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**Prediction of Enthalpy and Internal Energy of
Saturated Steam**

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Abstract

The main aim of this work is to establish an empirical formula for calculation the enthalpy and internal energy of saturated steam. The use of this formula reflects a good result under saturated steam conditions. In order to obtain this reliable model for calculating these thermodynamic prosperities, a formula is established by nonlinear regression based on experimental data collection, after a thorough survey of literatures.

Application of the proposed formula shows that, the average percentage error between the results obtained by this equation and the experimental data, is about (0.58%) for internal energy, and for enthalpy is about (0.64%), for 71 data points at each case.

الخلاصة

هدف البحث هو ايجاد علاقة رياضية تجريبية لحساب المحتوى الحراري والطاقة الداخلية للبخار المشبع. استعمال هذه العلاقة عكست نتائج جيدة في ظروف البخار المشبع. ولان تكون العلاقة اكثر شمولية تم الاعتماد على الاساس اللاخطي الرياضي للنتائج العملية المأخوذة من المصادر. تم تطبيق العلاقة المذكورة واطهرت النتائج بان معدل نسبة الخطأ مقارنة بالنتائج العملية هي (0.58%) للطاقة الداخلية و (0.64%) للمحتوى الحراري ول 71 نقطة عملية لكل حالة.

Keywords: Enthalpy, Internal energy, saturated steam, Formula

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Notation

$A_1, A_2, A_3, A_4, A_5, A_6, \& A_7$ constants of equation(1)

H enthalpy, kJ/kg

P saturated pressure, Pa

U internal energy

V volume, m³

T saturated temperature, °C

δQ represents the infinitesimal amount of energy attributed or added to the system.

δW represents the infinitesimal amount of work acted out by the system on the surroundings.

Introduction

Steam has many performance advantages that make it an indispensable delivering energy. These advantages include low toxicity, ease of transportability, and high capacity and low cost with respect to the other alternatives. Steam holds a significant amount of energy on a unit mass basis (between 1,000 and 1,250 British thermal units per pound) [1], that can be extracted as mechanical work through a turbine or as heat for process use, since most of the heat content of steam is stored as latent heat, large quantities of heat can be transferred efficiently at a

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constant temperature, which is a useful attribute in many process heating applications.

Steam is also used in many direct contact applications. For example, Conventional hydrocarbon resources become scarcer every day, while world energy needs continue to increase .For this reason, energy producing company's increasingly exploit non heavy conventional hydrocarbon resources' such as heavy oil and bitumen.Larage amounts of such resources' exist in many contries.Because of their large viscosity, production of such oils is frequently done through heating, in particular by means of steam injection [2].

Steam is used as a source of hydrogen in steam methane reforming, which is an important process for many chemical and petroleum refining applications, where an estimated 30% of all onsite energy use in most refineries is used in form of steam [3] .Steam is also used to control the pressures and temperatures of many chemical processes. Other significant applications of steam are to strip contaminants from a process fluid, to energy facilitate the fractionation of hydrocarbon components, and to dry all types of paper product.

Thus the aim of the present work is to find an analytical or an empirical formulae, rather than tables of thermodynamic and physical properties of saturated steam. These properties are enthalpy and internal energy over different range of operating conditions.

Enthalpy and internal energy

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In thermodynamics and molecular chemistry, the enthalpy or heat content (denoted as H, or, h) is a quotient or description of thermodynamic potential of a system, which can be used to calculate the "useful" work obtainable from a closed thermodynamic system under constant pressure and entropy .The sum of all microscopic forms of energy is called the internal energy of a system and denoted by U.Over the history of thermodynamics, several terms have been used to denote what is now known as the enthalpy of a system. Originally, it was thought that the word "enthalpy" was created by Benoit Paul Émile Clapeyron and Rudolf Claudius [4], through the publishing of the Clausius-Clapeyron relation in The Mollier Steam Tables and Diagrams in 1827, but it was later published that the earliest recording of the word was in 1875, by Josiah Willard Gibbs (1948)[5], in physical chemistry: an advanced treatise , although it is not referenced in Gibbs works directly .In 1909, Keith Landler discussed Gibbs' work on the 'heat function for constant pressure' and noted that Heike Kamerlingh Onnes had coined its modern name from the Greek word "enthalpies" (ενθαλπος) meaning "to put heat into". Enthalpy and internal energy relationships are the heat change which occurs when 1 mol of a substance reacts completely with oxygen to form products at 298 K and 1 atm. The function H was introduced by the Dutch physicist Kamerlingh Onnes in the early twentieth century in the following form:

