

Process Simulation with ASPEN PLUS

CHE654 Course Notes

Section 5: Sensitivity Analysis

These course materials are applicable to Version 8.4 of ASPEN PLUS

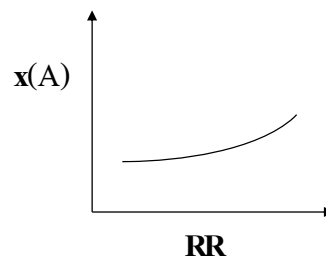
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Sensitivity Analysis Feature

- Sensitivity analysis examines the variation of process results with changes to key flowsheet variables.
- Sensitivity generates tables in the base case report.

	RR	x(A)	
Independent variable	1.0	0.900	Tabulated function
	1.2	0.916	
	1.4	0.935	
	1.6	0.964	
	1.8	0.992	



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Setting up a Sensitivity Analysis Block

1. Identify the flowsheet variables to be sampled.
2. Select or compute the variables that are to be tabulated (dependent variable or tabulated function).
3. Identify the variables to be varied.
4. Select values for the independent variables.

Caution: Each combination of independent variable values requires one evaluation of the sensitivity block. For sensitivity blocks with several independent variables, the number of combination can be surprisingly large.

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Setting up a Sensitivity Analysis (Cont'd)

$$\text{Total No. of Evaluations} = \prod_{i=1}^N \alpha_i$$

where N = total number of independent variables

α_i = total number of points in independent variable i

Example: 2 independent variables to vary T and P

$T(^{\circ}\text{F}) = 100, 200, 300, 400, 500$

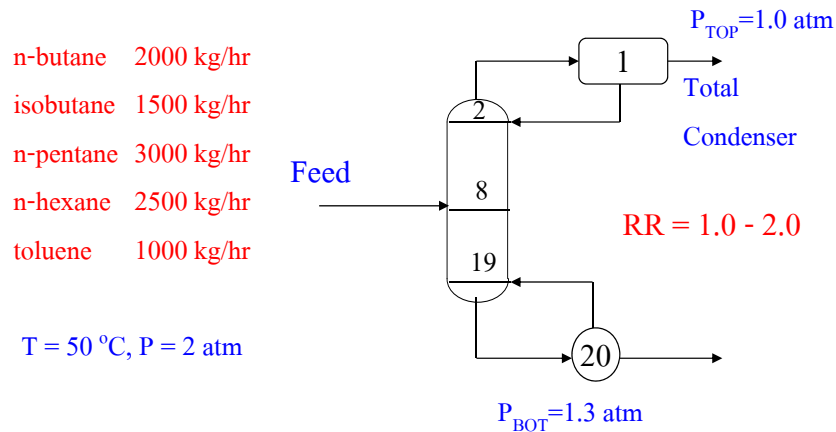
$P(\text{atm}) = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10$

No. of Combinations = (5)(10) = 50 points

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Example of Sensitivity Analysis: DISTL Problem

- Recall the $C_4 - C_7$ separation problem using DISTL
- Use Sensitivity to study the effect of Reflux Ratio (RR) in DISTL on product purity, namely x_{butane} and x_{toluene}



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Sensitivity Example (Cont'd)

- Sensitivity feature is invoked by selecting Model Analysis Tools in Data pulldown menu.
- Fill out 1. **Define** tab => access variables from flowsheet
 2. **Vary** tab => identify manipulated variable
 3. **Tabulate** tab => select/compute variables to be tabulated

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Accessing Variables

- Capability in A+ to sample or manipulate any desired block or stream variables
- Used primarily in Sensitivity, Case Studies, and Design-Spec
- **Sampled variables**
 - Any simulation block input/results, e.g. outlet temperature, block pressure
 - Any stream variable, e.g. mole fraction of a component
- **Manipulated variables**
 - Any block input such as distillation reflux ratio
 - Any stream input such as component feed flow

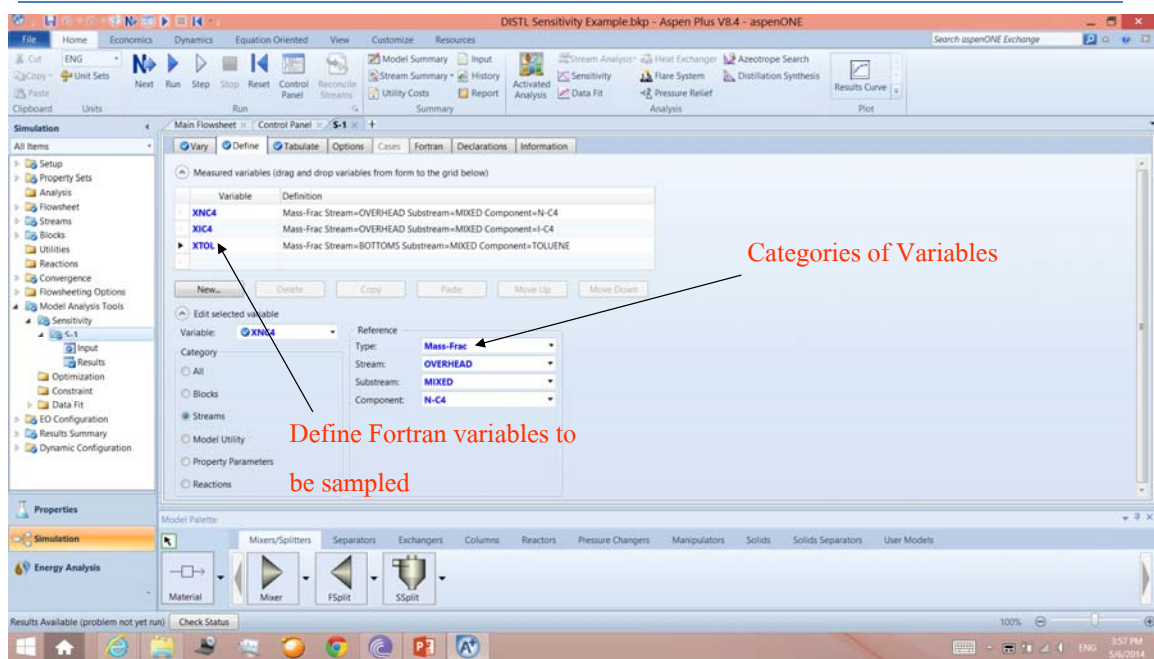
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Important Categories of Variables

