Enabling Advanced Problem Solving in Spreadsheets with Access to Physical Property Data

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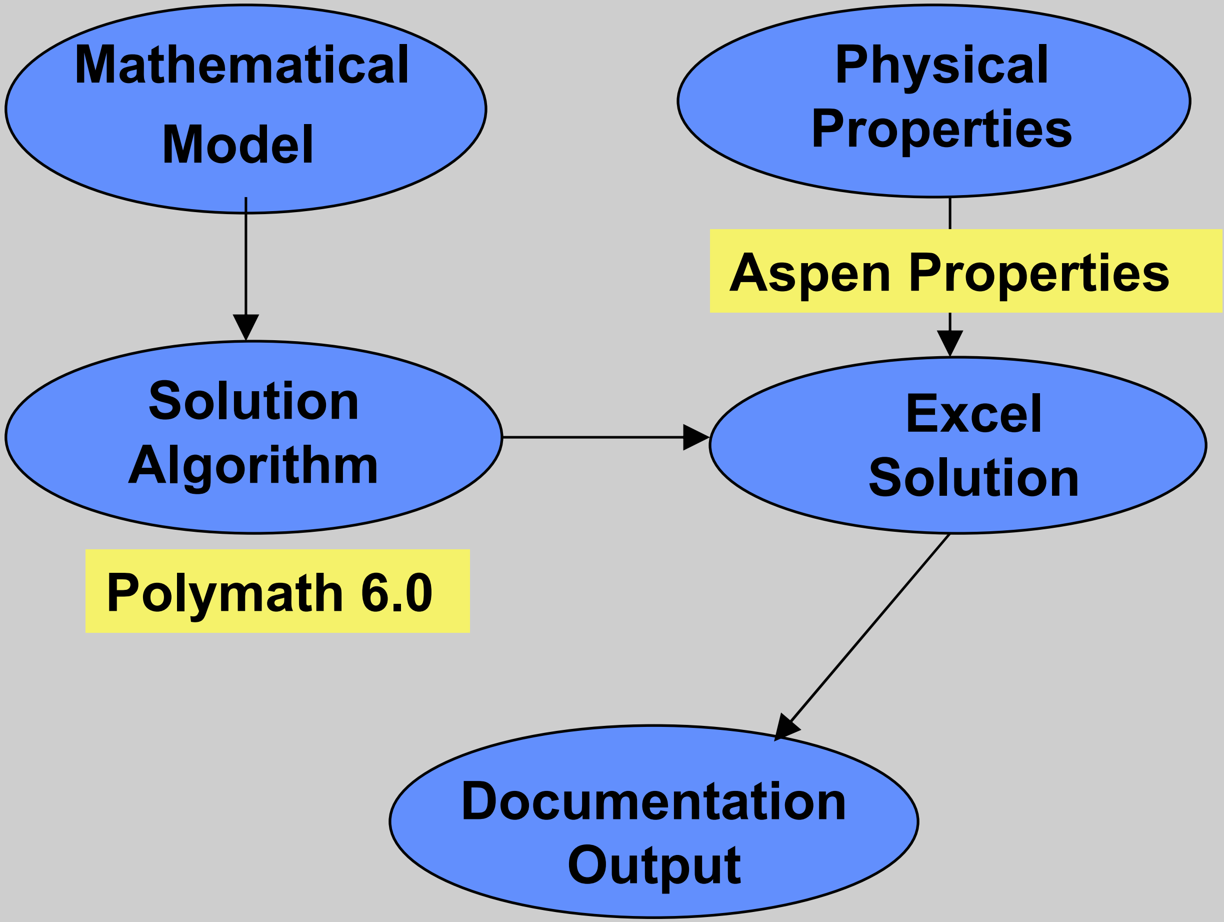
This Paper Deals with Increasing Engineering Productivity with a Novel Combination of Software Tools

- **Polymath© (advanced problem formulation)**
- **Excel™ (familiar spreadsheet environment)**
- **Aspen Properties™ Add-In for Excel (accurate physical property data)**

Demonstrate: Engineers and technical personnel at their personal computers can now efficiently solve much more sophisticated problems while calling upon accurate physical property data, all within the friendly spreadsheet environment of Excel.

A New Paradigm in Desktop Problem Solving Involving Polymath, Aspen Properties, and Excel

Provides Advanced Problem Solutions



POLYMATH Software Presents

POLYMATH 6.0
Numerical Computation Package

A Significant New Release

- Extremely Easy-to-Use
- Excellent Problem Solving Capabilities
- Now Works to Provide Excel Solutions
    - Automated Export of Problems to Excel
    - Enables Stand-Alone Excel Calculations
    - Provides Differential Equations Solver for Excel
    - Promotes the Use of Aspen Properties within Excel Calculations

POLYMATH 6.0

Professional problem solving capabilities include:

- **Linear Equations - up to 264 simultaneous equations**
- **Nonlinear Equations - up to 600 simultaneous nonlinear and explicit algebraic equations**
- **Differential Equations - up to 600 simultaneous ordinary differential and explicit algebraic equations**
- **Data analysis and Regression - up to 1000 data points with capabilities for linear, multiple linear, and nonlinear regressions with extensive statistics plus polynomial and spline fitting with interpolation and graphing capabilities**

POLYMATH 6.0 features include:

- EASE OF USE WITHOUT ANY PROGRAMMING LANGUAGES OR CONTROL LANGUAGES TO REMEMBER
- STANDARD WINDOWS EDITING
- EXTENSIVE USER ALGORITHM SELECTION AND CONTROL
- EXECUTION WITH ALL 32-BIT WINDOWS OPERATING SYSTEMS
- COMPATIBILITY WITH PREVIOUS VERSIONS
- THREE ON-BOARD UTILITIES: POWERFUL CALCULATOR, UNIT CONVERTER, AND EXTENSIVE ENGINEERING CONVERSION FACTORS
- EXTENSIVE ON-LINE DOCUMENTATION
- AUTOMATIC PROBLEM EXPORT TO EXCEL – EXCEL ADD-IN FOR DIFFERENTIAL EQUATIONS
- MATLAB OUTPUT GIVING ORDERED AND FORMATTED EQUATIONS

Demonstration Problem – Cocurrent Operation of a Double Pipe Heat Exchanger

One mode of operation of a double-pipe heat exchanger, which is diagramed in Figure 6–15 for cocurrent operation, is to cool a steady stream of m' lb$_m$/h of fluid in the tube from inlet temperature T_1 to an exit temperature T_2. The fluid in the shell side with a flow rate of m lb$_m$/h is correspondingly heated from inlet temperature T'_1 to exit temperature T'_2.

