Aspen Tutorial

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Contents

Chapter 1

CHEM-E1120 Thermochemical processes

1.1 Production of synthetic gas from a biomass

The task is to simulate a production of synthetic gas from a biomass. One way to do it is to develop an Aspen model. The model is divided into the biomass decomposition, gasification and separation units where the solids and syngas is separated. In the simulation, the gasifier is in steady state, isothermal, and decomposition products are estimated based on the biomass ultimate analysis. Tars are not considered in the model, but ashes are taken into account as non-conventional solids. The biomass is the pine sawdust, which is a common waste product of the forest industry. The process flow diagram is presented on figure 1.1.

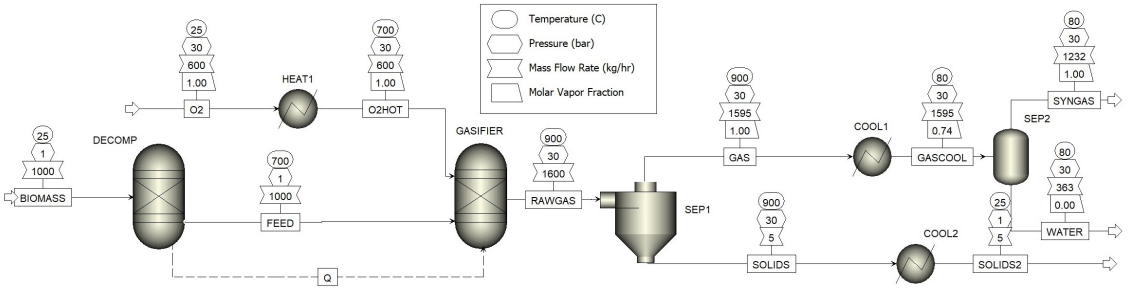

Figure 1.1: Gasification production plant

Add all simulation's components can be found in the table 1.1.

1.1.1 Thermodynamic model

The next step is to select a thermodynamic model. The chosen property method is the Redlich-Kwong-Soave cubic equation of state with Boston-Mathias alpha function ($RKS - BM$). This method is suitable for non-polar or slightly polar mixtures like hydrocarbons and light gases. The data base of Aspen contains only conventional components, which means that the properties of the biomass and the coal needs to be specified manually. In the software the properties of the non-conventional components can be specified in "Method/NC Props" tab. The biomass and the ash

Component ID	Type	Coponent name	Alias
WATER	Conventional	WATER	H2O
BIOMASS	Nonconventional		
ASH	Nonconventional		
H2	Conventional	HYDROGEN	H2
O2	Conventional	OXYGEN	O2
N2	Conventional	NITROGEN	N2
CO	Conventional	CARBON-MONOXIDE	CO
CO2	Conventional	CARBON-DIOXIDE	CO2
METHA-01	Conventional	METHANE	CH4
CARBOGRA	Solid	CARBON-GRAPHITE	C
S	Conventional	SULFUR	S
H2S	Conventional	HYDROGEN-SULFIDE	H2S
H3N	Conventional	AMMONIA	H3N

Table 1.1: Simulation component

properties can be estimated by HCOALGEN and DCOALIGT models. HCOALGEN and DCOALIGT models are used to calculate the enthalpy and density of non-conventional components, respectively. The HCOALGEN model requires these three component attributes for non-conventional components: proximate analysis results (denoted as PROXANAL in Aspen Plus), ultimate analysis results (denoted as ULTANAL in Aspen Plus), and sulfur analysis results (denoted as SULFANAL in Aspen Plus). The proximate analysis gives the weight content of moisture, fixed carbon, volatile matter and ash. The ultimate analysis gives the weight composition of coal in terms of ash, carbon, hydrogen, nitrogen, chlorine, sulfur, and oxygen. The sulfur analysis divides the sulfur content into three types, pyritic, sulfate, and organic sulfur. The DCOALIGT model requires only the two component attributes ULTANAL and SULFANAL. In Aspen Plus it is multiple correlations have been predefined to calculate the enthalpy. The HCOALGEN option codes are shown in table 1.2.

