

# Mathcad Lecture #7 In-class Worksheet "Smart" Solve Block Techniques Handout

At the end of this lecture, you will be able to:

- use *functions* in solve block equations to improve convergence
- construct solve blocks with *minimal number of equations* to improve convergence
- use *range variables* and *parametric* solve block to repeat implicit calculations many times.
- solve *engineering problem* using solve blocks

## 1. Using functions in Solve Blocks

### Background

Often in engineering, the same mathematical relationships occur over and over. When these appear in a system of equations to be solved, functions should be defined before the solve block and the function named used inside the Given..Find to reduce the possibility for error and ensure consistency.

### Demonstration

The flow of an incompressible fluid through a constant diameter, straight, horizontal pipe, from point 1 to point 2, is described by

$$\frac{P_2 - P_1}{\rho} = -f \frac{L v_{ave}^2}{D 2}$$

where  $P_i$  is the pressure at point  $i$ ,  $\rho$  is the density of the fluid,  $L$  is the length of the pipe,  $D$  is the diameter of the pipe,  $v_{ave}$  is the average velocity along the section of the pipe from point 1 to point 2, and  $f$  is the friction factor. The friction factor can be determined from the Colebrook formula

$$\frac{1}{\sqrt{f}} = -2.0 \log \left( \frac{\varepsilon / D}{3.7} + \frac{2.51}{\text{Re} \sqrt{f}} \right)$$

where  $\text{Re} = \frac{\rho D v_{ave}}{\mu}$  and  $\varepsilon$  is a value describing the roughness of the pipe.

Water flows through a section of horizontal copper piping 20 meters. If the pressure drop ( $P_2 - P_1$ ) along this section is measured to be -70 kPa, **what is the average velocity of the fluid in the pipe?** For water,  $\rho = 994 \text{ kg/m}^3$  and  $\mu = 0.00087645 \text{ Pa}\cdot\text{s}$ . For the copper piping,  $D = 1.91 \text{ cm}$  and  $\varepsilon = 1.524 \times 10^{-3} \text{ mm}$ . (Note: Friction factors have values on the order of  $10^{-3}$  and are always positive;  $\text{Pa} = \text{N/m}^2$ )

Step 1: Define all known quantities

$$\rho := 994 \frac{\text{kg}}{\text{m}^3} \quad \mu := 0.00087645 \text{ Pa}\cdot\text{s} \quad \varepsilon := 1.524 \cdot 10^{-3} \text{ mm} \quad D := 1.91 \text{ cm} \quad \Delta P := -70 \text{ kPa} \quad L := 20 \text{ m}$$

Step 2: Define a function for the Reynold's number.

$$\text{NRe}(v) := \frac{\rho \cdot D \cdot v}{\mu}$$

**Key Point:** The Reynold's number is defined as a function of  $v$  because the velocity is unknown.

Step 3: Solve for f and v, the two unknowns.

Guesses  $v_g := 2 \frac{\text{m}}{\text{s}}$   $f_g := 10^{-3}$

Given

$$\frac{\Delta P}{\rho} = -f_g \cdot \frac{L}{D} \cdot \frac{v_g^2}{2} \quad \frac{1}{\sqrt{f_g}} = -2.0 \cdot \log \left( \frac{\frac{\epsilon}{D}}{3.7} + \frac{2.51}{\text{NRe}(v_g) \cdot \sqrt{f_g}} \right)$$

$$\begin{pmatrix} v \\ f \end{pmatrix} := \text{Find}(v_g, f_g) \quad v = 2.547 \frac{\text{m}}{\text{s}} \quad f = 0.021$$

**Key Point:** When  $N_{\text{Re}}$  appears in the equations inside the Solve block, it is evaluated using the guess value for velocity  $v_g$ .

### Practice

The heat, q, needed to change the temperature of a gas at low pressures from  $T_1$  to  $T_2$  is given by

$$q = n \int_{T_1}^{T_2} c_p(T) dT$$

where  $c_p$  is the heat capacity of the gas. If 10,000 BTU is removed from 500 moles of ethane initially at 800 °F, calculate the final temperature of the gas. The heat capacity for ethane is given below. Please report your answer in Rankine.