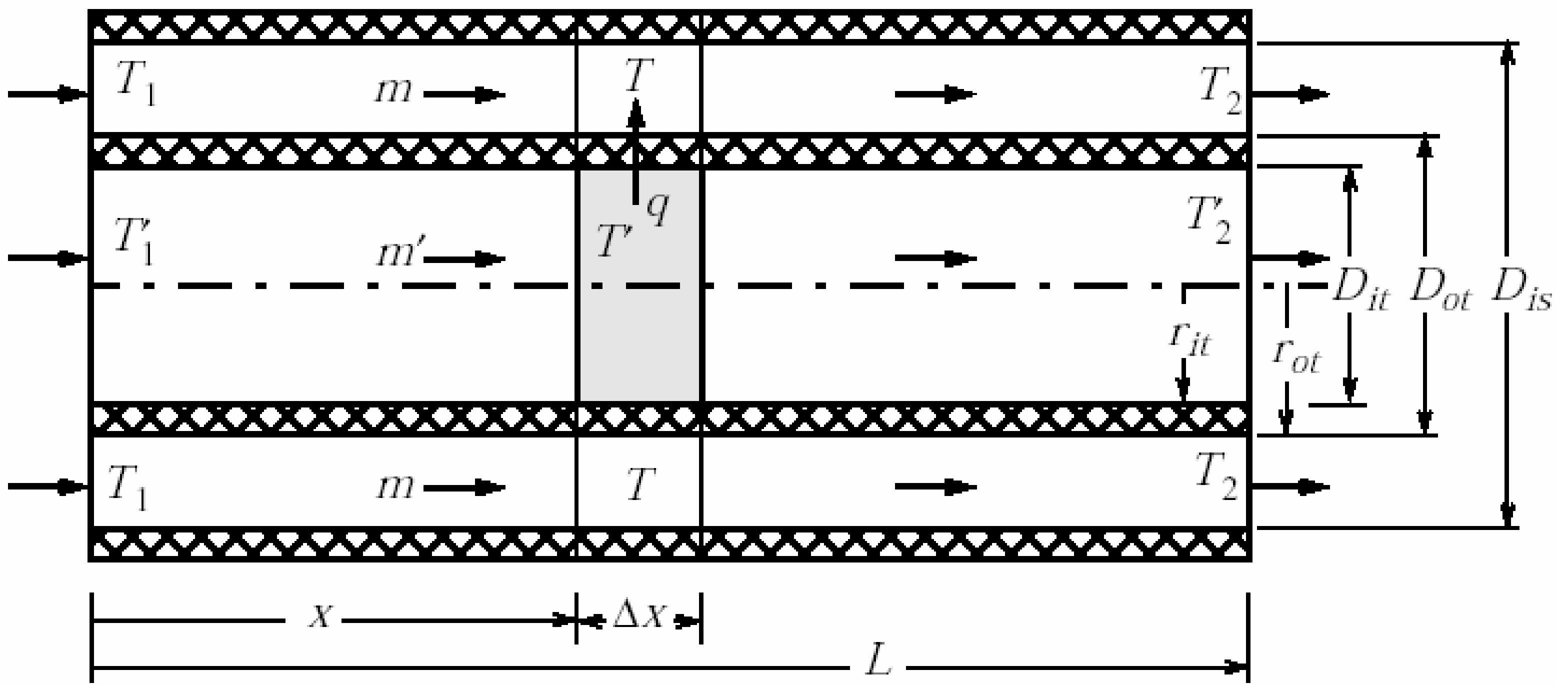


Figure 6–15 Double-Pipe Heat Exchanger for Cocurrent (Parallel) Flow

Some Problem Details – Local Heat Transfer Coefficient

The following equation represents the local heat transfer coefficient where the exponent n = 0.4 for heating and 0.3 for cooling

$$\frac{hD}{k} = 0.023\left(\frac{Dv\rho}{\mu}\right)^{0.8}\left(\frac{C_p\mu}{k}\right)^n$$

Overall Heat Transfer Coefficients The local overall heat transfer coefficient based on the inside area is calculated from (Geankoplis[4])

$$U_i = \frac{1}{1/h_i + ((r_{ot} - r_{it})D_{it})/(k_t D_{tlm}) + D_{it}/(D_{ot}h_o)} \quad \textbf{(6-66)}$$

where t represents the tube wall material and dimensions. The D_{tlm} term is the log mean diameter (or area) for the tube wall.

Demonstration Problem – Differential Equations for Heat Exchanger

Cocurrent or Parallel Flow A differential energy balance on the tube fluid in concurrent flow in a manner similar to that detailed in Problem 6.8, with the prime indicating the fluid temperature or property of the higher temperature fluid, leads to

$$\frac{d}{dx}(T') = -\frac{U_i(\pi D_i)(T' - T)}{m' C_p'} \qquad \textbf{(6-64)}$$

where the overall heat transfer coefficient U_i in btu/h·ft^2·°F is based on the inside area given by πD_i with the inside tube diameter D_i in ft. The initial condition for Equation (6-64) is just the inlet temperature T_1' to the tube, and the final condition is the outlet temperature T_2' from the tube.

Similarly, for the well insulated shell, a differential energy balance on the shell fluid in concurrent flow and the inside heat transfer area yields

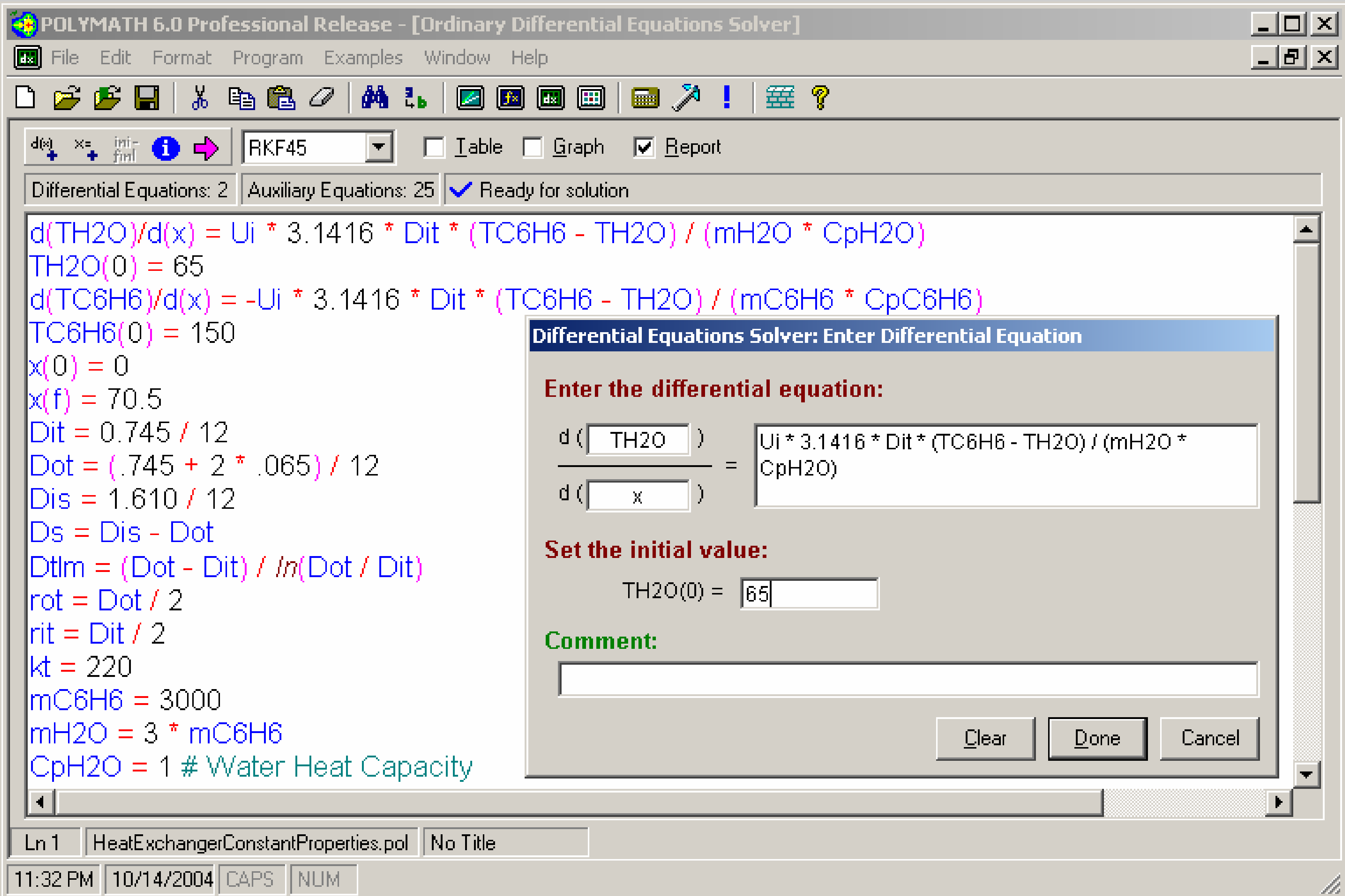
$$\frac{dT}{dx} = \frac{U_i(\pi D_i)(T' - T)}{mC_p} \qquad \textbf{(6-65)}$$

