

## **AC 2008-1398: INTRODUCING EXCEL BASED STEAM TABLE CALCULATIONS INTO THERMODYNAMICS CURRICULUM**

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# Introducing Excel Based Steam Table Calculations into Thermodynamics Curriculum

## Abstract

To perform and document engineering analyses, a tool with consistent utilization and ready availability is much needed. In the classroom, the abundant access and ease of use of Microsoft Excel make it an excellent instrument to perform engineering calculations. Integration of Excel into thermodynamics courses requires finding a suitable method of finding properties on steam tables. A recent internet search revealed three Excel-based macros which are suitable for computing steam properties in a spreadsheet. A property can then be found by calling a function from the Excel workbook and evaluating that function using other known properties. Performing and documenting any thermodynamics calculations becomes greatly simplified when the readily available Microsoft Excel is used. This paper describes these three tools and evaluates their accuracy against published tables, discusses their suitability to the task, and illustrates their utilization in spreadsheet based example problems.

## Introduction

In an introductory thermodynamics course, the students and professor spend a great deal of time reading steam tables. Though this is a perfectly accurate method for determining needed properties, the time invested into reading a steam table takes away from a student's time to apply the learned material of the course. Since the current process for finding properties in thermodynamics refers a student to a steam table, a better tool is needed. With the help of a powerful computational and organizational tool, more engineering analysis can be taught and learned throughout the thermodynamics course. An added ability to properly organize the analysis allows for better documentation and review at a later date. One of the most powerful tools with ready availability for most students is Microsoft Excel. Its unique capabilities like the macros in Visual Basic provide ample ability for calculations in engineering analysis. While a survey of students showed that Excel is a preferred tool over others such as Matlab and Mathcad, many freshmen already maintain some knowledge of the use of Excel from high school courses. The strength of using Excel in an introductory thermodynamics course lies with the ability to write macros for computing the steam properties in the spreadsheet atmosphere. With the ability to find a property without ever leaving a spreadsheet, engineering analysis can be well documented and saved for future reference.

## The Excel macros

Upon searching the internet for macros to compute steam table properties, several results turn up. The desire for the macros to be freeware that is open to the public is necessary. This allows access for all students and teachers at any computer at any time. Three Excel based macros suitable for computing steam properties in a spreadsheet are available. The authors of each Magnus Holmgren<sup>1</sup>, Dr. Bernhard Spang<sup>2</sup>, and Lynn McGuire<sup>3</sup> have all given consent for the usage of their macros with proper referencing. Both the Holmgren and Spang versions provide a list of functions that their macros are capable of calculating with known properties or states. The function calls the macro from the spreadsheet and outputs the desired value. The McGuire

macro is set up as a spreadsheet calculator, where two of any six properties are input and twelve other properties are output. Though the McGuire macro is useful for emphasizing the need of two properties to determine the rest, the Holmgren and Spang spreadsheet design is more beneficial for clean and orderly documentation of any engineering analysis. Their ability to be called from the open workbook without having to open another spreadsheet (i.e. the McGuire) to retrieve the property values is efficient and orderly. The proper use of the Excel functions provides the tools for completion of the necessary steps in solving a thermodynamics problem. While all three seemed to have unique benefits, a single Excel macro had to be chosen to allow for consistent usage throughout the thermodynamics course. These three macros were first compared on a basis of Excel formatting. The second step in selecting the macro which would provide the best benefits was determining the accuracy of each. The process for determining each macro's accuracy involved several steps. Several temperatures from the saturation tables and from the superheated tables for water were selected from Cengel and Boles<sup>4</sup> to perform the accuracy analysis.

### **Spang/Holmgren Functions**

To compare the Spang and Holmgren calculators, a list was composed to show every property that each macro is capable of finding. Many of the properties that the two can find are the same. However, in some cases the Holmgren macro has more calling functions for properties that the Spang macro does not have. This is also true for the opposite since in other cases the Spang macro contains functions that the Holmgren macro does not have. Table 1 shows the composed list of functions.