#### Equation

$$c_p(t) := \left[ \begin{array}{l} 5.01696 \cdot 10^8 + 1.08753 \cdot 10^6 \cdot \left( \frac{t}{\text{K}} - 273.15 \right) + 863.337 \cdot \left( \frac{t}{\text{K}} - 273.15 \right)^2 - 1.9525 \cdot \left( \frac{t}{\text{K}} - 273.15 \right)^3 \dots \\ + 8.58038 \cdot 10^{-4} \cdot \left( \frac{t}{\text{K}} - 273.15 \right)^4 \end{array} \right] \cdot \frac{\text{erg}}{\text{mol} \cdot \text{K}}$$

Known Quantities:

$$T_1 := (800 + 459.67) \cdot \text{R}$$

$$q := -10000 \text{ BTU}$$

$$n := 500 \text{ mol}$$

Guess

$$T_g := (600 + 459.67) \cdot \text{R}$$

Given  $q = n \cdot \int_{T_1}^{T_g} c_p(t) dt$

$$T_2 := \text{Find}(T_g)$$

$$T_2 = 819.48 \cdot \text{R}$$

#### Key Points:

1. Notice that the variable given to  $c_p$  is the variable of integration, not the guess.
2. By labeling the guess at  $T_g$ , you can use  $T_2$  to label the final answer.
3. By using a function for the heat capacity, you can use  $c_p$  for later calculations.

## 2. Reducing the Number of Equations in a Solve Block.

### Background

Numerical solvers, such as the solver in Excel or Given..Find Blocks in Mathcad, make use of sophisticated numerical algorithms to find answers to systems of equations. When using solvers, it is best to reduce the number of equations and unknowns. It is generally easier to solve for two unknowns than three unknowns.

### Techniques to Reduce Equations

1. Substitute simple relationships when possible. For example, mole fractions must sum to one, so instead of using  $x_1$  and  $x_2$ , use  $x_1$  and  $(1-x_1)$  in your equations.
2. Often, physical properties are correlated as a function of another variable such as temperature. In this case, define a function to reduce the number of equations.

### Demonstration/Practice

Imagine mixing liquid benzene(species 1) and toluene(species 2) together in an initially empty container. At temperatures and pressures at equilibrium, some of the liquid from both species will evaporate into the vapor phase and some will be left liquid phase. Raoult's law may be used to describe the distribution of species in each phase for ideal cases. For the specific example mentioned above, Raoult's law gives the following two expressions describing the equilibrium state

$$y_1 \cdot P = x_1 \cdot P_{\text{sat}1}$$

$$y_2 \cdot P = x_2 \cdot P_{\text{sat}2}$$

where  $y_i$  is the mole fraction of species  $i$  (either 1 or 2) in the vapor phase,  $x_i$  is the mole fraction of species  $i$  in the liquid phase,  $P_{\text{sat}i}$  is the vapor pressure of species  $i$  at the system temperature  $T$ , and  $P$  is the system pressure. The vapor pressure of benzene and toluene can be found using the Antoine Equation

$$\ln(P_{\text{sat}}) = A - \frac{B}{T + C}$$

where  $P_{\text{sat}}$  is in kPa,  $T$  is in °C, and  $A$ ,  $B$ , and  $C$  are found in the table below.

Antoine Constants for Acetone and Methanol			
Compound	A	B	C
Benzene	13.7819	2726.81	217.572
Toluene	13.9320	3056.96	217.625

If a mixture of benzene and toluene has  $y_1 = 0.33$  and  $P = 120$  kPa, find  $x_1$ .

### Solution Method 1 (Poor)

Step 1: Define the knowns:

$$y_1 := 0.33 \quad P := 120$$

Step 2: List the unknowns:

$$y_2 \quad x_1 \quad x_2 \quad P_{\text{sat}1} \quad P_{\text{sat}2} \quad T$$

Step 3: Define guesses for each unknown:

$$y_{2g} := 0.5 \quad x_{1g} := 0.5 \quad x_{2g} := 0.5 \quad P_{\text{sat}1g} := 100 \quad P_{\text{sat}2g} := 100 \quad T_{\text{avg}} := 50$$

Step 4: Use Given..Find to solve for six unknowns.