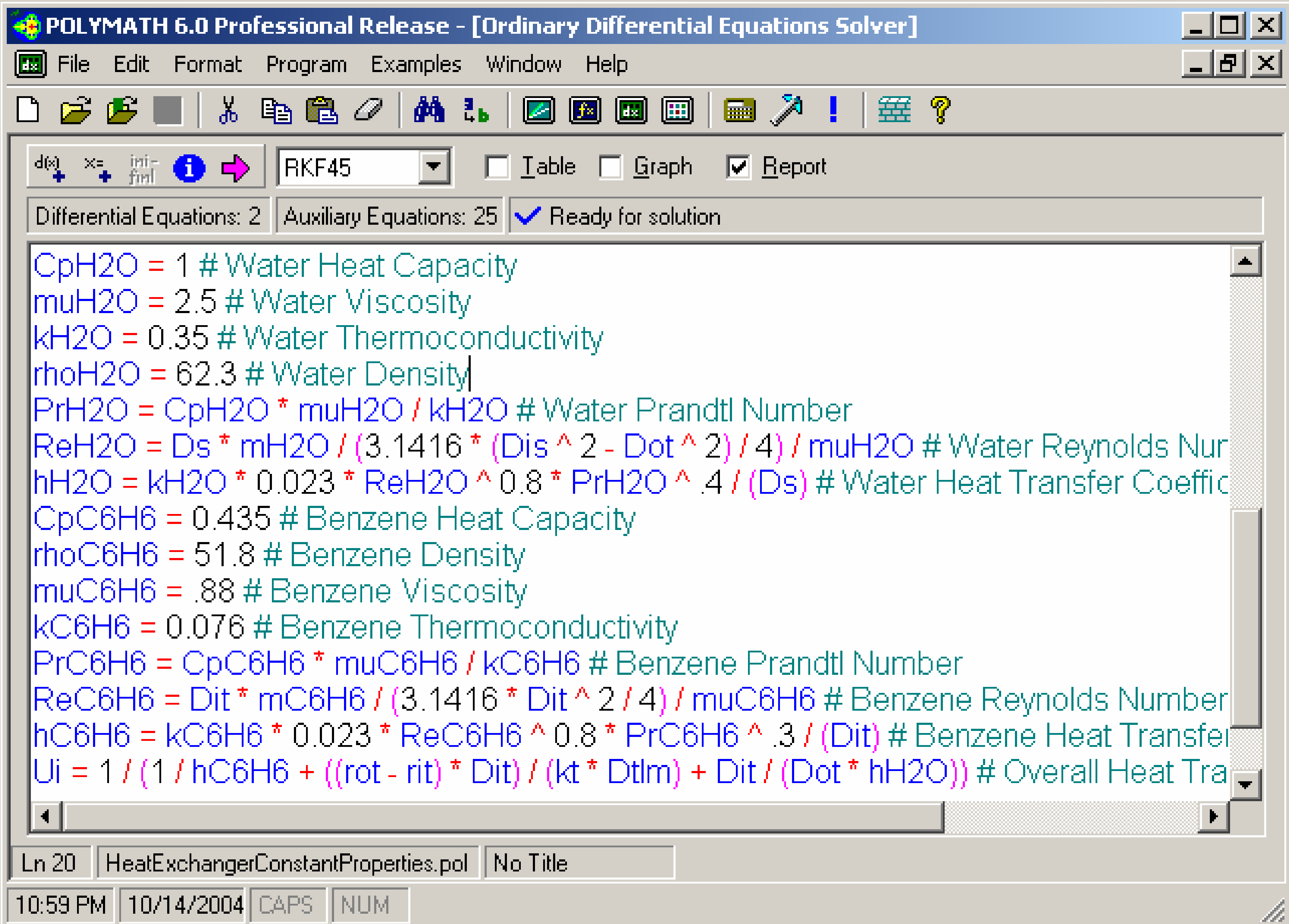
Demonstration Problem:

Calculate the required length of a concurrent double pipe heat exchanger with cooling water in the shell side and benzene in the tube side. The cooling water is available at 65 °F and has a flow that is three times that of the benzene. The configuration of the heat exchanger is given below:

Fluid	Flow	Inlet	Outlet	Inside Tube		Outside Pipe	
	m	T	T	OD		Nominal	
	lb_m/h	°F	°F	in.	BWG	Pipe, in.	Schedule
Benzene (liquid)	3000	150	80	7/8	16	$1\frac{1}{2}$	40