**Table 1** Function Capabilities in Excel Steam Table Calculators

Property	<b>Spang</b> Calling Function	<b>Holmgren</b> Calling Function
<b>1.) Density in single-phase state</b>		
(a.) As a function of pressure and temperature	densW(T;P)	rho_pT(p,T)
(b.) As a function of pressure and enthalpy	-----	rho_ph(p,h)
(c.) As a function of pressure and entropy	-----	rho_ps(p,s)
<b>2.) Specific internal energy in single-phase state</b>		
(a.) As a function of pressure and temperature	energyW(T;P)	u_pT(p,T)
(b.) As a function of pressure and enthalpy	-----	u_ph(p,h)
(c.) As a function of pressure and entropy	-----	u_ps(p,s)
<b>3.) Specific enthalpy in single-phase state</b>		
(a.) As a function of pressure and temperature	enthalpyW(T;P)	h_pT(p,T)
(b.) As a function of pressure and entropy	-----	h_ps(p,s)
(c.) As a function of pressure and vapor fraction	-----	h_px(p,x)
(d.) As a function of temperature and vapor fraction	-----	h_Tx(T,x)
(e.) As a function of pressure and density	-----	h_rho(p,rho)
<b>4.) Specific entropy in single-phase state</b>		
(a.) As a function of pressure and temperature	entropyW(T;P)	s_pT(p,T)
(b.) As a function of pressure and enthalpy	-----	s_ph(p,h)
<b>5.) Specific isobaric heat capacity in single-phase state</b>		
(a.) As a function of pressure and temperature	cpW(T;P)	Cp_pT(p,T)
(b.) As a function of pressure and enthalpy	-----	Cp_ph(p,h)
(c.) As a function of pressure and entropy	-----	Cp_ps(p,s)
<b>6.) Specific isochoric heat capacity in single-phase state</b>		
(a.) As a function of pressure and temperature	cvW(T;P)	Cv_pT(p,T)
(b.) As a function of pressure and enthalpy	-----	Cv_ph(p,h)
(c.) As a function of pressure and entropy	-----	Cv_ps(p,s)
<b>7.) Temperature</b>		

(a.) Boiling point as a function of pressure	tSatW(P)	Tsat_p(p)
(b.) As a function of pressure and enthalpy	-----	T_ph(p,h)
(c.) As a function of pressure and entropy	-----	T_ps(p,s)
(d.) As a function of enthalpy and entropy	-----	T_hs(h,s)
<b>8.) Pressure</b>		
(a.) Saturation pressure as a function of temperature	pSatW(T)	psat_T(T)
(b.) As a function of enthalpy and entropy	-----	p_hs(h,s)
(c.) As a function of enthalpy and density	-----	p_hrho(h,rho)
<b>9.) Specific Volume</b>		
(a.) As a function of pressure and temperature	-----	v_pT(p,T)
(b.) As a function of pressure and enthalpy	-----	v_ph(p,h)
(c.) As a function of pressure and entropy	-----	v_ps(p,s)
<b>10.) Vapor Fraction</b>		
(a.) As a function of pressure and enthalpy	-----	x_ph(p,h)
(b.) As a function of pressure and entropy	-----	x_ps(p,s)
<b>11.) Vapor Volume Fraction</b>		
(a.) As a function of pressure and enthalpy	-----	vx_ph(p,h)
(b.) As a function of pressure and entropy	-----	vx_ps(p,s)
<b>12.) Density in saturation state</b>		
a.) Of boiling water as a function of temperature	densSatLiqTW(T)	rhoL_T(T)
b.) Of boiling water as a function of pressure	densSatLiqPW(P)	rhoL_p(p)
c.) Of saturated steam as a function of temperature	densSatVapTW(T)	rhoV_T(T)
d.) Of saturated steam as a function of pressure	densSatVapPW(P)	rhoV_p(p)
<b>13.) Specific internal energy in saturation state</b>		
a.) Of boiling water as a function of temperature	energySatLiqTW(T)	uL_T(T)
b.) Of boiling water as a function of pressure	energySatLiqPW(P)	uL_p(p)
c.) Of saturated steam as a function of temperature	energySatVapTW(T)	uV_T(T)
d.) Of saturated steam as a function of pressure	energySatVapPW(P)	uV_p(p)
<b>14.) Specific enthalpy in saturation state</b>		
a.) Of boiling water as a function of temperature	enthalpySatLiqTW(T)	hL_T(T)
b.) Of boiling water as a function of pressure	enthalpySatLiqPW(P)	hL_p(p)