Option Code Value	Calculation Method Parameter	Names Component	Attributes
1 - Heat of Combustion			
1	Boie correlation	BOIEC	ULTANAL/SULFANAL/PROXANAL
2	Dulong correlation	DLNGC	ULTANAL/SULFANAL/PROXANAL
3	Grummel and Davis correlation	GMLDC	ULTANAL/SULFANAL/PROXANAL
4	Mott and Spooner correlation	MTSPC	ULTANAL/SULFANAL/PROXANAL
5	IGT correlation	CIGTC	ULTANAL/PROXANAL
6	User input value	HCOMB	ULTANAL/PROXANAL
2 - Standard Heat of Formation			
1	Heat-of-combusion based correlation	-	ULTANAL/SULFANAL
2	Direct correlation	HFC	ULTANAL/SULFANAL/PROXANAL
3 - Heat Capacity			
1	Kirov correlation	CP1C	PROXANAL
2	Cubic temperature equation	CP2C	-
4 - Enthalpy Basis			
1	Elements at 298.15K and 1 atm	-	-
2	Component at 298.15 K	-	-

Table 1.2: HCOALGEN Option Codes

Default = 1 for each option code. In the exercise, the HCOALGEN codes for the ash are [1 1 1 1], which means default values. In case of biomass the codes [6 1 1 1],

which means that the heat of combustion will be specified. The heat of combustion can be introduced by implementing a new non-conventional parameter in section "Pure Components". Choose the biomass from the list and select HCMOB option to introduce value $18.4[MJ/kg]$.

As there is multiple parameters which needs to evaluated, select option "Estimate all missing parameters" from "Estimation" tab.

1.1.2 Simulation

Each simulation start from defining an inlet streams. Specify the biomass feed to be $1000[kg/h]$ at $25°C]$ and $1[bar]$. Enter its Component attribute given in table 1.1. Add proximate, ultimate and sulphur analysis data of biomass feed in NC Solid.

Group	Components	w-%
Moisture content	H_2O	8
Proximate analysis		
	Volatile matter (VM)	82.29
	Fixed carbon (FC)	17.16
	Ash	0.55
Ultimate analysis		
	C	50.54
	H	7.08
	O	41.11
	N	0.15
	S	0.57
	Ash	0.55
Sulfur analysis		
	Pyritic	0
	Sulfate	0.057
	Organic	0.513

Table 1.3: Characteristics of Biomass (pine sawdust)

The biomass is defined as a non-conventional solid in Aspen Plus, as well as the ash present in the biomass. The presence of non-conventional components in the simulation need the stream class MIXINC, which is for models where both conventional solids (carbon) and non-conventional solids are present and when particle size distribution is unknown (go to Simulation-> set up-> specification-> Global setting stream class).

When the simulation parameters are defined, the operational blocks can be introduced. The first operational unit is the decomposer. The solid biomass is decomposed at into gaseous products, which can follow further processing. For the decomposition of biomass, the DECOMP module is Aspen *RYield* reactor where the biomass is decompose into H_2, O_2, N_2, H_2O, S, C and ash according to the biomass ultimate analysis data at $700[°C]$ and $1[bar]$. The RYield decomposes the biomass into the constituents shown in table 1.4.

Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash	Water
Yield (in mass %)	0.464968	0.065138	0.3782	0.00138	0.005244	0.00507	0.08

Table 1.4: Yields for the RYIELD reactor

The next operation unit to consider is the gasifier (presented on figure 1.2). For that purpose let's use the Gibbs Reactor will simply produce an outlet in which the Gibbs free energy of the mixture is minimized. A reaction set can be attached to this reactor, but it is important to note that any parameters specified in the set will not be included in the simulation as the minimization of free energy will be the dominant simulation method. An exception to this rule is the stoichiometry of the reaction set. Without a set, stoichiometry will not be considered in the simulation; however, with an attached reaction set with stoichiometric parameters, the simulation will account for them and the outlet conditions can change. However, if a set is attached, only the components specified in the set will reach an equilibrium point; other components will be neglected. The Gibbs Reactor can be very useful if the user does not possess any data pertinent to the reaction or desires only a simulation of the equilibrium state. At the very least, the Gibbs Reactor can provide simulation estimates as a starting point for a more rigorous simulation through another reactor type.

