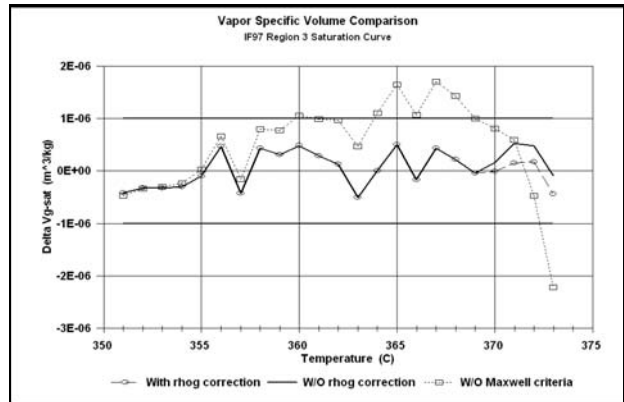


Figure 3 - Comparison of Δv_g calculations

Comparisons of the calculated saturation properties are provided in Tables 1 through 3.

Table 1 - Default saturation properties calculated with Maxwell criteria

P-sat (MPa)	T (C)	T (K)	Hf (kJ/kg)	Hg (kJ/kg)	Sf (kJ/kg-K)	Sg (kJ/kg-K)	Vf (m ³ /kg)	Vg (m ³ /kg)	Hfg (kJ/kg)	Sfg (kJ/kg-K)
16.733	351.00	624.15	1679.144	2556.715	3.79099	5.19702	0.0017525	0.008612	877.572	1.40603
16.939	352.00	625.15	1687.543	2549.561	3.80385	5.18275	0.0017654	0.008424	862.018	1.37890
17.147	353.00	626.15	1696.095	2542.146	3.81693	5.16813	0.0017789	0.008237	846.050	1.35119
17.358	354.00	627.15	1704.813	2534.452	3.83025	5.15312	0.0017930	0.008051	829.638	1.32287
17.570	355.00	628.15	1713.710	2526.459	3.84381	5.13769	0.0018078	0.007866	812.749	1.29388
17.785	356.00	629.15	1722.801	2518.143	3.85765	5.12181	0.0018233	0.007681	795.342	1.26415
18.002	357.00	630.15	1732.103	2509.477	3.87180	5.10543	0.0018396	0.007497	777.375	1.23363
18.221	358.00	631.15	1741.636	2500.430	3.88627	5.08851	0.0018569	0.007313	758.794	1.20224
18.443	359.00	632.15	1751.425	2490.963	3.90111	5.07099	0.0018751	0.007129	739.538	1.16988
18.666	360.00	633.15	1761.497	2481.034	3.91637	5.05281	0.0018945	0.006945	719.537	1.13644
18.893	361.00	634.15	1771.886	2470.589	3.93208	5.03388	0.0019152	0.006760	698.702	1.10179
19.121	362.00	635.15	1782.635	2459.565	3.94832	5.01410	0.0019374	0.006574	676.930	1.06578
19.352	363.00	636.15	1793.792	2447.883	3.96517	4.99337	0.0019614	0.006387	654.091	1.02820
19.586	364.00	637.15	1805.423	2435.444	3.98271	4.97152	0.0019873	0.006198	630.022	0.98881
19.822	365.00	638.15	1817.607	2422.115	4.00108	4.94836	0.0020157	0.006005	604.508	0.94728
20.061	366.00	639.15	1830.456	2407.749	4.02044	4.92366	0.0020470	0.005809	577.292	0.90322
20.302	367.00	640.15	1844.116	2392.112	4.04102	4.89706	0.0020820	0.005607	547.996	0.85604
20.546	368.00	641.15	1858.796	2374.893	4.06313	4.86808	0.0021216	0.005398	516.096	0.80495
20.793	369.00	642.15	1874.810	2355.628	4.08726	4.83602	0.0021675	0.005180	480.818	0.74876
21.043	370.00	643.15	1892.662	2333.578	4.11418	4.79974	0.0022222	0.004946	440.917	0.68556
21.296	371.00	644.15	1913.257	2307.462	4.14529	4.75727	0.0022902	0.004691	394.206	0.61198
21.553	372.00	645.15	1938.499	2274.565	4.18352	4.70443	0.0023815	0.004397	336.066	0.52091
21.813	373.00	646.15	1974.011	2227.245	4.23753	4.62944	0.0025258	0.004019	253.234	0.39191