- **Blocks Category**
 - **Block-Var** Type: Access variables associated with block input/output, such as column RR, flash outlet T, reactor duty, etc.
- **Streams Category**
 - **Stream-Var** Type: Access standard properties of streams, such as T, P, total flow, enthalpy, molar volume, etc.
 - **Mole-Flow** or **Mass-Flow** Type: Access component flow rates of streams
 - **Mole-Frac** or **Mass-Frac** Type: Access mole/mass fractions of components in a stream
 - **Stream-Prop** Type: Access non-standard properties (PROP-SET) of a stream, such as viscosity, surface tension, heat capacity, etc.
- **Property Category**
 - Access physical property parameters

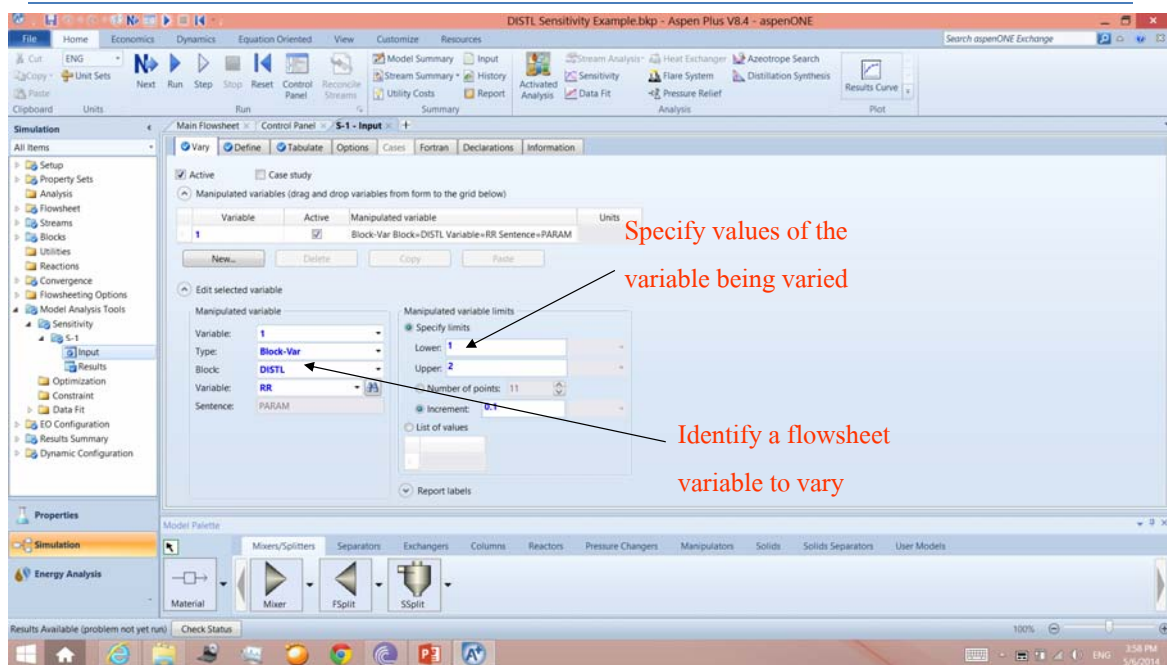
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Define Tab in Sensitivity