$$H = E + PV \quad (1)$$

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Where E represents the energy of the system. In the absence of an external field, the enthalpy(H) may be defined, as it is generally known, by;

$$H = U + PV \quad (2)$$

In terms of thermodynamics, enthalpy can be calculated by determine requirements for creating a system from "nothingness"; the mechanical required, PV differs, based upon the constancy of conditions present at the creation of the thermodynamic system. Internal energy(U) must be supplied to remove particles from a surrounding in order to allow space for the creation of a system, providing that environmental variables, such as pressure (p) remain constant. This internal energy also includes the energy required for activation and the breaking of bonded compounds into gaseous species.

This process is calculated within enthalpy calculations as U + PV, to label the amount of energy or work required to "set aside space for" and "create" the system; describing the work done by both the reaction or formation of systems, and the surroundings. For systems at constant pressure, the change in enthalpy is the heat received by the system plus the non-mechanical work that has been done.

Therefore, the change in enthalpy can be devised or represented without the need for compressive or expansive mechanics; for a simple system, with a constant number of particles, the difference in enthalpy is

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the maximum amount of thermal energy derivable from a thermodynamic process in which the pressure is held constant.

The term PV is the work required to displace the surrounding atmosphere in order to vacate the space to be occupied by the system. . As an expansion of the first law of thermodynamics, enthalpy can be related to several other thermodynamic formulae. As with the original definition of the first law;

$$dU = \delta Q - \delta W \quad (3)$$

Where, as defined by the law;

As a differential expression DeHoff, in (2006), defined the value of (H) as;

$$\begin{aligned} dH &= dU + (p dV + V dp) \\ &= (\delta Q - p dV) + (p dV + V dp) \\ &= \delta Q + V dp = TdS + V dp \end{aligned} \quad (4)$$

Correlation development

In order to find a functional relationship between enthalpy or internal energy with the corresponding saturated temperature (T) and saturated pressure (P) for saturated steam, all the available H and U data in Yunus [6], are introduced to the computer as an input data through a package program called(statistics version 5). The result of the program is the following empirical equation:

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$$H \text{ or } U = A_1 + A_2 (T^{A_3}/P^{A_4}) + A_5 (T/P) + A_6 T + A_7 P \quad (5)$$

Where

U internal energy, kJ/kg

H enthalpy, kJ/kg

T saturated temperature, °C

P saturated pressure, Pa

A1, A2, A3, A4, A5, A6, & A7 constants of equation (5) are summarized in Table (1)

Conclusion

The application of the proposed formula (Eqs.5) is represented in Table 2 and Table 3, also a comparisons of the observed and calculated results are shown in Figs. 1 and 2, for the saturated enthalpy and saturated internal energy of steam. These tables demonstrate also, the percentage error for each data point. In general the overall absolute average percentage error is calculated for internal energy and found to be, (0.58%) and for enthalpy (0.64%) for 71 data points of each case

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Table 1: Constants of Equation,(1)

constants	U	H
A ₁	2375.008	2514.727
A ₂	80.18524	84.0925
A ₃	0.578539	1.071697
A ₄	-0.10854	0.018843
A ₅	-14.5349	12.5368
A ₆	-17.6011	108.9091
A ₇	-0.040996	-0.050665

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Table 2: Comparisons of observed internal energy with the corresponding calculated one.

T	P	observed U	calculated U	%Error
0.01	0.6113	2375.3	2379.864	.19
5	0.8721	2382.3	2404.093	.91
10	1.2276	2389.2	2391.217	.08
15	1.7051	2396.1	2390.121	.25
20	2.339	2402.9	2396.168	.28
25	3.169	2409.8	2405.283	.19
30	4.246	2416.6	2415.268	.06
35	5.628	2423.4	2424.905	.06
40	7.384	2430.1	2433.694	.15
45	9.593	2436.8	2441.478	.19
50	12.349	2443.5	2448.343	.20
55	15.758	2450.1	2454.422	.18
60	19.94	2456.6	2459.875	.13
65	25.03	2463.1	2464.861	.07
70	31.19	2469.6	2469.587	.00
75	38.58	2475.9	2474.108	.07
80	47.39	2482.2	2478.543	.15
85	57.83	2488.4	2482.986	.22
90	70.14	2494.5	2487.533	.28
95	84.55	2500.6	2492.168	.34
100	101.35	2506.5	2496.968	.38
105	120.82	2512.4	2501.937	.42
110	143.27	2518.1	2507.059	.44
115	169.06	2523.7	2512.375	.45
120	198.53	2529.3	2517.844	.45
125	232.1	2534.6	2523.496	.44
130	270.1	2539.9	2529.224	.42
135	313	2545.0	2535.059	.39
140	361.3	2550.0	2541.009	.35
145	415.4	2554.9	2546.984	.31
150	475.8	2559.5	2552.961	.26
155	543.1	2564.1	2558.957	.20
160	617.8	2568.4	2564.905	.14