Entering the Problem into Polymath - Constant Properties




POLYMATH 6.0 Professional Release - [Ordinary Differential Equations Solver]
File Edit Format Program Examples Window Help
RKF45
Table
Graph
Report
Differential Equations: 2
Auxiliary Equations: 25
Ready for solution
CpH2O = 1 # Water Heat Capacity
muH2O = 2.5 # Water Viscosity
kH2O = 0.35 # Water Thermoconductivity
rhoH2O = 62.3 # Water Density
PrH2O = CpH2O * muH2O / kH2O # Water Prandtl Number
ReH2O = Ds * mH2O / (3.1416 * (Dis ^ 2 - Dot ^ 2) / 4) / muH2O # Water Reynolds Nur
hH2O = kH2O * 0.023 * ReH2O ^ 0.8 * PrH2O ^ .4 / (Ds) # Water Heat Transfer Coeffic
CpC6H6 = 0.435 # Benzene Heat Capacity
rhoC6H6 = 51.8 # Benzene Density
muC6H6 = .88 # Benzene Viscosity
kC6H6 = 0.076 # Benzene Thermoconductivity
PrC6H6 = CpC6H6 * muC6H6 / kC6H6 # Benzene Prandtl Number
ReC6H6 = Dit * mC6H6 / (3.1416 * Dit ^ 2 / 4) / muC6H6 # Benzene Reynolds Number
hC6H6 = kC6H6 * 0.023 * ReC6H6 ^ 0.8 * PrC6H6 ^ .3 / (Dit) # Benzene Heat Transfe
Ui = 1 / (1 / hC6H6 + ((rot - rit) * Dit) / (kt * Dtlm) + Dit / (Dot * hH2O)) # Overall Heat Tra
Ln 20
HeatExchangerConstantProperties.pol
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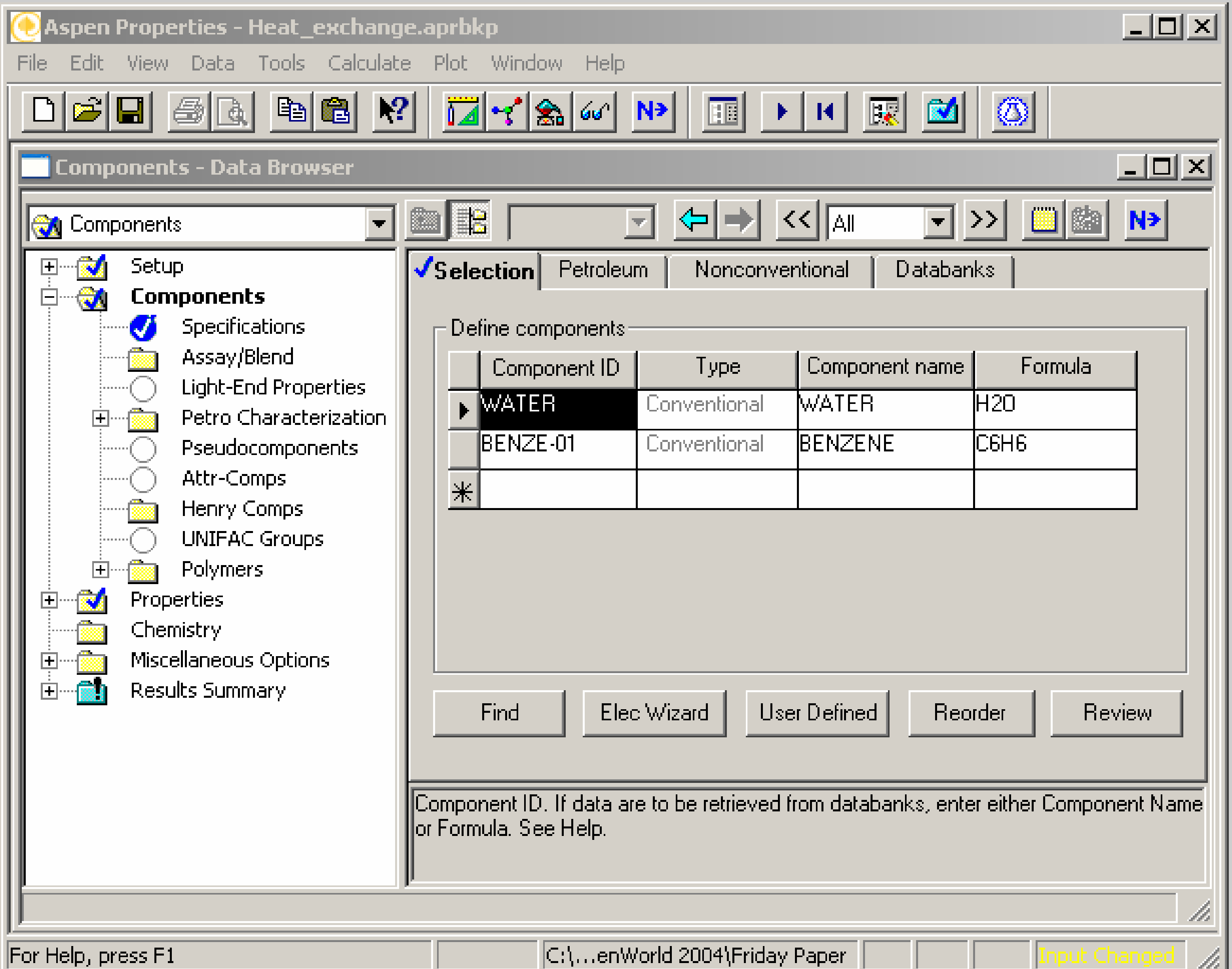
Aspen Properties Excel Calculator

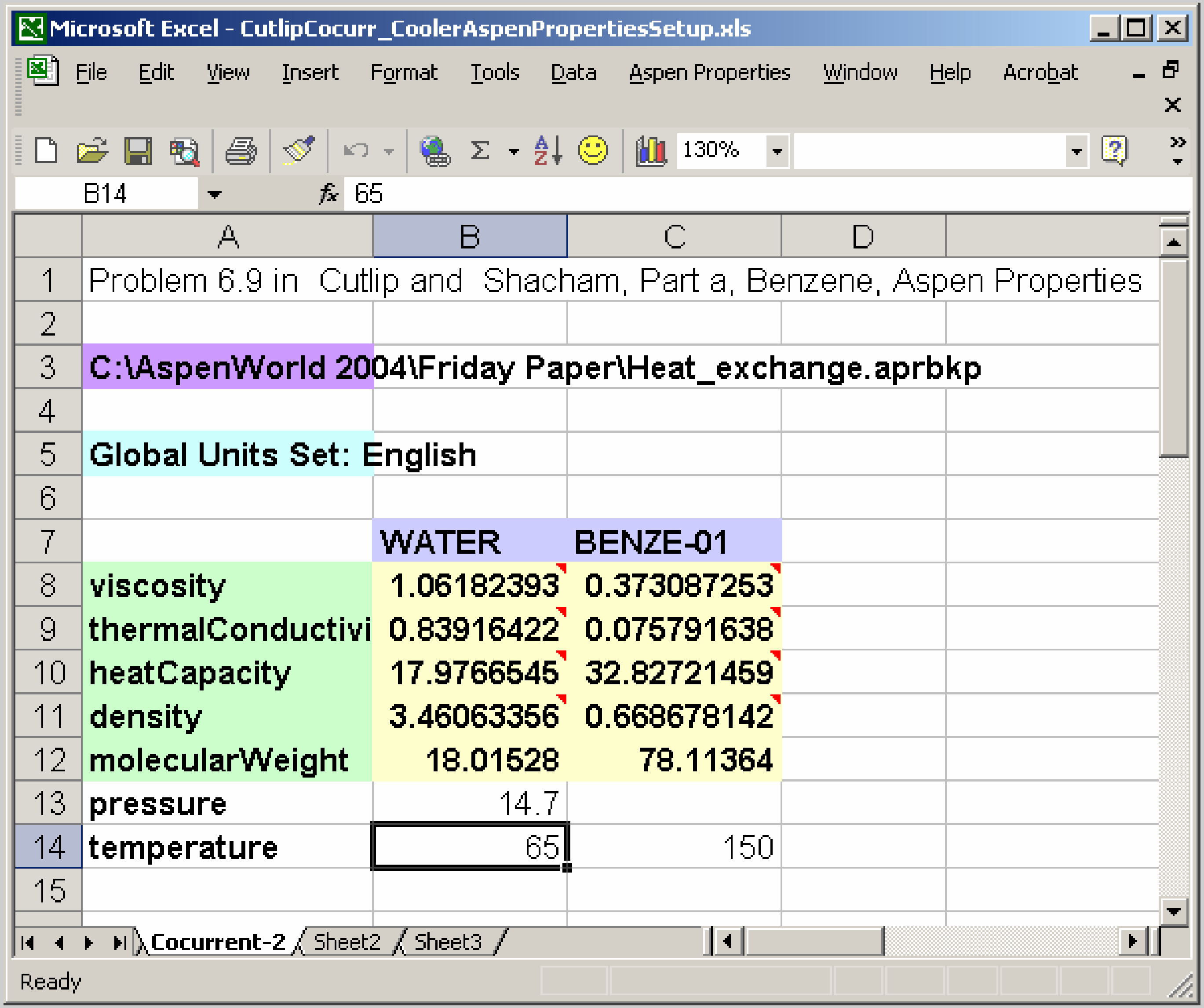
Brings Physical Property Data to Excel

- **Pure component constants (MW, Normal boiling point).**
- **Vapor pressure at a specified temperature**
- **Pure component property at specified temperature and pressure**
- **Mixture properties for a specified mixture at given temperature and pressure**
- **Two and three phase flash, bubble and dew point calculations**