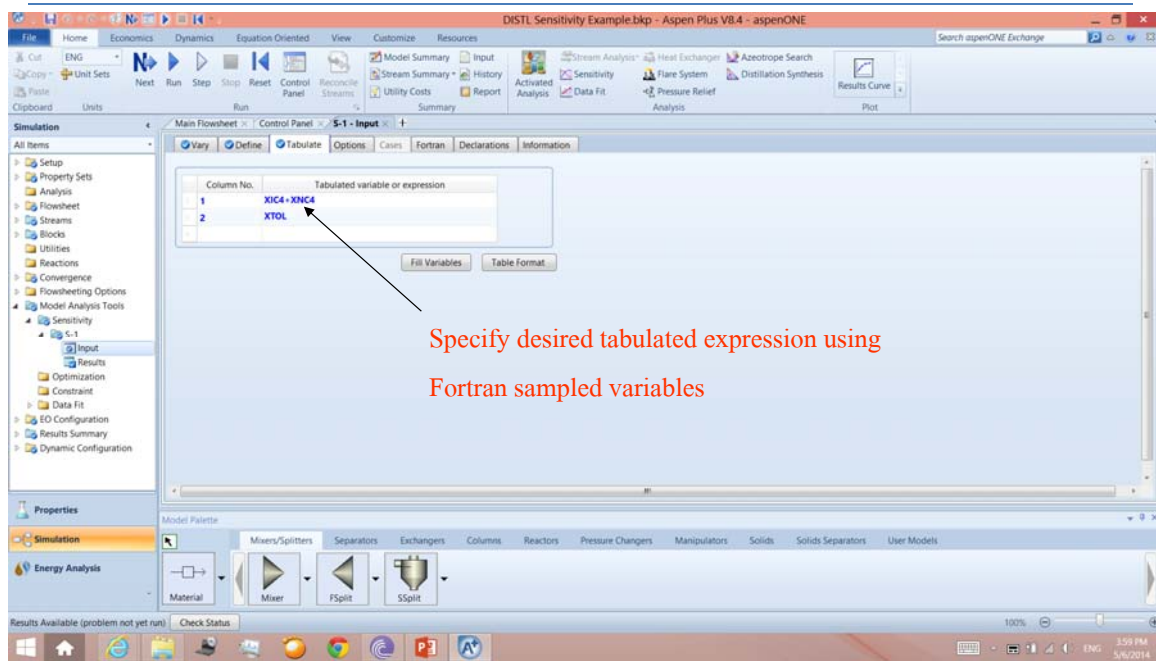
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Vary Tab in Sensitivity



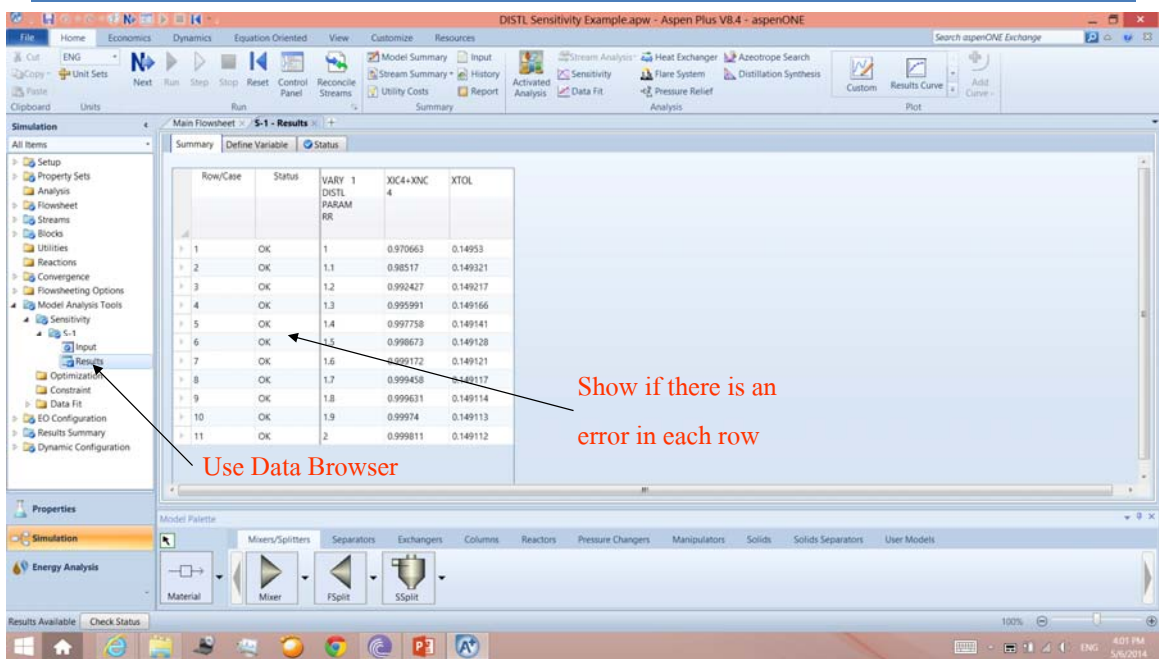
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Tabulate Tab in Sensitivity



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Viewing Sensitivity Results



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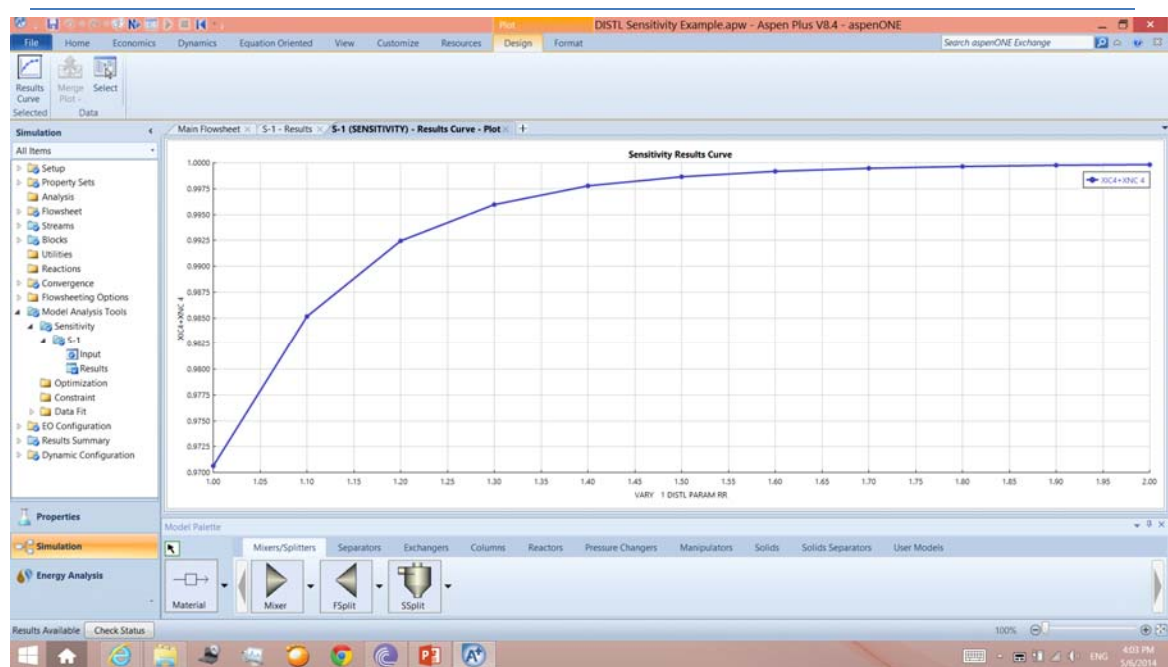
Plotting Sensitivity Results

