Process simulation of the integration of molecular distillation with fast pyrolysis of biomass for sustainable fuel production

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Supplementary Information

1. Sample Calculations

1.1 Mean Free Path

The example calculation is for the mean free path of levoglucosan in (MD2) for the rice husk model which can be applied to calculate subsequent components in Table 10. The critical pressure and temperature required to calculate the co-volume (b) (See Equation 2.5 in the manuscript) were simulated as thus:

Critical Pressure = 4800000 Pa

Critical Temperature = 905.7 K

Substituting these values into Equation (2.5):

$$b_i = \frac{0.08864\, RT_{c,i}}{P_{c,i}}$$

Equation (2.5)

The volume of the particle is given by:

$$\text{Vp} = \left(\frac{b}{4N_A}\right)$$

and substituting Vp calculated into Equation 2.6:

$$d = \left(\frac{6Vp}{\pi}\right)^{\frac{1}{3}}$$

Equation (2.6)

Thereafter, the particle diameter d, was substituted into the mean free path:

$$\lambda = \frac{RT}{\sqrt{2}\, \pi\, d^2 N_A P}$$

Equation (2.7)

as well as the optimized conditions for separation for the rice husk model:

Pressure = 0.10 Pa

Temperature = 293 K

1.2 Mass Evaporation Flux

The subsequent example calculation is for the mass evaporation flux of MD1. This required determining the average particle mass of the vapor phase. This was achieved by taking the sum of the individual particle masses multiplied by their gaseous mass fraction as shown below:

$$m_p = \sum yi \times \frac{m_i}{N_{A\ \times} M_i}$$

Equation

(2.8)

The m_p was then substituted into the mass evaporation flux, Equation 2.9 as well as the optimized value for temperature, 293 K and an assumed design pressure of 10 Pa:

$$\Gamma \ = \frac{d^2 m}{dA_e dt} = P\left(\frac{m_p}{2\ \pi K_B T}\right)^{\frac{1}{2}}$$

Equation

(2.9)

Recall that the vapour flow rate was 22441.07 kg/hr, and dividing this value by the mass evaporation flux, Γ would yield the area, A required for evaporation as thus:

$$A = \frac{Vapour\ flow\ rate}{3600 \times \Gamma}$$

1.3. Vapour Pressure Data for the Components of Rice Husk and Forestry Residue

Compound Vapour Pressure (Pa)	**Temperature (^{O}C)**							
	30	40	50	60	70	80	90	100
Oxygen	2.01E+08	2.45E+08	3.00E+08	3.66E+08	4.46E+08	5.44E+08	6.63E+08	8.08E+08
Nitrogen	8.56E+08	1.14E+09	1.52E+09	2.03E+09	2.71E+09	3.63E+09	4.86E+09	6.54E+09
Hydrogen	1.82E+21	1.45E+22	1.23E+23	1.11E+24	1.07E+25	1.10E+26	1.21E+27	1.41E+28
Carbon-monoxide	1.61E+09	2.46E+09	3.79E+09	5.93E+09	9.41E+09	1.51E+10	2.47E+10	4.09E+10
Carbon-dioxide	7.19E+06	8.94E+06	1.10E+07	1.35E+07	1.64E+07	1.98E+07	2.38E+07	2.85E+07
Water	4.21E+03	7.33E+03	1.23E+04	1.98E+04	3.10E+04	4.71E+04	6.97E+04	1.01E+05
Nitrogen-dioxide	5.84E+10	2.97E+11	1.98E+12	1.80E+13	2.33E+14	4.47E+15	1.34E+17	6.65E+18
Sulfur-dioxide	4.57E+05	6.23E+05	8.29E+05	1.08E+06	1.38E+06	1.73E+06	2.14E+06	2.60E+06
Methane	2.31E+05	1.96E+05	1.65E+05	1.37E+05	1.13E+05	9.18E+04	7.40E+04	5.92E+04
Ethylene	8.57E+06	1.04E+07	1.26E+07	1.51E+07	1.81E+07	2.15E+07	2.56E+07	3.03E+07
Toluene	4.86E+03	7.83E+03	1.22E+04	1.84E+04	2.69E+04	3.85E+04	5.38E+04	7.37E+04
Benzene	1.62E+04	2.49E+04	3.70E+04	5.35E+04	7.53E+04	1.04E+05	1.40E+05	1.85E+05
P-xylene	1.54E+03	2.62E+03	4.30E+03	6.80E+03	1.04E+04	1.55E+04	2.25E+04	3.19E+04
N-propyl-isobutyrate	2.56E+02	5.23E+02	1.01E+03	1.86E+03	3.27E+03	5.51E+03	8.95E+03	1.41E+04
Acetic Acid	2.72E+03	4.61E+03	7.53E+03	1.19E+04	1.82E+04	2.72E+04	3.96E+04	5.63E+04
Phenol	8.32E+01	1.74E+02	3.46E+02	6.52E+02	1.17E+03	2.03E+03	3.38E+03	5.44E+03
Cyclopentenone	6.06E+04	8.68E+04	1.21E+05	1.66E+05	2.21E+05	2.91E+05	3.75E+05	4.78E+05
2,4-dimethylfuran	9.81E+04	1.40E+05	1.95E+05	2.64E+05	3.52E+05	4.60E+05	5.92E+05	7.49E+05
P-ethylphenol	4.35E+02	9.57E+02	1.99E+03	3.91E+03	7.35E+03	1.32E+04	2.28E+04	3.80E+04
M-ethylphenol	1.15E+02	2.42E+02	4.83E+02	9.16E+02	1.66E+03	2.88E+03	4.81E+03	7.77E+03
1,2-benzenediol	2.10E+02	4.02E+02	7.34E+02	1.28E+03	2.16E+03	3.51E+03	5.51E+03	8.41E+03
4-hydroxystyrene	1.09E+03	1.90E+03	3.19E+03	5.15E+03	8.02E+03	1.21E+04	1.78E+04	2.55E+04
Indene	2.53E+05	3.80E+05	5.54E+05	7.87E+05	1.09E+06	1.49E+06	1.98E+06	2.60E+06
Acetone	4.24E+04	6.31E+04	9.14E+04	1.29E+05	1.78E+05	2.41E+05	3.20E+05	4.17E+05
Methyl-salicylate	1.72E+06	2.16E+06	2.67E+06	3.27E+06	3.96E+06	4.74E+06	5.64E+06	6.65E+06
Indane	1.58E+05	2.39E+05	3.51E+05	5.02E+05	7.02E+05	9.61E+05	1.29E+06	1.70E+06
N-propyl-benzoate	2.81E+02	5.33E+02	9.65E+02	1.67E+03	2.79E+03	4.50E+03	7.03E+03	1.07E+04
Levoglucosan	1.60E-03	7.40E-03	1.08E-02	1.57E-02	4.17E-02	1.05E-01	2.50E-01	5.69E-02
1-methylnaphthalene	2.81E+02	5.33E+02	9.65E+02	1.67E+03	5.82E+02	9.70E+02	1.57E+03	2.45E+03
Formic-Acid	7.16E+03	1.13E+04	1.72E+04	2.55E+04	3.69E+04	5.22E+04	7.24E+04	9.86E+04
Benzofuran	3.52E+04	4.69E+04	6.09E+04	7.70E+04	9.52E+04	1.15E+05	1.37E+05	1.60E+05
Furfural	1.06E-01	1.37E-01	1.73E-01	2.14E-01	2.58E-01	3.05E-01	3.55E-01	4.07E-01
P-hydroquinone	1.35E+02	2.61E+02	4.82E+02	8.55E+02	1.46E+03	2.42E+03	3.88E+03	6.06E+03

2. Numerical Data for Figures 3 – 10

2.1 Table A: The pyrolysis gas and bio-oil yields present in both the (a) rice husk and (b) forestry residue at temperatures between (350 ^{O}C - 550 ^{O}C). **(for Figure 3)**

3 (a) Gas

Components	Rice husk Yield (wt.%)					Forestry Residue Yield (wt.%)				
	Temperature (^{o}C)					Temperature (^{o}C)				
	350	400	450	500	550	350	400	450	500	550
CO	0.0009	0.0994	9.9391	9.9391	12.0291	0.001	0.994	10.0	10.02	16.0
CO_2	0.1184	0.0318	9.8784	10.4131	12.4131	0.018	0.012	8.878	9.413	11.413
H_2O	0.0428	0.4278	12.043	20.429	22.428	0.033	0.328	10.043	18.428	20.428
CH_4	0.0001	0.0240	0.8399	0.9985	1.9985	0.000	0.014	0.740	0.899	1.899