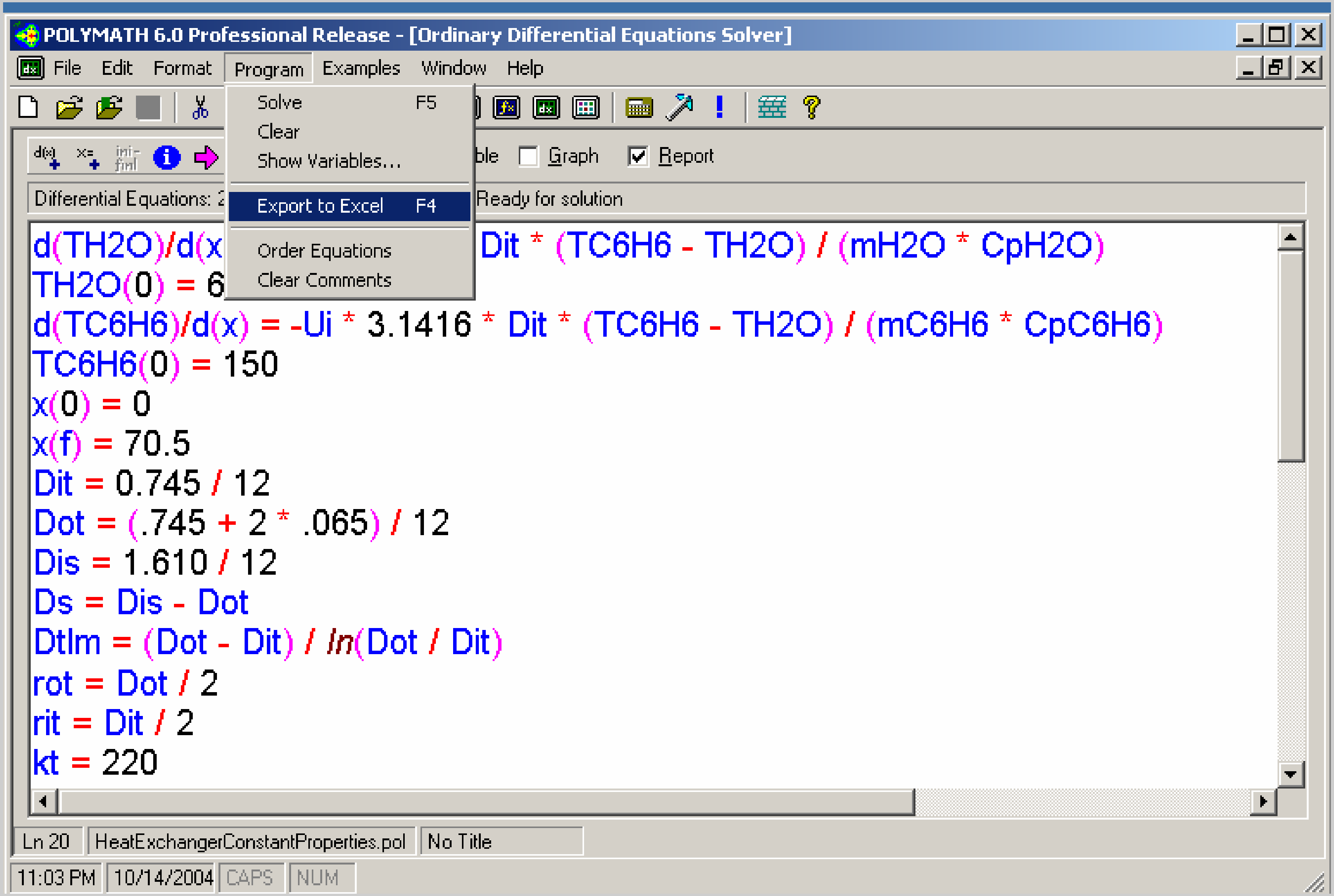
Preparing for Aspen Properties – Building the aprbkp file



Setting Up Aspen Property Data in an Excel Spreadsheet Using Aspen Properties Add-In for Excel



Export the Polymath Program to the Open Excel Book with a Single Keypress



The Polymath Problem is Automatically Exported to a new Excel Worksheet in the open Workbook.

Microsoft Excel - CutlipCocurr_CoolerAspenPropertiesSetup.xls

POLYMATH DEQ Migration Document

	A	B	C	D	E	F
1	POLYMATH DEQ Migration Document					
2		Variable	Value		*Polymath Equation*	*Comments*
3	Explicit Eqs	Dit	0.062083333		*Dit=0.745 / 12*	
4		Dot	0.072916667		*Dot=(.745 + 2 * .065) / 12*	
5		Dis	0.134166667		*Dis=1.610 / 12*	
6		Ds	0.06125		*Ds=Dis - Dot*	
7		Dtlm	0.06735486		*Dtlm=(Dot - Dit) / ln(Dot / Dit)*	
8		rot	0.036458333		*rot=Dot / 2*	
9		rit	0.031041667		*rit=Dit / 2*	
10		kt	220		*kt=220*	
11		mC6H6	3000		*mC6H6=3000*	
12		mH2O	9000		*mH2O=3 * mC6H6*	
13		CpH2O	1		*CpH2O=1*	*Water Heat Capacity*
14		muH2O	2.5		*muH2O=2.5*	*Water Viscosity*
15		kH2O	0.35		*kH2O=0.35*	*Water Thermoconductivity*
16		rhoH2O	62.3		*rhoH2O=62.3*	*Water Density*
17		PrH2O	7.142857143		*PrH2O=CpH2O * muH2O / kH2O*	*Water Prandtl Number*
18		ReH2O	22134.33389		*ReH2O=Ds * mH2O / (3.1416 * (Dis ^ 2 - Dot ^ 2) / 4) /*	*Water Reynolds Number*
19		hH2O	863.5584507		*hH2O=kH2O * 0.023 * ReH2O ^ 0.8 * PrH2O ^ .4 / (Ds)*	*Water Heat Transfer Coefficient*
20		CpC6H6	0.435		*CpC6H6=0.435*	*Benzene Heat Capacity*
21		rhoC6H6	51.8		*rhoC6H6=51.8*	*Benzene Density*
22		muC6H6	0.88		*muC6H6=.88*	*Benzene Viscosity*
23		kC6H6	0.076		*kC6H6=0.076*	*Benzene Thermoconductivity*
24		PrC6H6	5.036842105		*PrC6H6=CpC6H6 * muC6H6 / kC6H6*	*Benzene Prandtl Number*
25		ReC6H6	69915.36978		*ReC6H6=Dit * mC6H6 / (3.1416 * Dit ^ 2 / 4) / muC6H6*	*Benzene Reynolds Number*
26		hC6H6	[illegible]		*hC6H6=kC6H6 * 0.023 * ReC6H6 ^ 0.8 * PrC6H6 ^ .3*	*Benzene Heat Transfer Coefficient*