The screenshot shows the Aspen Plus V8.4 interface. The 'S-1 - Results' window is open, displaying a table of sensitivity results. The table has columns for Row/Case, Status, VARY 1 (DISTL PARAM RR), XIC4-XNIC 4, and XTOL. The data points are as follows:

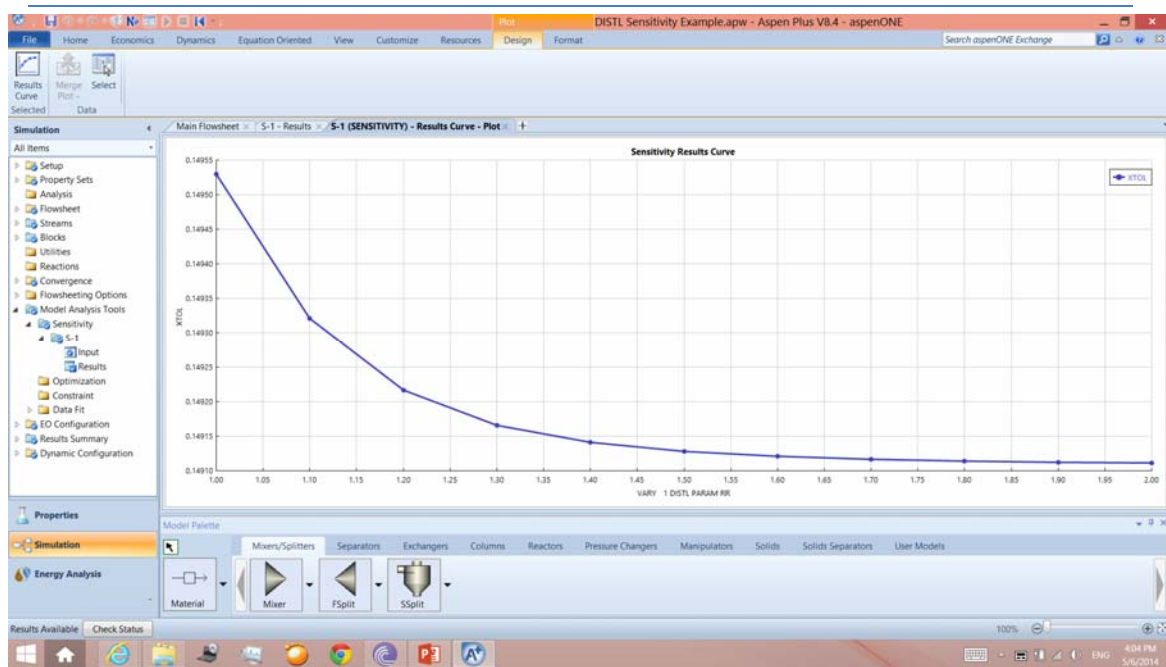
Row/Case	Status	VARY 1 DISTL PARAM RR	XIC4-XNIC 4	XTOL
1	OK	1	0.970663	0.14953
2	OK	1.1	0.98517	0.149321
3	OK	1.2	0.992427	0.149217
4	OK	1.3	0.995991	0.149166
5	OK	1.4	0.997758	0.149141
6	OK	1.5	0.998673	0.149128
7	OK	1.6	0.999172	0.149121
8	OK	1.7	0.999458	0.149117
9	OK	1.8	0.999631	0.149114
10	OK	1.9	0.99974	0.149113
11	OK	2	0.999811	0.149112

The 'Results Curve' plot function is highlighted in the ribbon, with an arrow pointing to it and the text 'Use Plot Function in the Ribbon'.

Sensitivity Plot #1



Sensitivity Plot #2



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Examples of Accessing Variables

Example 1: Access the temperature of a stream called FEED

The screenshot displays the Aspen Plus V8.4 interface with the "Vary" dialog box open. The "FEED" variable is selected in the "Measured variables" list. The "Reference" section shows the variable is accessed as "Stream-Var" for "FEED" in the "MIXED" substream, with the variable "TEMP" and units "F".