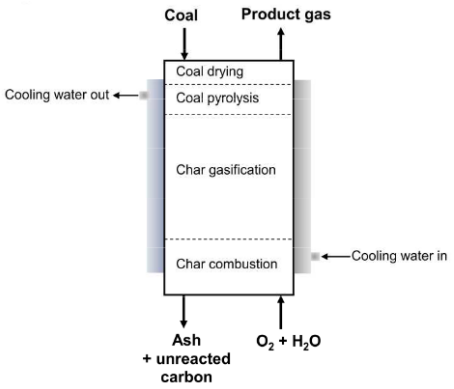

Figure 1.2: The gasifier

The pressure is at 30[bar] and 900[$^{\circ}C$], which is a typical value for real world gasifiers. Oxygen 600[kg/h] is used as the oxidizing agent, which is preheated to 700[$^{\circ}C$]. The possible products of the gasification were predefined to be: H_2, O_2, N_2, H_2O, S, $C(solid)$, CO, CO_2, H_2S, CH_4, C and NH_3. Aspen calculated the product distributions at various conditions.

Finally, in the separation part of the simulation the solids are separated from the hot gases in SEP1, which is an Aspen SSplit. The SSPLIT assumes perfect separation of solid particles from the main stream. The SEP2 column is a flash column used to separate the condensate. For this the gases is cooled to 80[$^{\circ}C$] with heat exchanger COOL1. The product of the process is the stream SYNGAS, which contains the main syngas components CO and H_2, but also contains impurities such as H_2S and NH_3. The product of this process need to be further purified in a separate purification facility to be useful feedstock for other processes.

The configuration of the simulation and its results are presented below:

1.1.3 Results

	Units	BIOMASS	FEED	GAS	GASCOOL	O2	O2HOT	RAWGAS	SOLIDS	SOLIDS2	SYNGAS	WATER
Description												
From			DECOMP	SEP1	COOL1		HEAT1	GASIFIER	SEP1	COOL2	SEP2	SEP2
To		DECOMP	GASIFIER	COOL1	SEP2	HEAT1	GASIFIER	SEP1	COOL2			
Stream Class		MIXCINC	MIXCINC	MIXCINC	MIXCINC	MIXCINC	MIXCINC	MIXCINC	MIXCINC	MIXCINC	MIXCINC	MIXCINC
Maximum Relative Error												
Cost Flow	$/hr											
− Total Stream												
Temperature	C	25	700	900	80	25	700	900	900	25	80	80
Pressure	bar	1.01325	1.01325	30	30.3975	30	30	30	30	1.01325	30.3975	30.3975
Mass Vapor Fraction		0	0.529962	1	0.772277	1	1	0.996831	0	0	1	0
Mass Liquid Fraction		0	0	0	0.227723	0	0	0	0	0	0	1
Mass Solid Fraction		1	0.470038	0	1.71182e-07	0	0	0.00316875	1	1	0	0
Mass Enthalpy	kcal/kg	-2116.59	118.101	-1265.87	-1721.12	-1.84382	162.869	-1261.79	22.2112	-191.945	-1136.33	-3704.33
Mass Density	kg/cum	1209.43	0.256624	6.40179	28.9242	39.1882	11.7698	6.4221	3486.88	3486.88	22.5431	722.435
Enthalpy Flow	Gcal/hr	-2.11659	0.118101	-2.01898	-2.74507	-0.00110629	0.0977213	-2.01887	0.000112611	-0.000973161	-1.39965	-1.34542
✚ Mass Flows	**kg/hr**	**1000**	**1000**	**1594.93**	**1594.93**	**600**	**600**	**1600**	**5.07**	**5.07**	**1231.73**	**363.202**
✚ Mass Fractions												