Given

$$x1_g + x2_g = 1$$

$$y1 + y2_g = 1$$

$$y1 \cdot P = x1_g \cdot Psat1_g$$

$$y2_g \cdot P = x2_g \cdot Psat2_g$$

$$\ln(Psat1_g) = 13.7819 - \frac{2726.81}{T_g + 217.572}$$

$$\ln(Psat2_g) = 13.9320 - \frac{3056.96}{T_g + 217.625}$$

$$\begin{pmatrix} x1 \\ x2 \\ y2 \\ Psat1 \\ Psat2 \\ T \end{pmatrix} := \text{Find}(x1_g, x2_g, y2_g, Psat1_g, Psat2_g, T_g)$$

$x1 = 0.173$	$x2 = 0.827$	$y2 = 0.67$
$Psat1 = 229.396$	$Psat2 = 97.175$	$T = 109.131$

Questions:

1. What don't you like about the above setup?
2. How can functions be used to improve the situation?
3. What simple relationships can be used to improve the situation?

### Solution Method 2 (Better)

$$\text{ORIGIN} := 1$$

$$A := \begin{pmatrix} 13.7819 \\ 13.9320 \end{pmatrix}$$

$$B := \begin{pmatrix} 2726.81 \\ 3056.96 \end{pmatrix}$$

$$C := \begin{pmatrix} 217.572 \\ 217.625 \end{pmatrix}$$

$$Psat(i, t) := \exp \left( A_i - \frac{B_i}{\frac{t}{K} - 273.15 + C_i} \right) \cdot \text{kPa}$$

$$y1 := 0.33$$

$$x1_g := 0.5$$

$$T_g := 400 \text{ K}$$

$$P := 120 \text{ kPa}$$

Given

$$x1_g \cdot Psat(1, T_g) = y1 \cdot P$$

$$(1 - x1_g) \cdot Psat(2, T_g) = (1 - y1) \cdot P$$

$$\begin{pmatrix} x1 \\ T \end{pmatrix} := \text{Find}(x1_g, T_g)$$

$$x1 = 0.173$$

$$T = 382.281 \text{ K}$$

### 3. Constructing Solve Blocks for Multiple Calculations

#### Description

Often, we want to perform an implicit calculation many times. (An implicit calculation means we can't directly solve for the variable of interest such as volume in the van der Waals equation of state.) We do so by constructing solve blocks in a parametric way and then using matrices of range variables to repeat the calculation over and over.

#### Demonstration

In the UO lab, you use saturated steam on the shell side of a heat exchanger to heat water. The temperature of the steam is not directly measured, but the pressure is. However, since the steam is saturated, you can calculate the temperature from the pressure using a vapor pressure correlation. Such an equation is given below.

$$P_{\text{sat}_{\text{wtr}}}(t) := \exp \left[ 73.649 - \frac{7258.2}{t} - 7.3037 \cdot \ln \left( \frac{t}{\text{K}} \right) + 4.1653 \cdot 10^{-6} \cdot \left( \frac{t}{\text{K}} \right)^2 \right] \cdot \text{Pa}$$

Part a: Given the measured pressure of the saturated steam found in the matrix below, calculate the temperature of the steam.

M :=

	1
1	2.299 · 10 <sup>3</sup>
2	2.398 · 10 <sup>3</sup>
3	2.503 · 10 <sup>3</sup>

$$P_{\text{exp}} := M \cdot \text{kPa}$$

Guess:

$$T_{\text{wga}} := 500 \text{K}$$

Given

$$P_{\text{sat}_{\text{wtr}}}(T_g) = p$$

$$T_{\text{steam}}(p) := \text{Find}(T_g)$$

$$i := 1 \dots \text{rows}(P_{\text{exp}})$$

$$T_{\text{exp}_i} := T_{\text{steam}}(P_{\text{exp}_i})$$

	1	
1	492.77	
2	494.988	
3	497.257	
4	499.241	
5	501.359	
6	503.35	
7	505.255	
8	507.149	K
9	508.961	
10	510.641	
11	512.46	
12	514.178	
13	515.858	
14	517.419	
15	519.049	
16	...	