Variable	Definition
XNC4	Mass-Frac Stream=OVERHEAD Substream=MIXED Component=N-C4
XIC4	Mass-Frac Stream=OVERHEAD Substream=MIXED Component=I-C4
XTOL	Mass-Frac Stream=BOTTOMS Substream=MIXED Component=TOLUENE
FEED	Stream-Var Stream=FEED Substream=MIXED Variable=TEMP Units=f

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Examples of Accessing Variables (Cont'd)

Example 2: Access the molar density of a stream called BOTTOMS

The screenshot displays the Aspen Plus V8.4 software interface. The 'Measured variables' dialog box is open, showing a list of variables. The variable 'RHOB' is selected, and its definition is 'Stream-Var Stream=BOTTOMS Substream=MIXED Variable=MOLE-DENSITY Units=lbmol/cuft'. The 'Reference' section shows 'Type: Stream-Var', 'Stream: BOTTOMS', 'Substream: MIXED', and 'Variable: MOLE-DENSITY'.

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Examples of Accessing Variables (Cont'd)

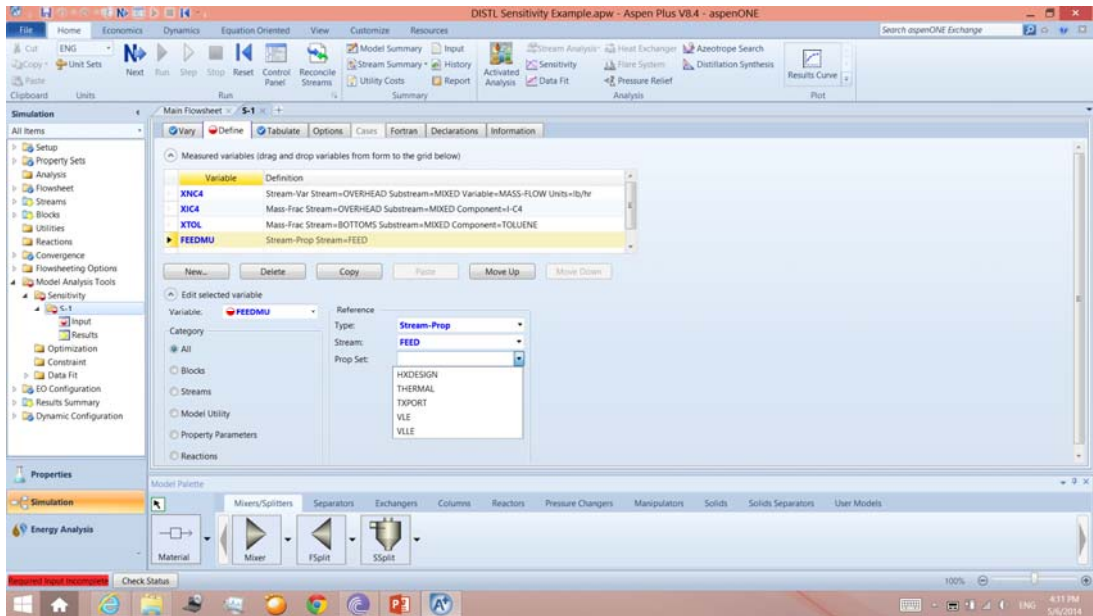
Example 3: Access the total mass flow of a stream called OVHDS

The screenshot displays the Aspen Plus V8.4 software interface. The 'Measured variables' dialog box is open, showing a list of variables. The variable 'TFLOW' is selected, and its definition is 'Stream-Var Stream=OVERHEAD Substream=MIXED Variable=MASS-FLOW Units=lb/hr'. The 'Reference' section shows 'Type: Stream-Var', 'Stream: OVERHEAD', 'Substream: MIXED', and 'Variable: MASS-FLOW'.

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Examples of Accessing Variables (Cont'd)

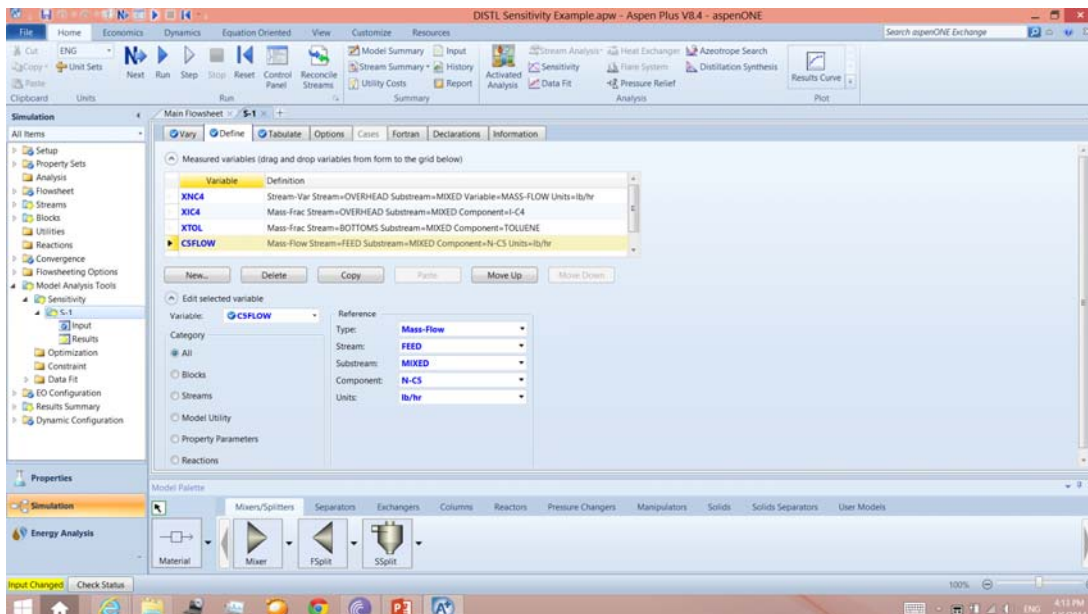
Example 4: Access the viscosity of a stream called FEED