c.) Of saturated steam as a function of temperature	enthalpySatVapTW(T)	$hV\_T(T)$
d.) Of saturated steam as a function of pressure	enthalpySatVapPW(P)	$hV\_p(p)$
<b>15.) Specific entropy in saturation state</b>		
a.) Of boiling water as a function of temperature	entropySatLiqTW(T)	$sL\_T(T)$
b.) Of boiling water as a function of pressure	entropySatLiqPW(P)	$sL\_p(p)$
c.) Of saturated steam as a function of temperature	entropySatVapTW(T)	$sV\_T(T)$
d.) Of saturated steam as a function of pressure	entropySatVapPW(P)	$sV\_p(p)$
<b>16.) Specific isobaric heat capacity in saturation state</b>		
a.) Of boiling water as a function of temperature	cpSatLiqTW(T)	$CpL\_T(T)$
b.) Of boiling water as a function of pressure	cpSatLiqPW(P)	$CpL\_p(p)$
c.) Of saturated steam as a function of temperature	cpSatVapTW(T)	$CpV\_T(T)$
d.) Of saturated steam as a function of pressure	cpSatVapPW(P)	$CpV\_p(p)$
<b>17.) Specific isochoric heat capacity in saturation state</b>		
a.) Of boiling water as a function of temperature	cvSatLiqTW(T)	$CvL\_T(T)$
b.) Of boiling water as a function of pressure	cvSatLiqPW(P)	$CvL\_p(p)$
c.) Of saturated steam as a function of temperature	cvSatVapTW(T)	$CvV\_T(T)$
d.) Of saturated steam as a function of pressure	cvSatVapPW(P)	$CvV\_p(p)$
<b>18.) Specific Volume</b>		
(a.) Saturated vapor volume as a function of pressure	-----	$vV\_p(p)$
(b.) Saturated liquid volume as a function of pressure	-----	$vL\_p(p)$
(c.) Saturated vapor volume as a function of temperature	-----	$vV\_T(T)$
(d.) Saturated liquid volume as a function of temperature	-----	$vL\_T(T)$

The use of these functions becomes simple within the Excel spreadsheet. Depending on the given properties and the desired property, the function for the desired property calls the Excel macro to compute a value based upon the input value. So, if the internal energy of saturated liquid water at 50 C is needed, the Spang macro could be called by using the function

=energySatLiqTW(50+273.16)

in the Excel spreadsheet. This would return the value 209.3655 in units of kJ/kg. Similarly, in the Holmgren macro, the function is called by

=uL\_T(50)

in the Excel spreadsheet returning the value 209.3237 in units of kJ/kg. Considering the functions that call the macro to compute the needed values, the main difference between the Spang and Holmgren calculators is their syntax for each property. The ability of each to be used as an “Add-In” in Excel makes them beneficial for organizing an analysis while providing a necessary calculation.

### McGuire Function

The McGuire calculator maintains a completely different format than both the Holmgren and Spang calculators. It requires input of two known properties out of the six available property inputs. The other four that are unknown require entering a value of 0. The structure of the McGuire calculator can be seen below in Table 2.

Table 2

#### McGuire Calculator Format

##### **Mcguire\_KORF**

English Units

Enter a zero value for any unknown inputs.

<b>Input</b>		
1	Temperature, F	750
2	Pressure, psia	3500.00
3	Quality, 0=L, 100=V	0
4	Spec volume, ft <sup>3</sup> /lb	0
5	Enthalpy, btu/lb	0
6	Entropy, btu/lb/f	0
<b>Output</b>		
1	Temperature, F	750.0
2	Pressure, psia	3500.00
3	Quality, 0=L, 100=V	100.00
4	Spec volume, ft <sup>3</sup> /lb	0.1048
5	Enthalpy, btu/lb	1127.06

6	Entropy, btu/lb/f	1.2450
7	Tsat, F	705.5
8	Psat, psia	0.00
9	Deg superheat, F	44.5
10	Deg subcool, F	0.0
11	Viscosity, cP	5.89E-07
12	Crit. velocity	1144.97
13	Density, lb/ft <sup>3</sup>	9.5428
14	SG	0.153

This type of organization is useful because of its emphasis for the need of two properties to determine another property or the state of the water, an important concept in a thermodynamics course. However, its macro cannot be used as an “Add-In” in Excel, which limits its ability to maintain organization for referencing in the future.

### Comparison of Functions

In order to determine more information about the accuracy of these Excel macros, an examination of several points from the steam tables and error calculations compared to the calculated values is necessary. To have a fair comparison of the three macros, all calculated values are measured against the values given by the International Association for the Properties of Water and Steam Industrial Formulation 1995 (IAPWS-IF95)<sup>5</sup>. These are the values that replace The 1967 IFC-Formulation for Industrial Use (IFC-67)<sup>6</sup>. While the Holmgren and Spang macros both reference the IAPWS-IF97<sup>7</sup> as the source of their calculations, the McGuire references the IFC-67 as its source. The change from the IFC-67 to the IAPWS-IF97 is not noticeably large but does seem to play a significant role in the accuracy of each macro. The output for the critical point and points close to it are especially affected by any small change in the input values.