PL1 / Cocurrent-2 / Sheet2 / Sheet3

Ready

The Excel Spreadsheet is Ready for Solving Differential Equations

Microsoft Excel - CutlipCocurr_CoolerAspenPropertiesSetup.xls

File Edit View Insert Format Tools Data Aspen Properties Window Help Acrobat

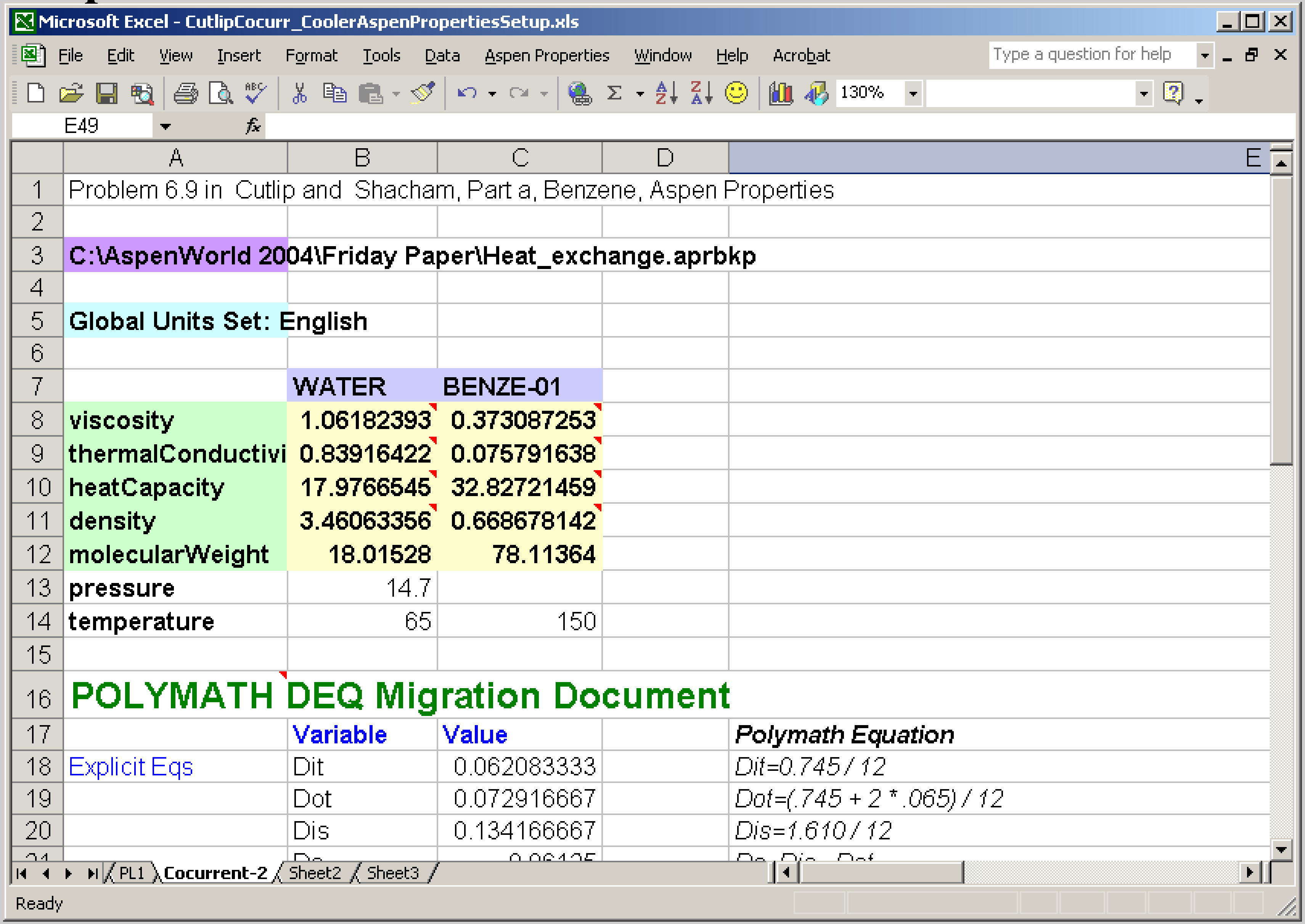
A39

	A	B	C	D	E	
12		mH2O	9000		mH2O=3 * mC6H6	
13		CpH2O	1		CpH2O=1	Water Heat Capaci
14		muH2O	2.5		muH2O=2.5	Water Viscosity
15		kH2O	0.35		kH2O=0.35	Water Thermocond
16		rhoH2O	62.3		rhoH2O=62.3	Water Density
17		PrH2O	7.142857143		PrH2O=CpH2O * muH2O / kH2O	Water Prandtl Num
18		ReH2O	22134.33389		ReH2O=Ds * mH2O / (3.1416 * (Dis ^ 2 - Dot ^ 2) / 4) /	Water Reynolds Nu
19		hH2O	863.5584507		hH2O=kH2O * 0.023 * ReH2O ^ 0.8 * PrH2O ^ .4 / (Ds	Water Heat Transfe
20		CpC6H6	0.435		CpC6H6=0.435	Benzene Heat Capa
21		rhoC6H6	51.8		rhoC6H6=51.8	Benzene Density
22		muC6H6	0.88		muC6H6=.88	Benzene Viscosity
23		kC6H6	0.076		kC6H6=0.076	Benzene Thermocc
24		PrC6H6	5.036842105		PrC6H6=CpC6H6 * muC6H6 / kC6H6	Benzene Prandtl Nu
25		ReC6H6	69915.36978		ReC6H6=Dit * mC6H6 / (3.1416 * Dit ^ 2 / 4) / muC6H6	Benzene Reynolds
26		hC6H6	343.4567292		hC6H6=kC6H6 * 0.023 * ReC6H6 ^ 0.8 * PrC6H6 ^ .3	Benzene Heat Tran
27		Ui	255.0875447		Ui=1 / (1 / hC6H6 + ((rot - rit) * Dit) / (kt * Dtlm) + Dit / (	Overall Heat Transf
28	Integration Vars	TH2O	65		TH2O(0)=65	
29		TC6H6	150		TC6H6(0)=150	
30	ODE Eqs	d(TH2O)/d(x)	0.469885004		d(TH2O)/d(x) = Ui * 3.1416 * Dit * (TC6H6 - TH2O) / (mH2O * CpH2O)	
31		d(TC6H6)/d(x	-3.240586232		d(TC6H6)/d(x) = -Ui * 3.1416 * Dit * (TC6H6 - TH2O) / (mC6H6 * CpC6H6)	
32	Indep Var	x	0		x(0)=0 ; x(f)=70.5	
33						
34						

PL1 / Cocurrent-2 / Sheet2 / Sheet3

Ready

The Polymath Solution Needs to be Copied into the Aspen Properties Worksheet



	A	B	C	D	E
1	Problem 6.9 in Cutlip and Shacham, Part a, Benzene, Aspen Properties				
2					
3	C:\AspenWorld 2004\Friday Paper\Heat_exchange.aprbkp				
4					
5	Global Units Set: English				
6					
7		WATER	BENZE-01		
8	viscosity	1.06182393	0.373087253		
9	thermalConductivi	0.83916422	0.075791638		
10	heatCapacity	17.9766545	32.82721459		
11	density	3.46063356	0.668678142		
12	molecularWeight	18.01528	78.11364		
13	pressure	14.7			
14	temperature	65	150		
15					
16	POLYMATH DEQ Migration Document				
17		Variable	Value		Polymath Equation
18	Explicit Eqs	Dit	0.062083333		Dit=0.745 / 12
19		Dot	0.072916667		Dot=(.745 + 2 * .065) / 12
20		Dis	0.134166667		Dis=1.610 / 12