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Examples of Accessing Variables (Cont'd)

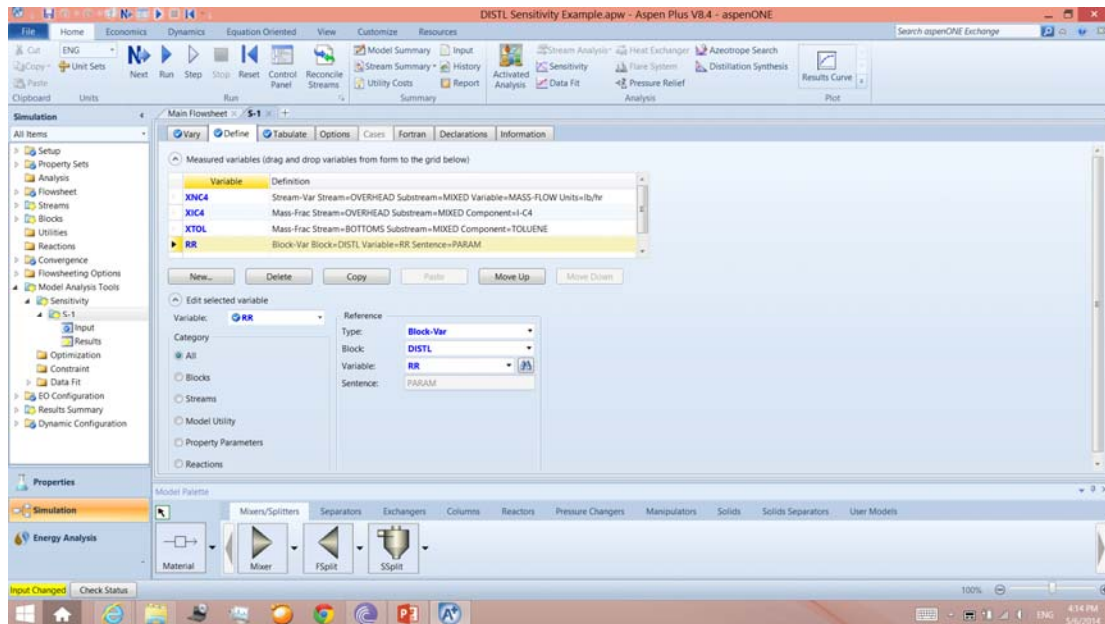
Example 5: Access the mass flow of component C5 in stream FEED



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Examples of Accessing Variables (Cont'd)

Example 6: Access the reflux ratio (input) of a DISTL block



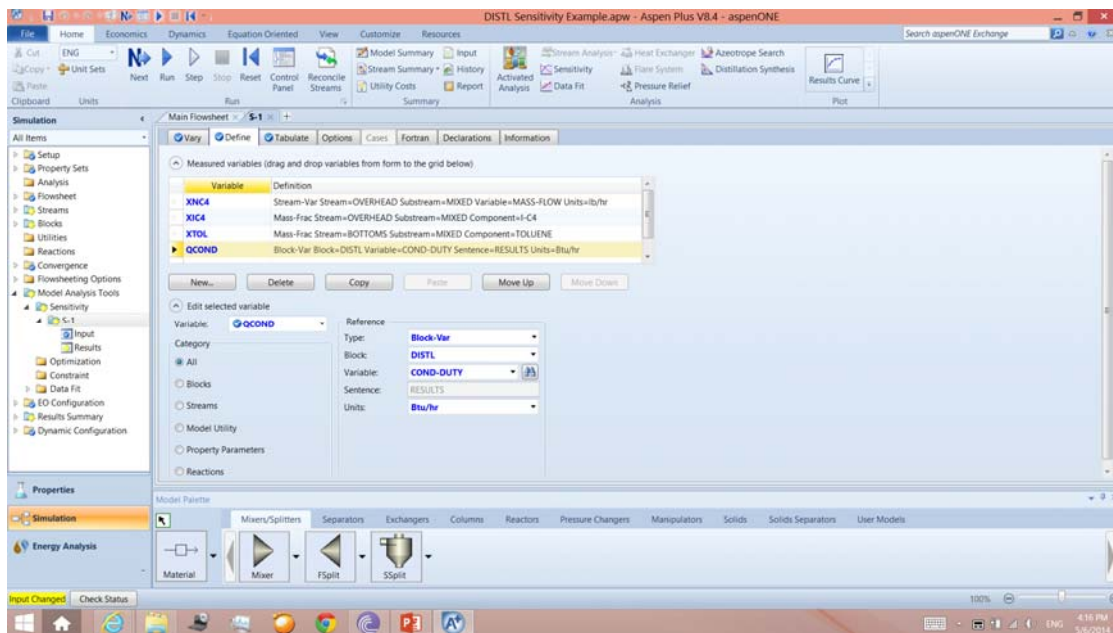
The screenshot shows the Aspen Plus V8.4 interface. The 'Measured variables' list is open, showing a table with columns 'Variable' and 'Definition'. The variable 'RR' is selected, with the definition 'Block-Var Block=DISTL Variable=RR Sentence=PARAM'. The 'Edit selected variable' dialog is open, showing 'RR' as the variable, 'Block-Var' as the type, 'DISTL' as the block, and 'PARAM' as the sentence. The 'Model Palette' at the bottom shows various process units, including 'Mixer', 'FSplit', and 'SSplit'.