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165	700.5	2572.5	2570.787	.07
170	791.7	2576.5	2576.524	.00
175	892	2580.2	2582.082	.07
180	1002.1	2583.7	2587.452	.15
185	1122.7	2587.0	2592.609	.22
190	1254.4	2590.0	2597.487	.29
195	1397.8	2592.8	2602.025	.36
200	1553.8	2595.3	2606.233	.42
205	1723	2597.5	2610.036	.48
210	1906.2	2599.5	2613.406	.53
215	2104	2601.1	2616.273	.58
220	2318	2602.4	2618.728	.63
225	2548	2603.3	2620.560	.66
230	2795	2603.9	2621.763	.69
235	3060	2604.1	2622.322	.70
240	3344	2604.0	2622.209	.70
245	3648	2603.4	2621.391	.69
250	3973	2602.4	2619.827	.67
255	4319	2600.9	2617.391	.63
260	4688	2599.0	2614.133	.58
265	5081	2596.6	2610.003	.52
270	5499	2593.7	2604.950	.43
275	5942	2590.2	2598.864	.33
280	6412	2586.1	2591.760	.22
285	6909	2581.4	2583.539	.08
290	7436	2576.0	2574.242	.07
295	7993	2569.9	2563.766	.24
300	8581	2563.0	2552.058	.43
305	9202	2555.2	2539.095	.63
310	9856	2546.4	2524.791	.85
315	10547	2536.6	2509.161	1.08
320	11274	2525.5	2492.090	1.32
330	12845	2498.9	2453.471	1.82
340	14586	2464.6	2408.509	2.28
350	16513	2418.4	2356.650	2.55
360	18651	2351.5	2297.274	2.31

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370	21030	2228.5	2229.568	.05
374.14	22090	2029.6	2198.882	8.34
Average absolute percentage error				0.58

Table 3: Comparisons of observed enthalpy with the corresponding calculated one.

T	P	observed H	calculated H	%Error
0.01	0.6113	2501.4	2514.970	.54
5	0.8721	2510.6	2514.242	.15
10	1.2276	2519.8	2513.587	.25
15	1.7051	2528.9	2521.623	.29
20	2.339	2538.1	2533.893	.17
25	3.169	2547.2	2547.276	.00
30	4.246	2556.3	2560.275	.16
35	5.628	2565.3	2572.158	.27
40	7.384	2574.3	2582.738	.33
45	9.593	2583.2	2592.060	.34
50	12.349	2592.1	2600.332	.32
55	15.758	2600.9	2607.767	.26
60	19.94	2609.6	2614.574	.19
65	25.03	2618.3	2620.944	.10
70	31.19	2626.8	2627.095	.01
75	38.58	2635.3	2633.097	.08
80	47.39	2643.7	2639.071	.18
85	57.83	2651.9	2645.107	.26
90	70.14	2660.1	2651.298	.33
95	84.55	2668.1	2657.625	.39
100	101.35	2676.1	2664.157	.45
105	120.82	2683.8	2670.893	.48
110	143.27	2691.5	2677.811	.51
115	169.06	2699.0	2684.942	.52
120	198.53	2706.3	2692.240	.52
125	232.1	2713.5	2699.724	.51