Table 2 - Corrected saturation properties values calculated with Maxwell criteria

P-sat (MPa)	T (C)	T (K)	Hf (kJ/kg)	Hg (kJ/kg)	Sf (kJ/kg-K)	Sg (kJ/kg-K)	Vf (m ³ /kg)	Vg (m ³ /kg)	Hfg (kJ/kg)	Sfg (kJ/kg-K)
21.043	370.00	643.15	1892.662	2333.599	4.11418	4.79977	0.0022222	0.0049470	440.937	0.68559
21.296	371.00	644.15	1913.257	2307.509	4.14529	4.75735	0.0022902	0.0046918	394.253	0.61205
21.553	372.00	645.15	1938.499	2274.606	4.18352	4.70450	0.0023815	0.0043978	336.107	0.52098
21.813	373.00	646.15	1974.011	2227.297	4.23753	4.62952	0.0025258	0.0040194	253.285	0.39199

Table 3 - Saturated properties calculated with simple method

P-sat (MPa)	T (C)	T (K)	Hf (kJ/kg)	Hg (kJ/kg)	Sf (kJ/kg-K)	Sg (kJ/kg-K)	Vf (m ³ /kg)	Vg (m ³ /kg)	Hfg (kJ/kg)	Sfg (kJ/kg-K)
16.733	351.00	624.15	1679.144	2556.719	3.79099	5.19702	0.0017525	0.0086125	877.575	1.40603
16.939	352.00	625.15	1687.543	2549.562	3.80385	5.18275	0.0017654	0.0084243	862.019	1.37890
17.147	353.00	626.15	1696.095	2542.144	3.81693	5.16813	0.0017789	0.0082373	846.049	1.35119
17.358	354.00	627.15	1704.813	2534.447	3.83025	5.15311	0.0017930	0.0080512	829.634	1.32286
17.570	355.00	628.15	1713.709	2526.450	3.84381	5.13767	0.0018078	0.0078660	812.741	1.29386
17.785	356.00	629.15	1722.799	2518.129	3.85765	5.12178	0.0018233	0.0076813	795.330	1.26413
18.002	357.00	630.15	1732.100	2509.457	3.87179	5.10540	0.0018396	0.0074972	777.357	1.23360
18.221	358.00	631.15	1741.633	2500.402	3.88626	5.08846	0.0018569	0.0073132	758.769	1.20220
18.443	359.00	632.15	1751.420	2490.927	3.90111	5.07093	0.0018751	0.0071292	739.506	1.16983
18.666	360.00	633.15	1761.491	2480.987	3.91636	5.05273	0.0018945	0.0069449	719.496	1.13637
18.893	361.00	634.15	1771.879	2470.530	3.93207	5.03378	0.0019152	0.0067600	698.651	1.10171
19.121	362.00	635.15	1782.625	2459.491	3.94831	5.01398	0.0019374	0.0065740	676.867	1.06568
19.352	363.00	636.15	1793.779	2447.794	3.96515	4.99323	0.0019613	0.0063865	654.015	1.02808
19.586	364.00	637.15	1805.407	2435.340	3.98269	4.97136	0.0019873	0.0061969	629.933	0.98867
19.822	365.00	638.15	1817.589	2422.004	4.00105	4.94818	0.0020156	0.0060044	604.415	0.94713
20.061	366.00	639.15	1830.435	2407.623	4.02040	4.92346	0.0020469	0.0058079	577.189	0.90305
20.302	367.00	640.15	1844.092	2391.978	4.04098	4.89685	0.0020819	0.0056063	547.887	0.85587
20.546	368.00	641.15	1858.770	2374.759	4.06309	4.86787	0.0021215	0.0053976	515.989	0.80478
20.793	369.00	642.15	1874.785	2355.509	4.08722	4.83584	0.0021674	0.0051790	480.725	0.74862
21.043	370.00	643.15	1892.643	2333.501	4.11415	4.79962	0.0022221	0.0049462	440.858	0.68547
21.296	371.00	644.15	1913.254	2307.453	4.14529	4.75726	0.0022902	0.0046914	394.199	0.61197
21.553	372.00	645.15	1938.540	2274.694	4.18358	4.70463	0.0023817	0.0043985	336.154	0.52105
21.813	373.00	646.15	1974.135	2227.554	4.23772	4.62992	0.0025264	0.0040212	253.419	0.39220

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