3 (b) Bio-oil

Components	Rice husk Yield (wt.%)					Forestry Residue Yield (wt.%)				
	Temperature (^{o}C)					Temperature (^{o}C)				
	350	400	450	500	550	350	400	450	500	550
Toluene	0.538	0.738	0.938	1.378	2.378	0.4378	0.6378	0.9378	1.3782	3.3782
Benzene	2.118	2.318	4.878	5.913	7.913	1.1184	1.3184	3.8784	4.9131	5.9131
Acetic Acid	9.943	9.983	10.043	12.428	14.428	1.9428	0.9828	2.0428	2.4278	4.4278
Phenol	9.940	10.955	15.840	20.0	21.98	1.9404	1.9547	1.8399	2.980	4.985
Levoglucosan	29.972	31.30	41.30	55.30	58.30	2.394	3.297	4.302	5.291	7.298

2.2 Table B: Overall yield of components for (a) rice husk and (b) forestry residue. **(for Figure 4)**

4 (a)

Components	Yield (wt.%)
Levoglucosan	29.97
4-Vinylhenol	17.53
1,2-Benzenediol	13.61
4-Ethylphenol	9.550
Pheno-01	9.404
Isoeugen	9.257
Acetic Acid	4.278
H_2O	2.972
Cyclopen	1.628
Propanoi	1.106
2,4-Dime	0.612
3-Ethylhenol	0.031
CO_2	0.017
Toluene	0.012
SO_2	0.011
NO_2	0.005
CO	0.001
C_2H_4	0.001
CH_4	0
H_2	0

P-Xylene	0
O_2	0
N_2	0
Mnapthen	0
Methyl-Salicylate	0
Indene	0
Indane	0
Benzene	0

4 (b)

Components	Yield (wt.%)
Mnapthen	38.04
Methyl-Salicylate	5.671
Levoglucosan	18.27
P-Hydroquinone	35.79
H_2O	0.707
Furfural	0.617
Indane	0.319
Indene	0.230
Acetic Acid	0.149
Benzene	0.156
Acetone	0.034
CO_2	0.011
Toluene	0.007
C_2H_4	0.001
SO_2	0.001
CO	0.001
NO_2	0.001
H_2	0
CH_4	0
O_2	0
N_2	0
P-Xylene	0
Ethane	0
Phenol	0
Formi-01	0
Benzofur	0
Syringol	0
Cypenton	0

2.3 Table C: The % recovery of Levoglucosan at varying temperatures and pressures for (a) rice husk and (b) forestry residue models. **(for Figure 5)**

5 (a)

Pressure (Pa)	Temperature (°C)	Yield (wt.%)
		Levoglucosan
0.10	10.0	99.88
	20.0	99.44
	30.0	97.60
	40.0	90.69
	50.0	66.69
1.0	10.0	99.92
	20.0	99.95
	30.0	99.77
	40.0	99.1
	50.0	96.80
	60.0	89.61
	70.0	68.54
	80.0	8.084

5.0	10.0	99.91
	20.0	99.93
	30.0	99.96
	40.0	99.83
	50.0	99.39
	60.0	97.98
	70.0	93.92
	80.0	82.95
	90.0	54.60
10.0	10.0	99.95
	20.0	99.97
	30.0	99.94
	40.0	99.92
	50.0	99.71
	60.0	99.01
	70.0	97.00
	80.0	91.60
	90.0	77.87
15.0	10.0	99.97
	20.0	99.98
	30.0	99.09
	40.0	99.95
	50.0	99.81
	60.0	99.36
	70.0	98.03
	80.0	94.45
	90.0	85.40
20.0	10.0	99.96
	20.0	99.98
	30.0	99.93
	40.0	99.97
	50.0	99.91
	60.0	99.53
	70.0	98.54
	80.0	95.87
	90.0	89.13
25.0	10.0	99.98
	20.0	99.95
	30.0	99.95
	40.0	99.97
	50.0	99.9
	60.0	99.63
	70.0	98.84
	80.0	96.71
	90.0	91.35
30.0	10.0	99.98
	20.0	99.90
	30.0	99.96
	40.0	99.94
	50.0	99.91
	60.0	99.70
	70.0	99.05
	80.0	97.28
	90.0	92.82

5 (b)

