

CADET \_\_\_\_\_ SECTION \_\_\_\_\_ TIME OF DEPARTURE \_\_\_\_\_

DEPARTMENT OF CHEMISTRY & LIFE SCIENCE

CH365 2023-2024

Veteran's Day Bonus - Steam Tables

31 October 2023

TEXT: Smith, Van Ness, & Abbott

SCOPE: Lessons 22-32

ANTICIPATED TIME: 60 Minutes

References Permitted: Open notes, book, internet, CHEMCAD, Mathematica, Excel.

**INSTRUCTIONS**

1. This is a BONUS exercise and is due **1630 13 November 2023**.
2. There are 2 problems on three pages (not including the cover or reference pages).
3. A Mathematica file "VDB\_Gibbs\_Generating\_Function.nb" that accompanies this handout is found in Canvas.
4. The reference article "VDB\_Reference\_Article\_IF97.pdf" that accompanies this handout is found in Canvas.
5. A Microsoft Word file "VDB\_Deliverables.docx" that accompanies this handout is found in Canvas.
6. Deliverables are your completed tables and Mathematica files in pdf format with cover sheet in a single pdf file, plus working Mathematica and CHEMCAD files (three files total). Save all electronic work in Canvas.

(TOTAL WEIGHT: 30 POINTS)

DO NOT WRITE IN THIS SPACE

PROBLEM	VALUE	ADD
A	15	
B	15	
TOTAL BONUS	30	

Problem:    Weight:  
 A                15

In Lesson 27, we discussed the idea that the Gibbs energy function is a generating function for all other thermodynamic properties. The steam tables are an important application of this principle.[1] The properties in the tables are calculated from the Gibbs energy according to the generating functions in Table 1.

*Table 1. Thermodynamic property relations derived from the Gibbs energy function (equation 1) and its derivatives.*

Property	Relation	Reference
Specific Volume	$v = (\partial g / \partial p)_T$	L27, Slide 11
Specific Internal energy	$u = g - T(\partial g / \partial T)_p - P(\partial g / \partial p)_T$	Eq. 6.1 (L27 Slide 6), combined with definitions of specific entropy and volume ( $s$ and $v$ ).
Specific entropy	$s = -(\partial g / \partial T)_p$	L27, Slide 11
Specific enthalpy	$h = g - T(\partial g / \partial T)_p$	Eq 6.4 (L27 Slide 6), combined with above definition of specific entropy $s$ .

The Gibbs energy generating function for steam is

$$\frac{g(T, p)}{RT} = \sum_{i=1}^{34} n_i (7.1 - \pi)^{I_i} (\tau - 1.222)^{J_i} \quad (1)$$

where  $\pi = p/p^*$ ,  $\tau = T^*/T$ ,  $p^* = 16.53$  MPa,  $T^* = 1386$  K and  $R = 0.461526$  kJ kg<sup>-1</sup> K<sup>-1</sup>. The constants  $n_i$ ,  $I_i$ , and  $J_i$ , as well an implementation of equation 1, are included in the Mathematica file that accompanies this exercise. [2]

In this assignment, you will modify the provided Mathematica file to calculate  $v$ ,  $u$ ,  $s$ , and  $h$  using the property relations in Table 1. To receive any credit, you must verify the test values in Table 2 on the following page. Ensure that your calculated answers contain the same precision as shown in Table 2 (nine significant figures), and complete Table 3 using your Mathematica results using the same format as in Table 2.

Cadet: \_\_\_\_\_

*Table 2. Thermodynamic property values calculated using equation 1 for selected values of  $T$  and  $p$ .*

Property	$T = 300 \text{ K}$ $p = 3 \text{ MPa}$	$T = 300 \text{ K}$ $p = 80 \text{ MPa}$	$T = 500 \text{ K}$ $p = 3 \text{ MPa}$
$v / (\text{m}^3 \text{ kg}^{-1})$	$0.100\,215\,168 \times 10^{-2}$	$0.971\,180\,894 \times 10^{-3}$	$0.120\,241\,800 \times 10^{-2}$
$h / (\text{kJ kg}^{-1})$	$0.115\,331\,273 \times 10^3$	$0.184\,142\,828 \times 10^3$	$0.975\,542\,239 \times 10^3$
$u / (\text{kJ kg}^{-1})$	$0.112\,324\,818 \times 10^3$	$0.106\,448\,356 \times 10^3$	$0.971\,934\,985 \times 10^3$
$s / (\text{kJ kg}^{-1} \text{ K}^{-1})$	0.392 294 792	0.368 563 852	$0.258\,041\,912 \times 10^1$

The format of the entries in this table follow Table 5 in Reference 1.

*Table 3. Cadet MATHEMATICA answers for comparison with Table 2.*

Property	$T = 300 \text{ K}$ $p = 3 \text{ MPa}$	$T = 300 \text{ K}$ $p = 80 \text{ MPa}$	$T = 500 \text{ K}$ $p = 3 \text{ MPa}$
$v / (\text{m}^3 \text{ kg}^{-1})$			
$h / (\text{kJ kg}^{-1})$			
$u / (\text{kJ kg}^{-1})$			
$s / (\text{kJ kg}^{-1} \text{ K}^{-1})$			

Note: Cadets should use the same format for numbers as in Table 2.

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Problem:    Weight:  
B                15

Design a CHEMCAD flow sheet that allows you to calculate  $v$ ,  $s$ ,  $u$ , and  $h$  and compare your answers to the values in Table 2. Complete Table 4 using nine significant figures and in the same format used in Table 2.

*Table 4. Cadet CHEMCAD answers for comparison with Table 2.*

Property	T = 300 K p = 3 MPa	T = 300 K p = 80 MPa	T = 500 K p = 3 MPa
$v / (\text{m}^3 \text{ kg}^{-1})$			
$h / (\text{kJ kg}^{-1})$			
$u / (\text{kJ kg}^{-1})$			
$s / (\text{kJ kg}^{-1} \text{ K}^{-1})$			

Note: Cadets should use the same format for numbers as in Table 2.

## References

1. The calculations in this exercise are found in IAPWS R7-97(2012), published by the International Association for the Properties of Water and Steam, Lucerne, Switzerland, August 2007. IAPWS R7-97(2012) is widely used in process simulators such as CHEMCAD and has been standardized by international convention.
2. The Gibbs energy function and the constants in this document pertain to Region 1 in Reference 1. Specifically, region 1 is  $273.15 < T < 623.15 \text{ K}$  and  $p^{\text{sat}}(T) < p < 100 \text{ MPa}$ . Other constants in Reference 1 pertain to other temperature-pressure regions.