#### *Point Comparisons*

Using temperature values for SI and English units, calculated values for each property on the tables of the Cengel and Boles Sixth Edition book were found with the Holmgren, Spang, and McGuire macros. The points were selected randomly but with distribution throughout the steam tables. Sample points were taken from both the saturated water temperature table and the superheated water table to provide ample distribution throughout the steam tables. The Holmgren and Spang macros were evaluated with SI units. The McGuire macro was only evaluated with English units since its macro is not available for SI units. The sample points can be seen in Table 3.



**Table 3 Sample Points for Steam Table Calculations**

<b>Saturated Water Temperature Table</b>	<b>English</b>		<b>SI</b>	
	F		C	
	32.018		0.01	
	100		50	
	200		100	
	300		150	
	400		200	
	500		250	
	550		300	
	600		350	
	650		355	
	680		360	
	700		370	
	705.10		373.95	
<b>Superheated Water</b>	F	Psi	C	Mpa
	695.41	3000	365.75	20
	700	3000	400	20
	750	3000	450	20
	800	3000	500	20
	650	3500	375	25
	700	3500	400	25
750	3500	425	25	

These values were found and compared to the table value. The percent error of each property was found using the calculated value and the actual (table) value. The formula for this calculation can be seen in Equation 1.

$$\%error = \frac{y_i - y_{data}}{y_{data}} \times 100\% = e_{rel_i} \quad (1)$$

Table 4 shows the Holmgren calculations for the sample points in SI units for several properties of water and includes the % error calculation.

**Table 4 Holmgren calculations for SI units**

**Holmgren**  
SI Units  
From Saturated Water Table

Temp (C)	Calculated			Table			Calculated			Table			Calculated			Table		
	$v_f$ (m <sup>3</sup> /kg)	$v_f$ (m <sup>3</sup> /kg)	% error	$v_g$ (m <sup>3</sup> /kg)	$v_g$ (m <sup>3</sup> /kg)	% error	$u_f$ (kJ/kg)	$u_f$ (kJ/kg)	% error	$u_g$ (kJ/kg)	$u_g$ (kJ/kg)	% error	$u_g$ (kJ/kg)	$u_g$ (kJ/kg)	% error			
0.01	0.0010002	0.001000	0.021%	205.9975	206.00	-0.001%	0.00000	0.000	0.000%	2374.911	2374.9	0.000%						
50	0.0010121	0.001012	0.014%	12.0279	12.026	0.016%	209.32370	209.33	-0.003%	2442.751	2442.7	0.002%						
100	0.0010435	0.001043	0.044%	1.67186	1.6720	-0.008%	418.99333	419.06	-0.016%	2506.015	2506.0	0.001%						
150	0.0010905	0.001091	-0.045%	0.39250	0.39248	0.006%	631.73237	631.66	0.011%	2559.048	2559.1	-0.002%						
200	0.0011565	0.001157	-0.042%	0.12722	0.12721	0.010%	850.59507	850.46	0.016%	2594.273	2594.2	0.003%						
250	0.0012517	0.001252	-0.021%	0.050087	0.050085	0.003%	1080.70998	1080.7	0.001%	2601.871	2601.8	0.003%						
300	0.0014042	0.001404	0.016%	0.0216631	0.021659	0.019%	1332.71228	1332.7	0.001%	2563.538	2563.6	-0.002%						
350	0.0017401	0.001741	-0.053%	0.0088009	0.008806	-0.058%	1642.09631	1642.4	-0.018%	2418.120	2418.3	-0.007%						
355	0.0018078	0.001808	-0.011%	0.0078660	0.007872	-0.077%	1681.94951	1682.2	-0.015%	2388.244	2388.6	-0.015%						
360	0.0018945	0.001895	-0.025%	0.0069450	0.006950	-0.072%	1726.12896	1726.2	-0.004%	2351.352	2351.9	-0.023%						
370	0.0022221	0.002217	0.230%	0.0049462	0.004953	-0.138%	1845.88643	1844.5	0.075%	2229.413	2230.1	-0.031%						
373.95	-----	0.003106	-----	-----	0.003106	-----	-----	2015.7	-----	-----	-----	-----	2015.7	-----	-----			
RMS			0.076%			0.056%			0.025%						0.013%			
Temp (C)	Calculated			Table			Calculated			Table			Calculated			Table		
	$h_f$ (kJ/kg)	$h_f$ (kJ/kg)	% error	$h_g$ (kJ/kg)	$h_g$ (kJ/kg)	% error	$s_f$ (kJ/kg*K)	$s_f$ (kJ/kg*K)	% error	$s_g$ (kJ/kg*K)	$s_g$ (kJ/kg*K)	% error	$s_g$ (kJ/kg*K)	$s_g$ (kJ/kg*K)	% error			
0.01	0.001	0.001	-38.822%	2500.91	2500.9	0.000%	0.00000	0.0000	0.000%	9.15549	9.1556	-0.001%						
50	209.336	209.34	-0.002%	2591.31	2591.3	0.000%	0.70379	0.7038	-0.001%	8.07491	8.0748	0.001%						
100	419.099	419.17	-0.017%	2675.57	2675.6	-0.001%	1.30701	1.3072	-0.014%	7.35408	7.3542	-0.002%						
150	632.252	632.18	0.011%	2745.92	2745.9	0.001%	1.84195	1.8418	0.008%	6.83703	6.8371	-0.001%						
200	852.393	852.26	0.016%	2792.06	2792.0	0.002%	2.33080	2.3305	0.013%	6.43030	6.4302	0.002%						
250	1085.687	1085.7	-0.001%	2801.01	2801.0	0.000%	2.79339	2.7933	0.003%	6.07222	6.0721	0.002%						