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130	270.1	2720.5	2707.286	.49
135	313	2727.3	2714.944	.45
140	361.3	2733.9	2722.701	.41
145	415.4	2740.3	2730.459	.36
150	475.8	2746.5	2738.188	.30
155	543.1	2752.4	2745.896	.24
160	617.8	2758.1	2753.511	.17
165	700.5	2763.5	2761.004	.09
170	791.7	2768.7	2768.294	.01
175	892	2773.6	2775.337	.06
180	1002.1	2778.2	2782.117	.14
185	1122.7	2782.4	2788.599	.22
190	1254.4	2786.4	2794.712	.30
195	1397.8	2790.0	2800.389	.37
200	1553.8	2793.2	2805.628	.44
205	1723	2796.0	2810.349	.51
210	1906.2	2798.5	2814.516	.57
215	2104	2800.5	2818.052	.63
220	2318	2802.1	2821.028	.68
225	2548	2803.3	2823.241	.71
230	2795	2804.0	2824.675	.74
235	3060	2804.2	2825.301	.75
240	3344	2803.8	2825.083	.76
245	3648	2803.0	2823.976	.75
250	3973	2801.5	2821.929	.73
255	4319	2799.5	2818.821	.69
260	4688	2796.9	2814.677	.64
265	5081	2793.6	2809.438	.57
270	5499	2789.7	2803.041	.48
275	5942	2785.0	2795.382	.37
280	6412	2779.6	2786.453	.25
285	6909	2773.3	2776.156	.10
290	7436	2766.2	2764.499	.06
295	7993	2758.1	2751.382	.24
300	8581	2749.0	2736.742	.45
305	9202	2738.7	2720.534	.66

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310	9856	2727.3	2702.676	.90
315	10547	2714.5	2683.136	1.16
320	11274	2700.1	2661.815	1.42
330	12845	2665.9	2613.580	1.96
340	14586	2622.0	2557.363	2.47
350	16513	2563.9	2492.451	2.79
360	18651	2481.0	2417.957	2.54
370	21030	2332.1	2332.749	.03
374.14	22090	2099.3	2294.075	9.28
Average absolute percentage error				0.64

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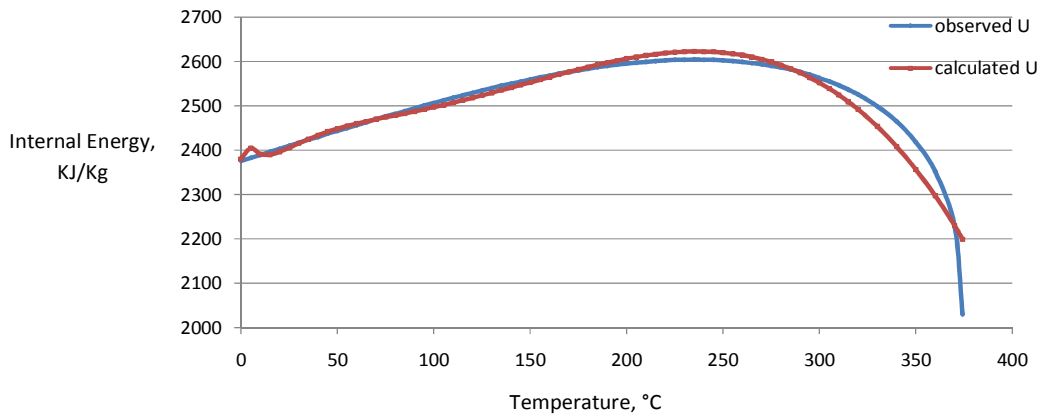


Fig.1 : Comparisons of observed and calculated internal energy

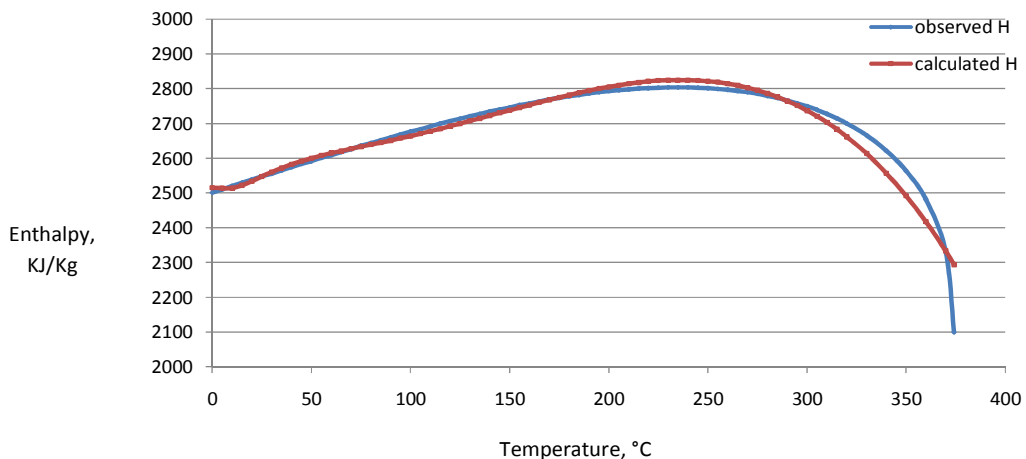


Fig.2 : Comparisons of observed and calculated enthalpy