Pressure (Pa)	Temperature (°C)	Yield (wt.%)
		Levoglucosan
0.10	10.0	99.20
	20.0	96.13
	30.0	83.42
	40.0	35.84
1.0	10.0	99.93
	20.0	99.64
	30.0	98.39
	40.0	93.70
	50.0	77.84
	60.0	28.37
5.0	10.0	99.99
	20.0	99.94
	30.0	99.71
	40.0	98.80
	50.0	95.67
	60.0	85.93
	70.0	57.93
10.0	10.0	99.98
	20.0	99.97
	30.0	99.87
	40.0	99.43
	50.0	97.89
	60.0	93.06
	70.0	79.16
	80.0	41.89
15.0	10.0	99.97
	20.0	99.98
	30.0	99.92
	40.0	99.64
	50.0	98.63
	60.0	95.43
	70.0	86.21
	80.0	61.50
	90.0	24.80
20.0	10.0	99.99
	20.0	99.99
	30.0	99.95
	40.0	99.75
	50.0	99.01
	60.0	96.62
	70.0	89.73
	80.0	71.26
	90.0	24.80
25.0	10.0	99.99
	20.0	99.96
	30.0	99.95
	40.0	99.81
	50.0	99.22
	60.0	97.33
	70.0	91.84
	80.0	77.10
	90.0	40.08
30.0	10.0	99.92
	20.0	99.97

	30.0	99.93
	40.0	99.85
	50.0	99.37
	60.0	97.80
	70.0	93.24
	80.0	81.46
	90.0	50.23

2.4 Table D: The % recovery of 1,2-benzenediol, and 4-vinylphenol at varying temperatures for (a) rice husk and % recovery of mnapthen, p-hydroquinone (C6H6O2), and methyl-salicylate (C8H8O3) for (b) forestry residue model. **(for Figures 6)**

6 (a)

Pressure (Pa)	Temperature (°C)	Yield (wt.%)	
		1,2-benzenediol	4-vinylphenol
0.10	10.0	8.274	0.271
	20.0	2.678	0.108
	30.0	0.925	0.046
	40.0	0.324	0.02
	50.0	0.095	0.007
1.0	10.0	57.11	3.167
	20.0	25.18	1.177
	30.0	9.358	0.486
	40.0	3.564	0.218
	50.0	1.419	0.103
	60.0	0.566	0.049
	70.0	0.195	0.02
	80.0	0.011	0.001
5.0	10.0	89.52	19.37
	20.0	70.21	7.008
	30.0	39.89	2.743
	40.0	17.38	1.17
	50.0	7.244	0.546
	60.0	3.114	0.271
	70.0	1.368	0.138
	80.0	0.579	0.067
	90.0	0.188	0.025
10.0	10.0	94.92	41.19
	20.0	84.04	15.45
	30.0	60.78	5.995
	40.0	32.21	2.496
	50.0	14.29	1.134
	60.0	6.272	0.558
	70.0	2.831	0.288
	80.0	1.289	0.151
	90.0	0.549	0.073
15.0	10.0	96.74	57.47
	20.0	89.34	24.59
	30.0	71.60	9.53
	40.0	43.80	3.938
	50.0	20.94	1.757
	60.0	9.388	0.854
	70.0	4.289	0.441
	80.0	1.998	0.235
	90.0	0.91	0.122
20.0	10.0	97.63	67.85
	20.0	92.11	33.70
	30.0	77.97	13.27
	40.0	52.62	5.467

	50.0	27.09	2.413
	60.0	12.44	1.159
	70.0	5.74	0.597
	80.0	2.706	0.319
	90.0	1.27	0.17
25.0	10.0	98.15	74.56
	20.0	93.8	42.11
	30.0	82.139	17.17
	40.0	59.354	7.066
	50.0	32.70	3.097
	60.0	15.43	1.473
	70.0	7.182	0.755
	80.0	3.413	0.405
	90.0	1.63	0.219
30.0	10	98.49	79.15
	20	94.92	49.43
	30	85.05	21.18
	40	64.58	8.722
	50	37.76	3.807
	60	18.35	1.795
	70	8.615	0.915
	80	4.119	0.491
	90	1.99	0.268

6 (b)