300	1344.771	1344.8	-0.002%	2749.57	2749.6	-0.001%	3.25474	3.2548	-0.002%	5.70576	5.7059	-0.002%
350	1670.889	1671.2	-0.019%	2563.63	2563.9	-0.011%	3.77828	3.7788	-0.014%	5.21089	5.2114	-0.010%
355	1713.710	1714.0	-0.017%	2526.45	2526.9	-0.018%	3.84382	3.8442	-0.010%	5.13768	5.1384	-0.014%
360	1761.491	1761.5	-0.001%	2480.99	2481.6	-0.025%	3.91636	3.9165	-0.004%	5.05273	5.0537	-0.019%
370	1892.643	1891.2	0.076%	2333.50	2334.3	-0.034%	4.11416	4.1119	0.055%	4.79961	4.8009	-0.027%
373.95	-----	2084.3	-----	-----	2084.3	-----	-----	4.4070	-----	-----	4.4070	-----
RMS			0.027%			0.014%			0.019%			0.011%

From Superheated Water Table

Temp (C)	Pressure (Mpa)	Calculated			Table			Calculated			Table			Calculated			Table		
		v (m <sup>3</sup> /kg)	v (m <sup>3</sup> /kg)	% error	u (kJ/kg)	u (kJ/kg)	% error	h (kJ/kg)	h (kJ/kg)	% error	s (kJ/kg*K)	s (kJ/kg*K)	% error						
365.75	20	0.005860	0.005862	-0.036%	2294.37	2294.8	-0.019%	2411.57	2412.1	-0.022%	4.93019	4.9310	-0.016%						
400	20	0.009950	0.00995	-0.004%	2617.84	2617.9	-0.002%	2816.84	2816.9	-0.002%	5.55247	5.5526	-0.002%						
450	20	0.012720	0.012721	-0.006%	2807.13	2807.3	-0.006%	3061.53	3061.7	-0.005%	5.90407	5.9043	-0.004%						
500	20	0.014793	0.014793	0.000%	2945.33	2945.3	0.001%	3241.19	3241.2	0.000%	6.14455	6.1446	-0.001%						
375	25	0.001978	0.001978	-0.017%	1799.79	1799.9	-0.006%	1849.18	1849.4	-0.012%	4.03418	4.0345	-0.008%						
400	25	0.006006	0.006005	0.019%	2428.57	2428.5	0.003%	2578.75	2578.7	0.002%	5.14006	5.1400	0.001%						
425	25	0.007886	0.007886	-0.004%	2607.76	2607.8	-0.001%	2804.90	2805.0	-0.003%	5.47061	5.4708	-0.003%						
RMS				0.017%			0.008%			0.010%			0.007%						

The Holmgren macro was also evaluated with steam table values in SI units from the Keenan, Keys, Hill, and Moore<sup>8</sup>. The temperature value of 355 C had to be eliminated on this evaluation since it was not given in the table. Values given for the critical point temperature vary from the different sources. The IAPWS-IF95 source gives the critical temperature value of 373.95 C. The Keenan, Keys, Hill, and Moore source lists the critical temperature value of 374.136 C. The values that are highlighted are excluded from any error calculations.

*RMS errors*

Once the percent error was found, a total error or RMS error was found by summing at every evaluated temperature. The RMS error was found for the Holmgren, Spang, and McGuire macros. It was also found for the Keenan, Keys, Hill, and Moore (1978) tables using the Holmgren macro. Equation 2 shows the computation to find the RMS error.

$$RMS_{rel} = \sqrt{\frac{\sum_{i=1}^n e_{rel_i}^2}{n}}$$

Once every RMS error was found they were compared in a table. This comparison can be seen in Table 5.