Volume Flow	cum/hr	0.826835	3896.75	249.138	55.1417	15.3107	50.978	249.139	0.00145402	0.00145402	54.6389	0.502747
− MIXED Substream												
Phase			Vapor Phase	Vapor Phase		Vapor Phase	Vapor Phase	Vapor Phase			Vapor Phase	Liquid Phase
Temperature	C		700	900	80	25	700	900			80	80
Pressure	bar	1.01325	1.01325	30	30.3975	30	30	30		1.01325	30.3975	30.3975
Molar Vapor Fraction			1	1	0.736558	1	1	1			1	0
Molar Liquid Fraction			0	0	0.263442	0	0	0			0	1
Molar Solid Fraction			0	0	0	0	0	0			0	0
Mass Vapor Fraction			1	1	0.772277	1	1	1			1	0
Mass Liquid Fraction			0	0	0.227723	0	0	0			0	1
Mass Solid Fraction			0	0	0	0	0	0			0	0
Molar Enthalpy	kcal/mol		-0.0754248	-26.5249	-36.0642	-0.0590001	5.21161	-26.5249			-24.9653	-67.0958
Mass Enthalpy	kcal/kg		-6.94315	-1265.87	-1721.12	-1.84382	162.869	-1265.87			-1136.33	-3704.33
Molar Entropy	cal/mol-K		9.4715	13.3201	-3.0995	-6.90086	2.21927	13.3201			9.02204	-36.9901
Mass Entropy	cal/gm-K		0.871889	0.635689	-0.14792	-0.21566	0.0693548	0.635689			0.410652	-2.04221
Molar Density	kmol/cum		0.0125201	0.305518	1.38038	1.22468	0.36782	0.305518			1.02608	39.8853
Mass Density	kg/cum		0.136008	6.40179	28.9242	39.1882	11.7698	6.40179			22.5431	722.435
Enthalpy Flow	Gcal/hr		-0.00367961	-2.01898	-2.74507	-0.00110629	0.0977213	-2.01898			-1.39965	-1.34542
Average MW			10.8632	20.9539	20.9539	31.9988	31.9988	20.9539			21.97	18.1128
✚ Mole Flows	**kmol/hr**	**0**	**48.7851**	**76.1162**	**76.1162**	**18.7507**	**18.7507**	**76.1162**	**0**	**0**	**56.064**	**20.0522**
✚ Mole Fractions												
✚ Mass Flows	**kg/hr**		**529.962**	**1594.93**	**1594.93**	**600**	**600**	**1594.93**			**1231.73**	**363.202**
✚ Mass Fractions												
Volume Flow	cum/hr		3896.54	249.138	55.1417	15.3107	50.978	249.138			54.6389	0.502747
✚ Vapor Phase												
✚ Liquid Phase												
✚ CISOLID Substream												
− NC Substream												
Temperature	C	25	700					900	900	25		
Pressure	bar	1.01325	1.01325		30.3975	30	30	30	30	1.01325	30.3975	30.3975
Mass Enthalpy	kcal/kg	-2116.59	-36.1888					22.2112	22.2112	-191.945		
Mass Density	kg/cum	1209.43	3486.88					3486.88	3486.88	3486.88		
Enthalpy Flow	Gcal/hr	-2.11659	-0.000183477					0.000112611	0.000112611	-0.000973161		
✚ Mass Flows	**kg/hr**	**1000**	**5.07**	**0**	**0**	**0**	**0**	**5.07**	**5.07**	**5.07**	**0**	**0**
✚ Mass Fractions												
Volume Flow	cum/hr	0.826835	0.00145402					0.00145402	0.00145402	0.00145402		