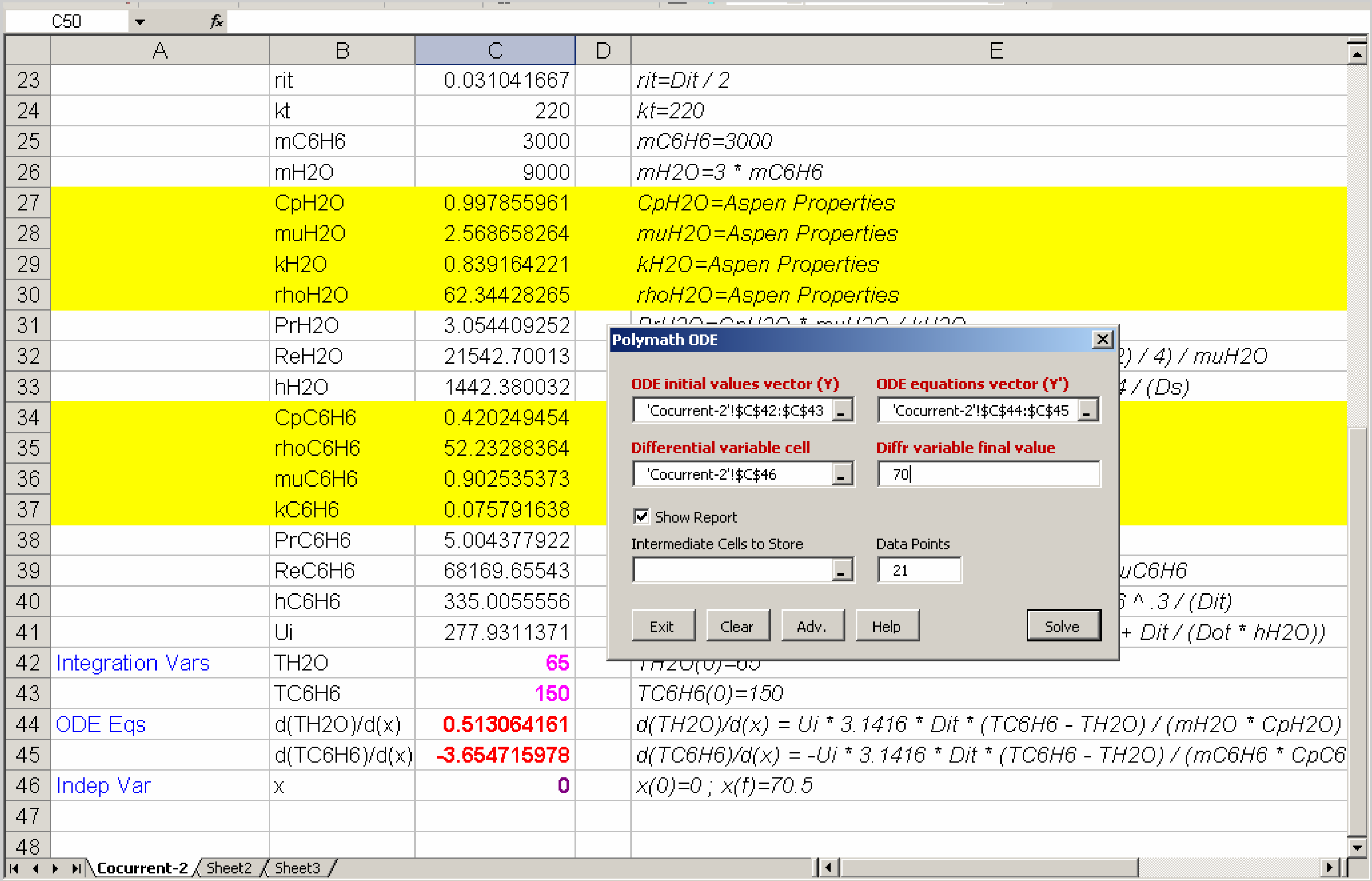
The Physical Property Information Is Copied into the Excel Problem Solution

C29 =B9

	A	B	C	D	E
7		**WATER**	**BENZE-01**		
8	**viscosity**	**1.0618239**	**0.37308725**		
9	**thermalConducti**	**0.8391642**	**0.07579164**		
10	**heatCapacity**	**17.976655**	**32.8272146**		
11	**density**	**3.4606336**	**0.66867814**		
12	**molecularWeight**	**18.01528**	**78.11364**		
13	**pressure**	14.7			
14					
15	**POLYMATH DEQ Migration Document**				
16		**Variable**	**Value**		***Polymath Equation***
17	Explicit Eqs	Dit	0.062083333		*Dit=0.745 / 12*
18		Dot	0.072916667		*Dot=(.745 + 2 * .065) / 12*
19		Dis	0.134166667		*Dis=1.610 / 12*
20		Ds	0.06125		*Ds=Dis - Dot*
21		Dtlm	0.06735486		*Dtlm=(Dot - Dit) / ln(Dot / Dit)*
22		rot	0.036458333		*rot=Dot / 2*
23		rit	0.031041667		*rit=Dit / 2*
24		kt	220		*kt=220*
25		mC6H6	3000		*mC6H6=3000*
26		mH2O	9000		*mH2O=3 * mC6H6*
27		CpH2O	0.997855961		*CpH2O=Aspen Properties*
28		muH2O	2.568658264		*muH2O=Aspen Properties*
29		kH2O	0.839164221		*kH2O=Aspen Properties*
30		rhoH2O	62.34428265		*rhoH2O=Aspen Properties*
31		PrH2O	3.054409252		*PrH2O=CpH2O * muH2O / kH2O*

Cocurrent-2 / Sheet2 / Sheet3

The Add-In (Ode_Solver) for Solving Differential Equations is Selected and Initialized



	A	B	C	D	E
23		rit	0.031041667		rit=Dit / 2
24		kt	220		kt=220
25		mC6H6	3000		mC6H6=3000
26		mH2O	9000		mH2O=3 * mC6H6
27		CpH2O	0.997855961		CpH2O=Aspen Properties
28		muH2O	2.568658264		muH2O=Aspen Properties
29		kH2O	0.839164221		kH2O=Aspen Properties
30		rhoH2O	62.34428265		rhoH2O=Aspen Properties
31		PrH2O	3.054409252		
32		ReH2O	21542.70013		) / 4) / muH2O
33		hH2O	1442.380032		4 / (Ds)
34		CpC6H6	0.420249454		
35		rhoC6H6	52.23288364		
36		muC6H6	0.902535373		
37		kC6H6	0.075791638		
38		PrC6H6	5.004377922		
39		ReC6H6	68169.65543		uC6H6
40		hC6H6	335.0055556		^ .3 / (Dit)
41		Ui	277.9311371		+ Dit / (Dot * hH2O))
42	Integration Vars	TH2O	65		
43		TC6H6	150		TC6H6(0)=150
44	ODE Eqs	d(TH2O)/d(x)	0.513064161		d(TH2O)/d(x) = Ui * 3.1416 * Dit * (TC6H6 - TH2O) / (mH2O * CpH2O)
45		d(TC6H6)/d(x)	-3.654715978		d(TC6H6)/d(x) = -Ui * 3.1416 * Dit * (TC6H6 - TH2O) / (mC6H6 * CpC6
46	Indep Var	x	0		x(0)=0 ; x(f)=70.5
47					
48					

The Report of the Differential Equation Solution is Automatically Generated on a new Worksheet