**Table 5 RMS Errors**

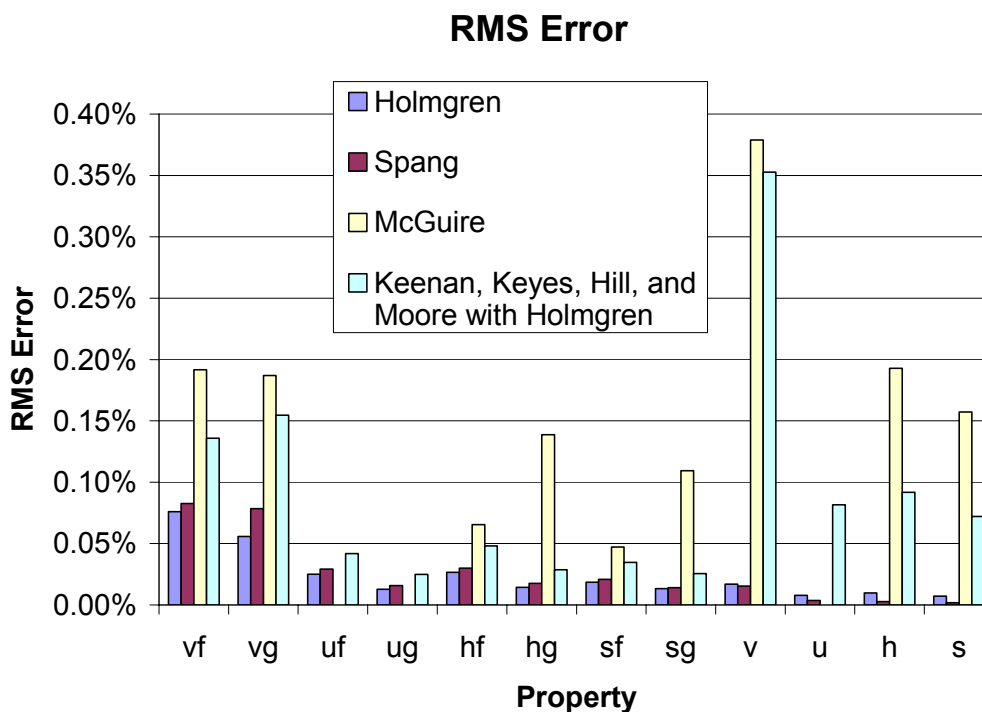
RMS Calculations

	<b>Holmgren (SI)</b>	<b>Spang (SI)</b>	<b>Holmgren with Keenan, Keyes, Hill, and Moore (SI)</b>	<b>McGuire (English)</b>
v <sub>f</sub>	0.0761%	0.0826%	0.1359%	0.1917%
v <sub>g</sub>	0.0558%	0.0784%	0.1546%	0.1870%
u <sub>f</sub>	0.0250%	0.0292%	0.0419%	
u <sub>g</sub>	0.0128%	0.0157%	0.0248%	
h <sub>f</sub>	0.0267%	0.0300%	0.0481%	0.0655%
h <sub>g</sub>	0.0142%	0.0177%	0.0288%	0.1388%
s <sub>f</sub>	0.0185%	0.0209%	0.0346%	0.0472%
s <sub>g</sub>	0.0133%	0.0141%	0.0255%	0.1095%

Superheated

v	0.0170%	0.0154%	0.3527%	0.3790%
u	0.0079%	0.0037%	0.0816%	
h	0.0098%	0.0027%	0.0918%	0.1928%
s	0.0072%	0.0017%	0.0720%	0.1573%

The RMS errors for all four evaluations were then compared on a bar chart to determine the best macro for use in completing an accurate analysis. To maintain an accurate and fair analysis of the best macro, the critical point temperature was excluded from RMS calculations. Figure 1 shows the bar chart with the RMS comparison.



**Figure 1 RMS errors**

From Figure 1, it is evident that the Holmgren and Spang functions provide very accurate values compared to the values listed in the steam tables. Once learned, the Holmgren syntax for calling each function is simple in use and terse in length. This proves to be advantageous when documenting a solution process in an Excel spreadsheet. For these reasons, the Holmgren functions are chosen for engineering analyses in the thermodynamics course.

### Examples

Two different examples are presented below to demonstrate use of these Excel macros. Both examples illustrate the advantages of spreadsheet-based problem solving. The first involves a

two-phase closed system calculation, and the second involves a superheated open system calculation.