#### Key Points:

1. Notice that the statement containing the find in the solve block is a function of p. This is telling Mathcad to solve for the temperature given any pressure.
2. We can perform solve block calculation many times given the input data in a matrix and using a range variable.

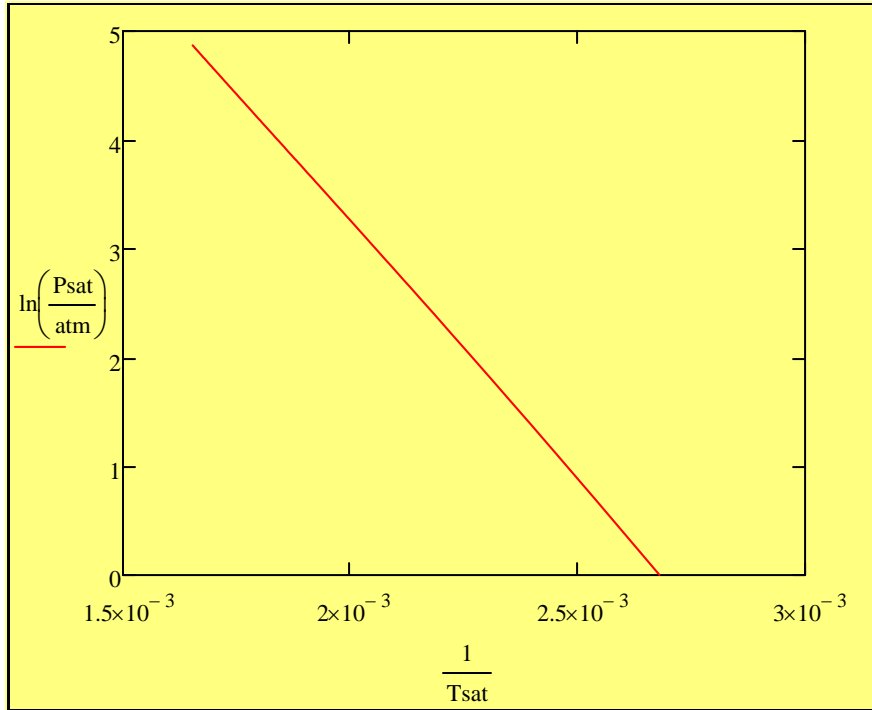
3. The range variable starts at the ORIGIN and ends at the number of rows in the matrix of data.

Part b: Plot  $\ln P$  vs  $1/T$  at saturation for water for saturation pressures from 1 atm to 130 atm.

$j := 1 .. 130$

$Psat_j := 1 \text{ atm} \cdot j$

$Tsat_j := T_{\text{steam}}(Psat_j)$



**Key Point:** We can use range variables to define inputs for the parametric given block. This is often done when plotting or when you want to see the effect of a certain variable on the outcome or other trends.

### Practice

Create a T-x-y diagram for  $P = 130 \text{ kPa}$  for the benzene/toluene system described above. You do this by repeating the Raoult's Law calculation over and over. Remember, in the example above we were given a  $y$  and a  $P$  and were asked to find  $x$  and  $T$ . Now, you need to calculate  $x$  and  $T$  for all possible values of  $y$  at  $P = 130 \text{ kPa}$ . For your reference, I have copied the Raoult's Law equations and the vapor pressure correlations below.

$ORIGIN := 1$      $A := \begin{pmatrix} 13.7819 \\ 13.9320 \end{pmatrix}$      $B := \begin{pmatrix} 2726.81 \\ 3056.96 \end{pmatrix}$      $C := \begin{pmatrix} 217.572 \\ 217.625 \end{pmatrix}$

Raoult's Law

$y_1 \cdot P = x_1 \cdot Psat_1$

$y_2 \cdot P = x_2 \cdot Psat_2$

$$Psat(i, t) := \exp \left( A_i - \frac{B_i}{\frac{t}{K} - 273.15 + C_i} \right) \cdot \text{kPa}$$