Figure 1.3: Gasification results

1.2 The fast pyrolysis of the biomass

Biomass fast pyrolysis is a highly non-equilibrium reaction where the main components (lignin, celluloses and hemicelluloses) are broken down into shorter molecules like acids, aldehydes, phenols, sugars and non-condensable gases. More than 200 different components have are identified in pyrolysis oil and their share depends on the feedstock, process parameters and on the measurement equipment. Therefore, modelling of biomass fast pyrolysis is not trivial. The following assumptions will allow modelling of biomass fast pyrolysis:

- Biomass, ash, char and lignin are define as non-conventional component (neither molecular weight nor molecular structure can be given); Biomass attributes are computed with AspenPlus' built-in enthalpy and density models HCOALGEN and DCOALLIGT (for reference check chapter 1.1.1)
- Pyrolysis is modelled with a yield reactor where user defines the pyrolysis products.

The process flow diagram is presented on figure 1.4. The biomass is fed directly to the pyrolysis unit, which operates at high temperature and atmospheric pressure. Then the gaseous streams is cooled down, and two-phase mixture is separated.

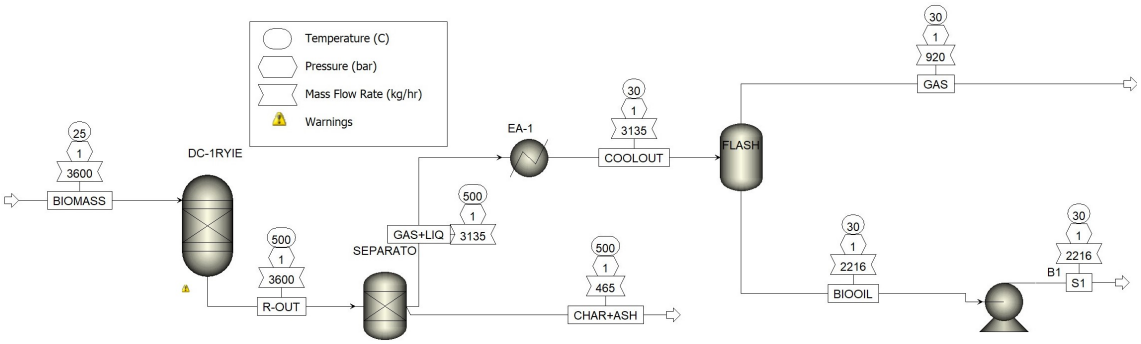

Figure 1.4: Fast pyrolysis plant

1.2.1 Thermodynamic model

Add all the conventional components in the component list as given in the table 1.5 and non-conventional components BIOMASS, ASH, CHAR and LIGNIN.

The thermodynamic method used in this exercise is UNIQUAC (universal quasichemical), which is an activity coefficient model used in description of phase equilibria The model is a so-called lattice model and has been derived from a first order approximation of interacting molecule surfaces in statistical thermodynamics. The model is however not fully thermodynamically consistent due to its two liquid mixture approach. In this approach the local concentration around one central molecule is assumed to be independent from the local composition around another type of molecule. The UNIQUAC model also serves as the basis of the development of the group contribution method UNIFAC, where molecules are subdivided into functional

groups. In fact, UNIQUAC is equal to UNIFAC for mixtures of molecules, which are not subdivided; e.g. the binary systems water-methanol, methanol-acryonitrile and formaldehyde-DMF.

The properties of the non-conventional components need to define. To do so by introducing default values for HCOALGEN and DCOALLIGT.

Group	Component	Formula	CAS	Final yield [kg/kg biomass]
Proximate analysis				
	Carbonmonoxide	CO	630-08-0	0,05681
	Hydrogen	$H2$	1333-74-0	0,00813
	Methane	CH_4	74-82-8	0,00048
	Carbondioxide	CO_2	124-38-9	0,04693
	Ethane	C_2H_6	74-84-0	0,00196
	Propane	C_3H_8	74-98-6	0,00210
	Ammonia	NH_3	7664-41-7	0,00172
	Hydrogensulfide	$H2S$	7783-06-4	0,00075
Liquid / Oil				
	Phenol	C_6H_6O	108-95-2	0,04201
	Formic Acid	CH_2O_2	64-18-6	0,1001
	Formaldehyde	CH_2O	50-00-0	0,14865
	Glucose	$C_6H_{12}O_6$	50-99-7	0,05841
	Fluoranthene	$C_{16}H_{10}$	206-44-0	0,08807
	Dihydrogenoxide	H_2O	7732-18-5	0,17202
	Pyrolitic Lignin	NC	$CH_{1.1}O_{0.3}$	0,14285
Solid				
	Char	NC	$CH_{0.48}O_{0.23}$	0,12185
	Ash	NC	Ash	0,00716
Sum				1

Table 1.5: Characteristics of Biomass (pine sawdust)

1.2.2 Simulation

In the Simulation section, Main Flowsheet, select a yield reactor and connect IN and Out streams. In the Setup sheet, set Stream class to 'MIXNC'. This will enable calculation of non-conventional components (go to Simulation-> set up-> specification-> Global setting stream class).

The next step is to define Biomass feed at 25 °C, 1bar and 1kg/s. Use Component Attribute given in table 1.6a. The biomass strem enters the yield reactor which represent the pyrolysis unit. The reaction works at following conditions: 1[bar] and 500[$°C$]. The reaction yields are shown in table 1.6a. In the reactor block, the non-conventional product components need to be defined by their analyses according to tables 1.6b, 1.6c and 1.6d. The products compositions should be included in "Comp. Attr." tab of the reactor unit.