### *Closed System, Two Phase Calculation*

#### **Problem 1**

2 kg of water at 80 C and a quality of 0.6 are contained in a sealed, rigid container. Heat transfer occurs until the tank contains only saturated vapor. Determine the work and the heat transfer for this process.

Applying an energy balance, the heat transferred from the tank can be found by the difference in internal energy at the initial and final states. A traditional solution to this problem involves reference to steam tables at each state. These internal energies can be easily found by calling the Holmgren functions with the known properties instead of the standard steam table referencing. In addition to the ability to use the Holmgren functions from the spreadsheet, the goal seek function can also be used. In this example problem, the ability to use goal seek simplifies the solution process, by allowing change of the  $T_2$  in order to make  $v_2 = v_1$ . The remaining portion of the problem only involves calling the Holmgren functions at the desired states with the known properties. For example, the final internal energy is found with the Holmgren functions by calling the internal energy function with the known properties, quality and temperature. The input into the cell to call the function is `=uV_T(temp_2)` which returns a value of  $u_2 = 2498.94$  kJ/kg. During the solution process, the Excel spreadsheet allows for efficient organization of all equations used and values obtained. The Holmgren macros allow this problem to be solved without referencing any tables and makes organizing the solution neat and efficient in Excel. Efficient organization helps for reviewing and referencing of the solution in the future.

	A	B	C	D	E	F	G	H	I	J	K	L
1	<b>Problem_1 Closed System</b>											
2												
3	2 kg of water at 80 C and a quality of 0.6 are contained in a sealed, rigid											
4	container. Heat transfer occurs until the tank contains only saturated vapor.											
5	Find the work and the heat transfer for this process in kJ.											
6	mass	2	kg									
7	temp_1	80	C									
8	quality	0.6										
9	$E_{in} - E_{out} = \Delta E_{system}$											
10												
11	A closed system with no boundary or shaft work.											
12	Now can find u_1 and u_2 with known states.											
13	$-Q = \Delta U = U_2 - U_1$											
14	$Q = -m(u_2 - u_1)$											
15	$u_1 = u_f + xu_{fg}$											
16	(a.)	u_f	334.8999	kJ/kg	=uL_T(temp_1)							
17	Since no moving boundaries or work inputs	u_g	2481.555	kJ/kg	=uV_T(temp_1)							
18	work	0	kJ	u_fg	2146.655	kJ/kg	=u_g-u_f					
19												
20	(b.)	u_1	1622.893	kJ/kg	=u_f+quality*u_fg							
21	Since boundary does not change, v_1=v_2.											
22	Start by finding v_1 from known temp_1.											
23	$v_1 = v_f + xv_{fg}$											
24	$q_{12} = -1752.1$ kJ = -mass*(u_2-u_1)											
25	v_f	0.001029	m^3/kg	=vL_T(temp_1)								
26	v_g	3.405265	m^3/kg	=vV_T(temp_1)								
27	v_fg	3.404236	m^3/kg	=v_g-v_f								
28	v_1	2.043571	m^3/kg	=v_f+quality*v_fg								
29												
30	Can find T_2 using goal seek since v_2=v_1 which is needed for determining u_2.											
31	v_2	2.043513	m^3/kg	=vV_T(temp_2)	temp_2	94.09498	C					
32												
33	used goal seek to get this value											
34												
35												

Figure 2 Excel workbook for closed-system example problem

*Open System, Superheated Calculation*

**Problem 2**

Steam enters an adiabatic turbine steadily at 3 MPa and 400 C and leaves at 50 kPa and 100 C. If the power output of the turbine is 2 MW, determine the isentropic efficiency of the turbine.

In this example, the turbine's efficiency is found by computation based on enthalpies of various states. Each enthalpy can be found by calling the Holmgren functions with known properties. Here, the enthalpy at state 1 is found by input in the cell of `=h_pt(P_1,T_1)` and multiplying P\_1 by 10 to convert to bar for proper units, returning a value of 3231.6 kJ/kg. Finding all the needed states on a table can become burdensome but is simplified when the Holmgren functions are called from the Excel spreadsheet. This solution is computed without any reference to a table, and can be saved and referenced later for review.

A second solution illustrates the power of the Holmgren functions. Since pressure and entropy are always independent properties, the Holmgren function `h_ps` can be used to find the enthalpy for any valid state. Thus, the required enthalpy,  $h_{2s}$ , can be found directly from  $P_2$  and  $s_2 = s_1$ . This eliminates the need to determine all the  $s_f$ ,  $s_{fg}$ ,  $h_f$ , and  $h_{fg}$  values that are artifacts of a table-based solution. (Note: the alternate solution was computed using a modified version of Holmgren's original package, in which pressure is in units of kPa and not bar).