Known:  $P := 130 \text{ kPa}$

Guess:  $T_g := 400$      $x1_g := 0.5$

Given

$x1_g \cdot Psat(1, T_g \cdot K) = y1 \cdot P$

$$(1 - x1_g) \cdot \text{Psat}(2, T_g \cdot K) = (1 - y1) \cdot P$$

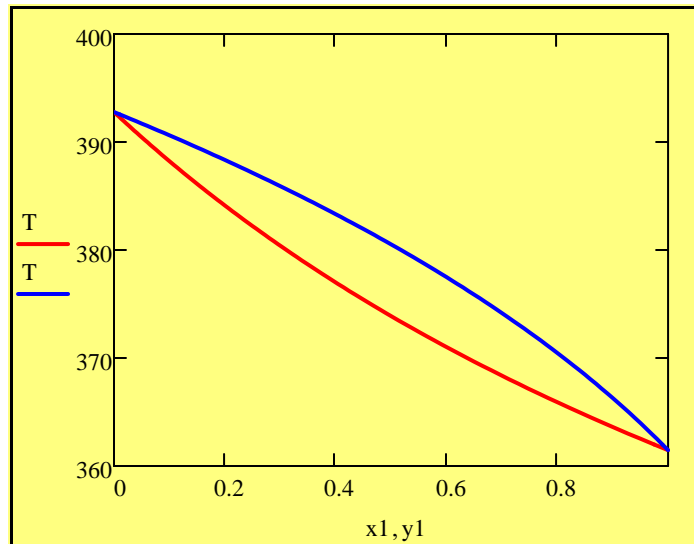
$$\text{ans}(y1) := \text{Find}(x1_g, T_g)$$

$$j := 1 \dots 101$$

$$y1_j := j \cdot (.01) - 0.01$$

$$x1_j := \text{ans}(y1_j)_1$$

$$T_j := \text{ans}(y1_j)_2 \cdot K$$



### Important Point about the above Problem:

Note that  $T_g$  does not have units. However, it is multiplied by K (Kelvin) in the two equations. The reason it cannot have units stems from the fact that the values in a matrix must all have the same units. We have used the following trick (shown below) to overcome this in the past. However, in this case we are creating a function from the given block and there is no way around the same units in the output matrix. Thus we have to take away the units from  $T_g$ . We then make sure  $T_g$  is used as it would be if it had units of Kelvin by multiplying it by Kelvin in the equations in the given block. Then once we solve for T we give it the units of Kelvin.

How we used to overcome the problem of the answers from the solve block having different units (will not work with equations made from given blocks):

$$\begin{pmatrix} \bar{x}_1 \\ \text{Temp} \end{pmatrix} := \text{find}(x1_g, T_g)$$

### Extra Practice

The van der Waals equation of state,  $p = \frac{R \cdot T}{v - b} - \frac{a}{v^2}$  describes the PVT behavior of real gases better than

the ideal gas equation of state. For butane,  $a = 1.3701 \times 10^7 \text{ atm cm}^6 \text{ mol}^{-2}$  and  $b = 116.4 \text{ cm}^3 \text{ mol}^{-1}$ . Create a function (using a parametric give block) to calculate the the volume of butane for any T and P. Make the function versatile so that you can use it to calculate both liquid and vapor volumes (if they are present). Test your function by calculating the vapor and liquid volumes of butane at 100 °C and 15.41 bar. These volumes are 1611 and 212  $\text{cm}^3/\text{mol}$  respectively.

$$a := 1.3701 \cdot 10^7 \frac{\text{atm} \cdot \text{cm}^6}{\text{mol}^2}$$

$$b := 116.4 \frac{\text{cm}^3}{\text{mol}}$$

$$R_g := 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$

$$\text{Given } P = \frac{R_g \cdot T}{v_g - b} - \frac{a}{v_g^2} \quad \text{vol}(P, T, v_g) := \text{Find}(v_g)$$

$$\text{vol}\left[15.41 \text{ bar}, (100 + 273.15) \cdot \text{K}, \frac{R_g \cdot 373 \text{ K}}{15.41 \text{ bar}}\right] = 1.611 \times 10^3 \cdot \frac{\text{cm}^3}{\text{mol}}$$

$$\text{vol}[15.41 \text{ bar}, (100 + 273.15) \cdot \text{K}, 1.1 \cdot b] = 212.465 \cdot \frac{\text{cm}^3}{\text{mol}}$$

## 4. Debugging Solve Blocks

### Background

Solve blocks (Given...Find Blocks) are a very valuable tools to solve non-linear, simultaneous equations. You may solve for up to 400 unknowns. However, solve blocks are not forgiving of syntax errors or other mistakes, and debugging is often frustrating and time consuming. While experience and practice are the best teachers to improve your ability to debug solve blocks, some general tips can help facilitate the endeavor.