The outlet stream from the reactor flows to the separator. The solid particles The SSPLIT assumes perfect separation of solid particles from the main stream. Then the mixture of gaseous and liquid products enter the heat exchanger, which work at 30[$°C$] and 1[bar]. As the results the condensation occurs. The following step is to separate vapour from the liquid phase in the flash. The flash is assumed

Group	Components	w-%
Moisture content	H_2O	10
Proximate analysis		
	Volatile matter (VM)	82.73
	Fixed carbon (FC)	16.47
	Ash	0.8
Ultimate analysis		
	C	50.64
	H	6.18
	O	42.22
	N	0.16
	S	0.08
	Ash	0.80
Sulfur analysis		
	Pyritic	0.0
	Sulfate	0.0
	Organic	0.08

(a) Biomass fuel analysis

Group	Components	w-%
Moisture content	H_2O	0
Proximate analysis		
	Volatile matter (VM)	80.00
	Fixed carbon (FC)	20.00
	Ash	0.0
Ultimate analysis		
	C	66.80
	H	6.18
	O	27.02
	N	0.0
	S	0.0
	Ash	0.0
Sulfur analysis		
	Pyritic	0.0
	Sulfate	0.0
	Organic	0.0

(b) The composition of lignin

Group	Components	w-%
Moisture content	H_2O	0
Proximate analysis		
	Volatile matter (VM)	80.00
	Fixed carbon (FC)	20.00
	Ash	0.0
Ultimate analysis		
	C	74.32
	H	2.99
	O	22.69
	N	0.0
	S	0.0
	Ash	0.0
Sulfur analysis		
	Pyritic	0.0
	Sulfate	0.0
	Organic	0.0

(c) The composition of char

Group	Components	w-%
Moisture content	H_2O	0
Proximate analysis		
	Volatile matter (VM)	0.00
	Fixed carbon (FC)	0.00
	Ash	100.0
Ultimate analysis		
	C	0.0
	H	0.0
	O	0.0
	N	0.0
	S	0.0
	Ash	100.0
Sulfur analysis		
	Pyritic	0.0
	Sulfate	0.0
	Organic	0.0

(d) The composition of char

Table 1.6: The composition of pyrolysis products

to be adiabatic and isobaric. The liquid stream is the main product and represents the bio-oil.