	A	B	C	D	E	F	G	H	I	J	K	L	M	
1	<b>Problem_2 Open System</b>													
2														
3	Steam enters an adiabatic turbine steadily at 3 Mpa and 400 C and leaves at													
4	50 kPa and 100 C. If the power output of the turbine is 2 MW, determine the													
5	isentropic efficiency of the turbine.													
6	P_1	3 MPa												
7	T_1	400 C												
8	P_2a	50 kPa												
9	T_2a	100 C												
10	Power_out	2 MW												
11														
12	Assume: Steady flow and operating conditions							Steam exits as a saturated mixture since						
13								$s_f < s_{2s} < s_g$						
14	Find the enthalpies at various states							so find quality at state 2s						
15								$x_{2s} = \frac{s_{2s} - s_f}{s_{fg}}$						
16	State 1:													
17	h_1	3231.6 kJ/kg	=h_pt(P_1*10,T_1)											
18	s_1	6.9233 kJ/kgK	=s_pT(P_1*10,T_1)											
19														
20	State 2a:													
21	h_2a	2682.40 kJ/kgK	=h_pt(P_2a/100,T_2a)							h_2s	2407.82 kJ/kg	=h_f+x_2s*h_fg		
22														
23	The exit enthalpy of the steam for the isentropic process h_2s is to be found.							Isentropic efficiency of the turbine is						
24	The entropy of the steam remains constant, so s_2s=s_1.													
25	State 2s:													
26	s_2s	6.9233 kJ/kgK	=s_1											
27	P_2s	50 kPa												
28	s_f	1.0910 kJ/kgK	=sL_p(P_2s/100)											
29	s_g	7.5930 kJ/kgK	=sV_p(P_2s/100)											
30	s_fg	6.5020 kJ/kgK	=s_g-s_f											
31	h_f	340.48 kJ/kg	=hL_p(P_2s/100)											
32	h_g	2645.21 kJ/kg	=hV_p(P_2s/100)											
33	h_fg	2304.74 kJ/kg	=h_g-h_f											
34														
								<b>eff_turb</b> <b>0.667 or 66.7%</b> =(h_1-h_2a)/(h_1-h_2s)						
	Example 7-14 Cengel and Boles <sup>4</sup>													

Figure 3 Excel workbook for open-system example problem – textbook solution

	A	B	C	D	E	F	G	H	I	J	K
1	<b>Problem 2 - Open System</b>										
2	Steam enters an adiabatic turbine steadily at 3 Mpa and 400 C and leaves at										
3	50 kPa and 100C. If the power output of the turbine is 2 MW, determine the										
4	isentropic efficiency of the turbine.										
5											
6	Given:										
7	P_1	3000	kPa								
8	T_1	400	C								
9	P_2	50	kPa								
10	T_2	100	C								
11											
12	Find the enthalpies for the actual process										
13	h_1	3231.571	kJ/kg	=h_pT(P_1,T_1)							
14	h_2a	2682.397	kJ/kg	=h_pT(P_2,T_2)							
15											
16	Now need to find the enthalpy for ideal isentropic expansion to P_2										
17	First get s_1										
18	s_1	6.923259	kJ/kg-K	=s_pT(P_1,T_1)							
19	Now use this s_1=s_2 to find the final ideal state h_2s										
20	h_2s	2407.825	kJ/kg	=h_ps(P_2,s_1)							
21											
22	w_act	549.174	kJ/kg	=h_1-h_2a							
23	w_isen	823.7464		=h_1-h_2s							
24											
25	eta_is	66.67%		=w_act/w_isen							
26											

Figure 4 Excel workbook for open-system example problem - alternate solution

## Conclusions

Through the discovery of three Excel macros on the internet, all cost free, a more efficient method for evaluating the properties of water is readily available. The simplicity and accuracy of the macros created by Magnus Holmgren of Excel-Engineering provide the most practical functions for finding properties without reference to any steam tables. The Holmgren functions' ability to be called from the Excel spreadsheet is also beneficial allowing for organized documentation and ease of use. Any engineering analysis can then be saved and referenced in the future or altered for a proper solution. Since shortage of time is often a problem that surfaces in teaching an engineering course, any methods to simplify teaching in order to save time should always be considered. This is probably most true in an introductory thermodynamics course. The need to reference the steam tables becomes time consuming and burdensome in engineering analysis when approach and solution need the most emphasis. The nearly "universal" tool of Microsoft Excel proves to be essential in linking the need for teaching more approach and implementing proper documentation of an analysis.

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## Disclaimer

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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