### Debugging Techniques

- 1. Ensure that all function defined before the solve block work properly.** In engineering, we often define expressions, such as the Antoine Equation, which are later used in solve blocks. It is good practice to always check that your function works for some value before using it in a solve block.
- 2. Copy the LHS and RHS of each expression in a solve block to ensure correct: calculation, units, order of magnitude.** When a solve block is set up, you have to define everything, including guesses, before typing Given. This means that each side of each equation should evaluate to some numerical value. You should check to see if the units on each side of the equation are consistent and if the magnitudes of the numbers on each side are "close."
- 3. Ensure that each Solve block starts with a given and ends with a find.** Often, when working problems, you set up a solve block with a Given, but don't finish it with a find because you cannot figure out what equations to input. If you forget to finish the given block, and begin another one, you will have problems.
- 4. Double check that the correct variables are used.** Make sure the guess variables are the same before the given block, within the given block, and in the find statement.
- 5. Don't over/under specify the problem.** If a solve block has two equations, the given statement must have two unknowns. If the solve block has three equations, the find statement should have three unknowns.

### Demonstration: Debug the following Solve Block

The van der Waals equation of state,  $P = \frac{R \cdot T}{v - b} - \frac{a}{v^2}$  describes the PVT behavior of real gases better than

the ideal gas equation of state. For butane,  $a = 1.3701 \times 10^7 \text{ atm cm}^6 \text{ mol}^{-2}$  and  $b = 116.4 \text{ cm}^3 \text{ mol}^{-1}$ . Using the van der Waals EOS, calculate the liquid and vapor volume of butane at 100 °C and 15.41 bar.

$$R_g := 8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}}$$

$$a := 1.3701 \cdot 10^7 \frac{\text{atm} \cdot \text{cm}^6}{\text{mol}^2}$$

$$b := 116.4 \frac{\text{cm}^3}{\text{mol}}$$

$$p := 15.41 \text{ bar}$$

$$T := (100 + 273.15) \cdot \text{K}$$



$$v_g := \frac{R_g \cdot T}{p} \quad \text{Given} \quad p = \frac{R_g \cdot T}{v_g - b} - \frac{a}{v_g^2} \quad v_{\text{gas}} := \text{Find}(v_g) \quad v_{\text{gas}} = 1.611 \times 10^3 \cdot \frac{\text{cm}^3}{\text{mol}}$$

$$v_g := 1.1 \cdot b \quad \text{Given} \quad p = \frac{R_g \cdot T}{v_g - b} - \frac{a}{v_g^2} \quad v_{\text{liq}} := \text{Find}(v_g) \quad v_{\text{liq}} = 212.465 \cdot \frac{\text{cm}^3}{\text{mol}}$$

Problems  
 pressure definition needs to be lower case  
 temperature definition needs to be upper case  
 units of a is incorrectly entered

**Practice: Debug the following Solve Blocks**

Problem A

$$\text{kmol} := 1000 \text{mol} \quad \rho := 55.19 \frac{\text{kg}}{\text{m}^3} \quad \mu := 0.00087645 \text{Pa}\cdot\text{s} \quad \varepsilon := 1.524 \cdot 10^{-3} \text{mm} \quad D := 1.91 \text{cm} \quad \Delta P := -70 \text{kPa} \quad \text{Len} := 20 \text{m}$$

Guesses:  $v_g := 2 \frac{\text{m}}{\text{s}} \quad f_g := 10^{-3}$

Given

$$\frac{\Delta P}{\rho} = -f_g \cdot \frac{\text{Len}}{D} \cdot \frac{v_g^2}{2} \quad \frac{1}{\sqrt{f_g}} = -2.0 \cdot \log \left( \frac{\varepsilon}{D} + \frac{2.51}{\frac{\rho \cdot D \cdot v_g}{\mu} \cdot \sqrt{f_g}} \right)$$

$$\begin{pmatrix} vv \\ ff \end{pmatrix} := \text{Find}(v_g, f_g)$$

$$vv = 8.921 \frac{\text{m}}{\text{s}} \quad ff = 0.03$$

**Problem**  
 change rho to kg/m^3  
 v.g not v  
 Len not L  
 Change to matrix definition of answers as different units