1.2.3 Results

	Units	BIOMASS	BIOOIL	CHAR+ASH	COOLOUT	GAS	GAS+LIQ	R-OUT	S1
Description									
From			FLASH	SEPARATO	EA-1	FLASH	SEPARATO	DC-1RYIE	B1
To		DC-1RYIE	B1		FLASH		EA-1	SEPARATO	
Stream Class		MIXNC	MIXNC	MIXNC	MIXNC	MIXNC	MIXNC	MIXNC	MIXNC
Maximum Relative Error									
Cost Flow	$/hr								
− Total Stream									
Temperature	C	25	30	500	30	30	500	500	30
Pressure	bar	1	1	1	1	1	1	1	1
Mass Vapor Fraction		0	0	0	0.293757	1	0.835974	0.72805	0
Mass Liquid Fraction		0	0.767749	0	0.542217	0	0	0	0.767749
Mass Solid Fraction		1	0.232251	1	0.164026	0	0.164026	0.27195	0.232251
Mass Enthalpy	kcal/kg	-1553.33	-1725.08	-268.029	-1556.12	-1149.93	-1184.67	-1066.33	-1725.08
Mass Density	kg/cum	1266.25	1079.87	1518.11	2.85618	0.840595	0.536065	0.615498	1079.87
Enthalpy Flow	Gcal/hr	-5.59199	-3.81974	-0.124569	-4.87882	-1.05909	-3.71421	-3.83878	-3.81974
+ Mass Flows	**kg/hr**	**3600**	**2214.24**	**464.76**	**3135.24**	**920.999**	**3135.24**	**3600**	**2214.24**
+ Mass Fractions									
Volume Flow	cum/hr	2.84304	2.05047	0.306144	1097.7	1095.65	5848.62	5848.92	2.05047
− MIXED Substream									
Phase			Liquid Phase			Vapor Phase	Vapor Phase	Vapor Phase	Liquid Phase
Temperature	C		30		30	30	500	500	30
Pressure	bar	1	1	1	1	1	1	1	1
Molar Vapor Fraction			0		0.477811	1	1	1	0
Molar Liquid Fraction			1		0.522189	0	0	0	1
Molar Solid Fraction			0		0	0	0	0	0
Mass Vapor Fraction			0		0.351395	1	1	1	0
Mass Liquid Fraction			1		0.648605	0	0	0	1
Mass Solid Fraction			0		0	0	0	0	0
Molar Enthalpy	kcal/mol		-71.5735		-49.0161	-24.3637	-37.744	-37.744	-71.5735
Mass Enthalpy	kcal/kg		-2000.17		-1701.4	-1149.93	-1310.13	-1310.13	-2000.17
Molar Entropy	cal/mol-K		-45.2759		-21.7435	3.97449	4.6746	4.6746	-45.2759
Mass Entropy	cal/gm-K		-1.26527		-0.754741	0.18759	0.16226	0.16226	-1.26527
Molar Density	kmol/cum		28.9365		0.0829104	0.0396748	0.0155564	0.0155564	28.9365
Mass Density	kg/cum		1035.45		2.38858	0.840595	0.448168	0.448168	1035.45
Enthalpy Flow	Gcal/hr		-3.40026		-4.45934	-1.05909	-3.43383	-3.43383	-3.40026
Average MW			35.7836		28.8092	21.1871	28.8092	28.8092	35.7836
+ Mole Flows	**kmol/hr**	**0**	**47.5072**	**0**	**90.9771**	**43.4698**	**90.9771**	**90.9771**	**47.5072**
+ Mole Fractions									
− Mass Flows	**kg/hr**		**1699.98**		**2620.98**	**920.999**	**2620.98**	**2620.98**	**1699.98**
CO	kg/hr		0.210696		204.516	204.305	204.516	204.516	0.210696
H2	kg/hr		0.00334524		29.268	29.2647	29.268	29.268	0.00334524
CH4	kg/hr		0.00423811		1.728	1.72376	1.728	1.728	0.00423811
CO2	kg/hr		2.08479		168.948	166.863	168.948	168.948	2.08479
C2H6	kg/hr		0.119714		7.056	6.93629	7.056	7.056	0.119714
C3H8	kg/hr		0.493963		7.56	7.06604	7.56	7.56	0.493963
NH3	kg/hr		2.06668		6.192	4.12532	6.192	6.192	2.06668
H2S	kg/hr		0.105075		2.7	2.59493	2.7	2.7	0.105075
C6H6O	kg/hr		150.956		151.236	0.279673	151.236	151.236	150.956
CH2O2	kg/hr		351.921		360.036	8.1153	360.036	360.036	351.921
CH2O	kg/hr		70.7053		535.14	464.435	535.14	535.14	70.7053
C6H12O6	kg/hr		210.276		210.276	5.56162e-11	210.276	210.276	210.276
H2O	kg/hr		593.984		619.272	25.2883	619.272	619.272	593.984
C16H10	kg/hr		317.05		317.052	0.00177661	317.052	317.052	317.05
O2	kg/hr		0		0	0	0	0	0
N2	kg/hr		0		0	0	0	0	0
SO2	kg/hr		0		0	0	0	0	0
NO2	kg/hr		0		0	0	0	0	0
C	kg/hr		0		0	0	0	0	0
+ Mass Fractions									
Volume Flow	cum/hr		1.64177		1097.29	1095.65	5848.21	5848.21	1.64177
+ Vapor Phase									
+ Liquid Phase									
− NC Substream									
Temperature	C	25	30	500	30		500	500	30
Pressure	bar	1	1	1	1	1	1	1	1
Mass Enthalpy	kcal/kg	-1553.33	-815.699	-268.029	-815.699		-545.207	-413.625	-815.699
Mass Density	kg/cum	1266.25	1258.31	1518.11	1258.31		1258.31	1369.57	1258.31
Enthalpy Flow	Gcal/hr	-5.59199	-0.419481	-0.124569	-0.419481		-0.280378	-0.404947	-0.419481
− Mass Flows	**kg/hr**	**3600**	**514.26**	**464.76**	**514.26**	**0**	**514.26**	**979.02**	**514.26**
BIOMASS	kg/hr	3600	0	0	0	0	0	0	0
ASH	kg/hr	0	0	26.1	0	0	0	26.1	0
CHAR	kg/hr	0	0	438.66	0	0	0	438.66	0
LIGNIN	kg/hr	0	514.26	0	514.26	0	514.26	514.26	514.26

Figure 1.5: Fast pyrolysis results

Chapter 2

The Second Chapter