J35

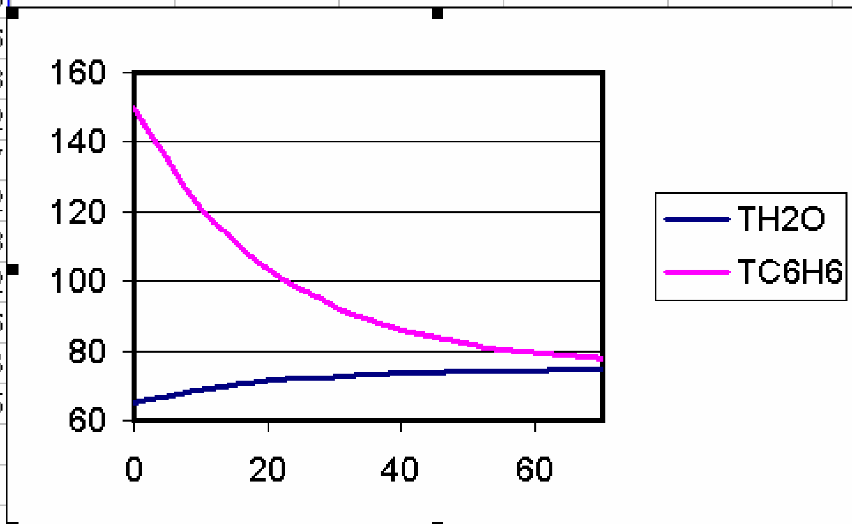
	A	B	C	D	E	F	G	H	I	J
1	**POLYMATH Report DEQ**									
2	Ordinary Differential Equations (RKF45).									
3										
4	**Calculated values of DEQ variables**									
5		Variable	Initial	Minimal	Maximal	Final				
6	1	x	0	0	70	70				
7	2	TH2O	65	65	74.61302	74.61302				
8	3	TC6H6	150	77.695	150	77.695				
9										
10	**Differential equations**									
11	[1] d(C42)/d(C46) = ((((C41 * 3.1416) * C17) * (C43 - C42)) / (C26 * C27))									
12	[2] d(C43)/d(C46) = (0 - ((((C41 * 3.1416) * C17) * (C43 - C42)) / (C25 * C34)))									
13										
14	**Independent variable**									
15	Variable name: C46									
16	Initial value: 0									
17	Final value: 70									
18										
19	**Intermediate data points**									
20		x	TH2O	TC6H6						
21	1	0	65	150						
22	2	8.0639849	68.345245	125.73445						
23	3	10.730652	69.168869	119.62095						
24	4	13.397318	69.884922	114.25916						
25	5	18.730652	71.052294	105.42218						

Ccurrent-2 | DEQ Solution (1) | Sheet2 | Sheet3

A Graph can be Generated on the Report Worksheet

Chart 1

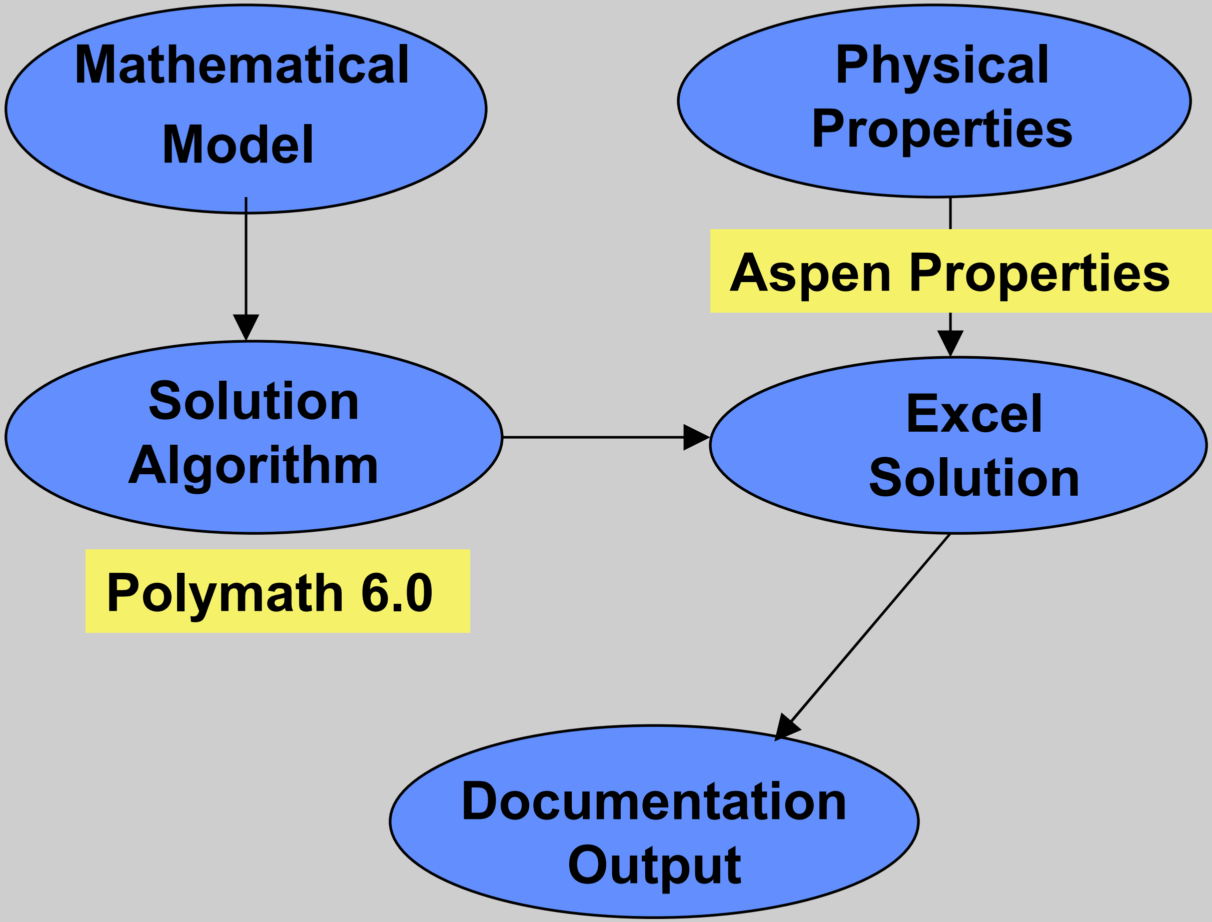
	A	B	C	D
19	**Intermediate data points**			
20		x	TH2O	TC6H6
21	1	0	65	150
22	2	8.0639849	68.345245	125.73445
23	3	10.730652	69.168869	119.62095
24	4	13.397318	69.884922	114.25916
25	5	18.730652	71.052294	105.42218
26	6	21.397318	71.527214	101.79232
27	7	24.063985	71.942474	98.601657
28	8	26.730652	72.30597	95.79572
29	9	32.063985	72.903787	91.154198
30	10	34.730652	73.148942	89.241052
31	11	37.397318	73.364262	87.556
32	12	40.063985	73.5535	86.071403
33	13	45.397318	73.866312	83.609765
34	14	48.063985	73.995176	82.592921
35	15	50.730652	74.108646	81.69621
36	16	53.397318	74.208595	80.905301
37	17	58.730652	74.374283	79.592039
38	18	61.397318	74.442711	79.048879
39	19	64.063985	74.503048	78.569552
40	20	66.730652	74.556263	78.146516
41	21	70	74.61302	77.695
42				
43				
44				



Cocurrent-2 | DEQ Solution (1) | Sheet2 | Sheet3

SUMMARY - A New Paradigm in Desktop Problem Solving Involving Polymath, Aspen Properties, and Excel

Provides Advanced Problem Solutions in Excel



Engineers and technical personnel at their personal computers can now efficiently solve much more sophisticated problems on a personal computer while calling upon accurate physical property data, all within a friendly spreadsheet environment.

Software:

- Aspen Properties is a product of AspenTech
  http://www.aspentech.com/

- Excel is a product of Microsoft Corporation
  http://www.microsoft.com/

- Polymath is a product of Polymath Software
  http:// www.polymath-software.com