Variable	Definition
XNCA	Stream-Var Stream=OVERHEAD Substream=MIXED Variable=MASS-FLOW Units=lb/hr
XICA	Mass-Frac Stream=OVERHEAD Substream=MIXED Component=I-C4
XTOL	Mass-Frac Stream=BOTTOMS Substream=MIXED Component=TOLUENE
RR	Block-Var Block=DISTL Variable=RR Sentence=PARAM

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Examples of Accessing Variables (Cont'd)

Example 7: Access the condenser duty (result) in a DISTL block



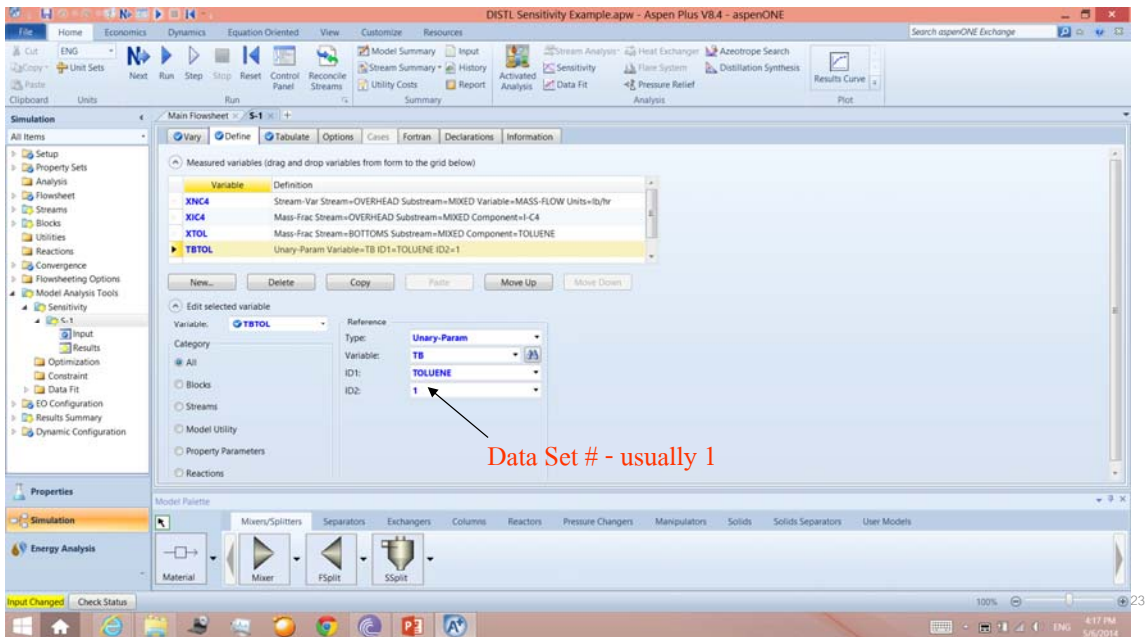
The screenshot shows the Aspen Plus V8.4 interface. The 'Measured variables' list is open, showing a table with columns 'Variable' and 'Definition'. The variable 'QCOND' is selected, with the definition 'Block-Var Block=DISTL Variable=COND-DUTY Sentence=RESULTS Units=Btu/hr'. The 'Edit selected variable' dialog is open, showing 'QCOND' as the variable, 'Block-Var' as the type, 'DISTL' as the block, 'RESULTS' as the sentence, and 'Btu/hr' as the units. The 'Model Palette' at the bottom shows various process units, including 'Mixer', 'FSplit', and 'SSplit'.

Variable	Definition
XNCA	Stream-Var Stream=OVERHEAD Substream=MIXED Variable=MASS-FLOW Units=lb/hr
XICA	Mass-Frac Stream=OVERHEAD Substream=MIXED Component=I-C4
XTOL	Mass-Frac Stream=BOTTOMS Substream=MIXED Component=TOLUENE
QCOND	Block-Var Block=DISTL Variable=COND-DUTY Sentence=RESULTS Units=Btu/hr

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Examples of Accessing Variables (Cont'd)

Example 8: Access the normal boiling point of component TOLUENE



The screenshot shows the Aspen Plus V8.4 interface. The 'Main Flowsheet' window is open, displaying the 'Sensitivity' tool. The 'Measured variables' list includes:

Variable	Definition
XNC4	Stream-Var Stream=OVERHEAD Substream=MIXED Variable=MASS-FLOW Units=lb/hr
XIC4	Mass-Frac Stream=OVERHEAD Substream=MIXED Component=I-C4
XTOL	Mass-Frac Stream=BOTTOMS Substream=MIXED Component=I-TOLUENE
TBTOL	Unary-Param Variable=TB ID1=TOLUENE ID2=1