Problem B

$$f_g := .001 \quad \text{Re} := 25000$$

Given

$$\frac{1}{\sqrt{\frac{f_g}{2}}} = 2.5 \cdot \ln \left( \operatorname{Re} \cdot \sqrt{\frac{f_g}{8}} \right) + 1.75$$

$$f_g := \operatorname{Find}(f_g) \quad f = 6.108 \times 10^{-3}$$

**Problem**

Change the f.g to be dot not matrix subscript  
Change the ln to not be multiplied but ln() not ln\*()

Problem C

$$A := 4.0326 \cdot 10^4 \quad B := 1.3422 \cdot 10^5 \quad C := 1655.5 \quad D := 7.3223 \cdot 10^4 \quad E := 7.5287 \cdot 10^2$$

$$C_p(T) := \left[ A + B \cdot \left( \frac{\frac{C \cdot K}{T}}{\sinh\left(\frac{C \cdot K}{T}\right)} \right)^2 + D \cdot \left( \frac{\frac{E \cdot K}{T}}{\cosh\left(\frac{E \cdot K}{T}\right)} \right) \right] \cdot \frac{J}{\text{kmol} \cdot K}$$

Guess  $T_g := (500 + 459.67) \cdot R$        $n := 500 \text{ mol}$        $T_1 := 1300 R$        $q := 10000 \text{ BTU}$

Given

$$-n \cdot \left( \int_{T_1}^{T_g} C_p(T) dT \right) = q$$

**Problem**

Change T.2 in integral to Tg  
Change Given to not be a text box

$$T_2 := \operatorname{Find}(T_g) \quad T_2 = 947.496 \cdot R$$

Problem D

$$x := -2$$

Given

$$\text{if}(x < 1, x^2 + 2 \cdot x - 1, \sqrt[3]{x} + \log(x) + 2) = 0$$

Problem  
Get rid of Given hidden behind if statement

$$\text{ans} := \text{Find}(x) \quad \text{ans} = -2.414$$

### Problem E

$$\text{ORIGIN} := 0$$

$$\gamma_0(x_0) := \exp[0.95 \cdot (1 - x_0)^2] \quad \gamma_1(x_0) := \exp(0.95 \cdot x_0^2)$$

$$\underline{A} := \begin{pmatrix} 8.04494 \\ 7.96681 \end{pmatrix} \quad \underline{B} := \begin{pmatrix} 1554.3 \\ 1668.21 \end{pmatrix} \quad \underline{C} := \begin{pmatrix} 222.63 \\ 228.0 \end{pmatrix}$$

$$\text{Psat}(i, t) := \frac{1}{760} \cdot 10^{\left( A_i - \frac{B_i}{\frac{t}{K} + C_i} \right)} \cdot \text{atm}$$

### Define the known conditions

$$T := 300\text{K} \quad y_0 := 0.5$$

### Use a solve block to calculate the unknown quantities.

$$\text{Guesses} \quad P_g := 2\text{atm} \quad x_{0g} := 0.5$$

Given

$$x_{0g} \cdot \gamma_0(x_{0g}) \cdot \text{Psat}(0, T) = y_0 \cdot P_g$$

$$(1 - x_{0g}) \cdot \gamma_1(x_{0g}) \cdot \text{Psat}(1, T) = (1 - y_0) \cdot P_g$$

$$\begin{pmatrix} x_0 \\ P \end{pmatrix} := \text{Find}(x_{0g}, P_g)$$

$$x_1 := 1 - x_0$$

$$\gamma_0(x_0) = 1.695 \quad \gamma_1(x_0) = 1.064 \quad x_0 = 0.255 \quad p = 133.834 \cdot \text{atm} \quad x_1 = 0.745$$

Problem  
add ORIGIN:=0  
change t to T in equations  
change P to P.g in equations