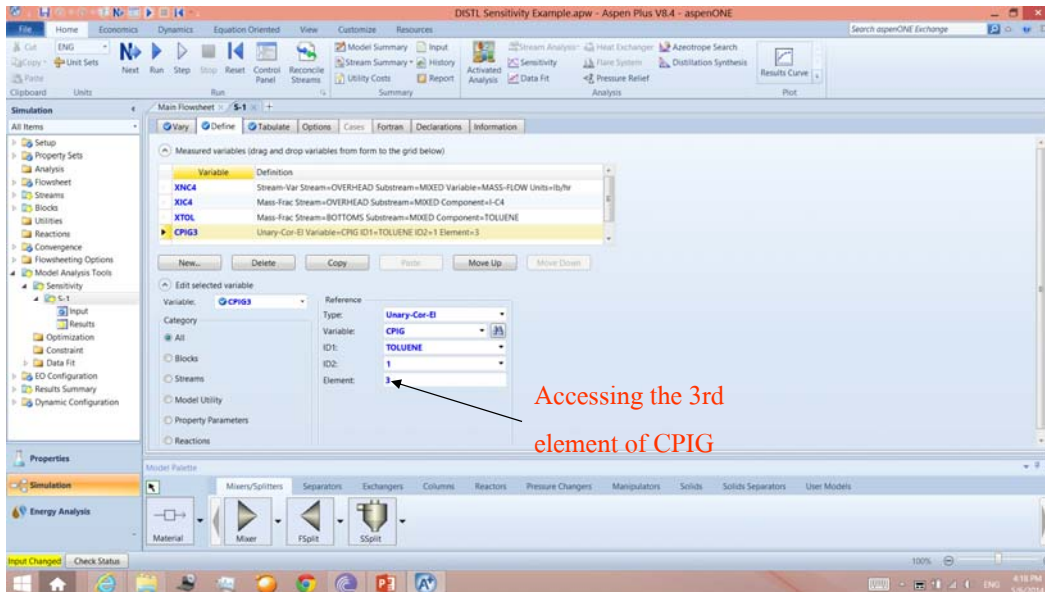
The 'Edit selected variable' window for 'TBTOL' is open, showing the 'Reference' section with the following values:

Type	Variable	ID1	ID2
Unary-Param	TB	TOLUENE	1

An arrow points to the 'ID2' field, which is set to '1'. A red text annotation below the arrow reads: "Data Set # - usually 1".

Examples of Accessing Variables (Cont'd)

Example 9: Access the 3rd element or coefficient in the ideal gas heat capacity equation of TOLUENE



The screenshot shows the Aspen Plus V8.4 interface. The 'Main Flowsheet' window is open, displaying the 'Sensitivity' tool. The 'Measured variables' list includes:

Variable	Definition
XNC4	Stream-Var Stream=OVERHEAD Substream=MIXED Variable=MASS-FLOW Units=lb/hr
XIC4	Mass-Frac Stream=OVERHEAD Substream=MIXED Component=I-C4
XTOL	Mass-Frac Stream=BOTTOMS Substream=MIXED Component=I-TOLUENE
CPIG3	Unary-Cor-EI Variable=CPIG ID1=TOLUENE ID2=1 Element=3

The 'Edit selected variable' window for 'CPIG3' is open, showing the 'Reference' section with the following values:

Type	Variable	ID1	ID2	Element
Unary-Cor-EI	CPIG	TOLUENE	1	3

An arrow points to the 'Element' field, which is set to '3'. A red text annotation below the arrow reads: "Accessing the 3rd element of CPIG".

Ideal Gas Heat Capacity Equation in A+

- A+ contains many physical property parameters which are in the form of equations or correlations.
- For example, CPIG is the ideal gas heat capacity with 11 elements (coefficients)

$$C_P^{IG} = C_1 + C_2 T + C_3 T^2 + C_4 T^3 + C_5 T^4 + C_6 T^5 \quad \text{for } C_7 \leq T \leq C_8$$
$$C_P^{IG} = C_9 + C_{10} T^{C_{11}} \quad \text{for } T < C_7$$

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Sampled Variable vs. Manipulated Variable

- All flowsheet variables (both input and results) can be sampled.
- But only certain flowsheet variables can be manipulated.
- **Examples:** Can we manipulate the following?
 - The total flow of stream OVHDS?
 - The mass fraction of C6 in stream BOTTOMS?
 - The flow rate of TOLUENE in stream FEED?
 - The molar volume of stream FEED?
 - The reflux ratio of the DISTL column?
 - The condenser duty of the DISTL column?
 - The feed tray location?
- Allowed to adjust or manipulate flowsheet input only !!!

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Fortran and Declaration Tabs

- The **Fortran tab** is used to enter Fortran executable statements for use in the Sensitivity Analysis.

- The **Declaration tab** is used to enter Fortran declaration statements such as declaring real and integer variables, and dimensioning arrays and vectors.
 - **Examples:**
 - **REAL*8 TRAYT(30)** => Declaring a real variable TRAYT as a vector with 30 elements
 - **INTEGER NS(5)** => Declaring an integer variable NS as a vector with 5 elements
 - **REAL*8 SAT(5,10)** => Declaring a real variable
 - **REAL*8 KVL** => Forcing a variable KVL to be a real number

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Some Fortran Tips

1. All variables are limited to 6 characters or less.
2. A variables can consist of alphabets and numbers, but may not start with a number. In A+, do not begin variable names with IZ or ZZ.
3. By default, variables starting with a character between A-H and O-Z are real numbers (e.g. 1.42532), while those starting with a character between I-N are integer numbers.
4. All Fortran executable statements must start on column 7 or after.
5. Column 1 is reserved to indicate a comment line (and leave column 2 blank).
6. Column 6 is reserved to indicate a continuation line.

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Workshop 3A: VCM Sensitivity Analysis

- Go to Course Notes Section 9 and work on Workshop 3A.