Pressure (Pa)	Temperature (°C)	Yield (wt.%)		
		Mnapthen (%)	P-hydroquinone (%)	Methyl-salicylate (%)
0.10	10.0	0.002	2.155	0.025
	20.0	0.001	0.710	0.009
	30.0	0	0.226	0.003
	40.0	0	0.038	0.007
1.0	10.0	0.033	21.39	0.347
	20.0	0.013	7.412	0.113
	30.0	0.006	2.693	0.045
	40.0	0.003	1.014	0.019
	50.0	0.002	0.355	0.008
	60.0	0	0.058	0.001
5.0	10.0	1.142	72.86	6.212
	20.0	0.122	35.21	0.91
	30.0	0.041	13.75	0.277
	40.0	0.019	5.394	0.11
	50.0	0.01	2.198	0.049
	60.0	0.005	0.882	0.022
	70.0	0.002	0.28	0.008
10.0	10.0	27.16	93.36	47.64
	20.0	0.601	60.08	3.335
	30.0	0.113	27.11	0.704
	40.0	0.044	10.93	0.246
	50.0	0.022	4.526	0.106
	60.0	0.012	1.918	0.049
	70.0	0.006	0.768	0.022
	80.0	0.002	0.201	0.006
15.0	10.0	49.89	96.75	68.58
	20.0	4.061	77.67	12.54
	30.0	0.238	39.18	1.347
	40.0	0.075	16.47	0.41
	50.0	0.035	6.876	0.167
	60.0	0.019	2.962	0.077

	70.0	0.01	1.259	0.036
	80.0	0.005	0.687	0.014
	90.0	0.00	0.123	0.004
20.0	10.0	62.44	97.86	77.90
	20.0	16.91	88.15	32.19
	30.0	0.466	49.73	2.331
	40.0	0.116	21.94	0.607
	50.0	0.05	9.243	0.234
	60.0	0.026	4.012	0.107
	70.0	0.014	1.751	0.051
	80.0	0.007	0.687	0.022
	90.0	0.002	0.123	0.004
25.0	10.0	70.12	98.43	83.03
	20.0	30.72	92.60	47.91
	30.0	0.932	60.0	3.956
	40.0	0.168	27.28	0.845
	50.0	0.067	11.62	0.308
	60.0	0.034	5.069	0.137
	70.0	0.019	2.246	0.066
	80.0	0.01	0.931	0.03
	90.0	0.003	0.249	0.009
30.0	10.0	75.24	98.76	86.26
	20.0	41.67	94.74	58.48
	30.0	2.086	67.49	7.029
	40.0	0.236	32.46	1.132
	50.0	0.085	14.01	0.388
	60.0	0.042	6.132	0.169
	70.0	0.023	2.742	0.081
	80.0	0.013	1.175	0.038
	90.0	0.005	0.376	0.014

2.5 Tables E: The % Purity of Levoglucosan in the LVG stream of MD2 at varying temperatures and pressures for (a) rice husk and (b) forestry residue model. **(for Figure 7)**

7 (a)

Pressure (Pa)	Temperature (°C)	Yield (wt.%)
		Levoglucosan
0.10	10.0	96.23
	20.0	98.73
	30.0	99.54
	40.0	99.83
	50.0	99.93
1.0	10.0	78.25
	20.0	89.18
	30.0	95.65
	40.0	98.27
	50.0	99.28
	60.0	99.68
	70.0	99.85
	80.0	99.93
	90.0	99.93
5.0	10.0	65.79
	20.0	73.53
	30.0	83.52
	40.0	92.09
	50.0	96.5
	60.0	98.42
	70.0	99.26
	80.0	99.64
	90.0	99.82

10.0	10.0	59.8
	20.0	67.93
	30.0	76.27
	40.0	86.14
	50.0	93.31
	60.0	96.89
	70.0	98.52
	80.0	99.27
	90.0	99.63
15.0	10.0	56.31
	20.0	64.53
	30.0	72.41
	40.0	81.83
	50.0	90.45
	60.0	95.43
	70.0	97.8
	80.0	53.13
	90.0	99.44
20.0	10.0	54.33
	20.0	61.89
	30.0	69.84
	40.0	78.67
	50.0	87.92
	60.0	94.02
	70.0	97.09
	80.0	98.54
	90.0	99.25
25.0	10.0	53.13
	20.0	59.79
	30.0	67.86
	40.0	76.28
	50.0	85.7
	60.0	92.68
	70.0	96.39
	80.0	98.19
	90.0	99.06
30.0	10.0	52.34
	20.0	58.12
	30.0	66.21
	40.0	74.38
	50.0	83.75
	60.0	91.4
	70.0	95.7
	80.0	97.83
	90.0	98.87

7 (b)

Pressure (Pa)	Temperature (°C)	Yield (wt.%)
		Levoglucosan
0.10	10.0	98.41
	20.0	99.43
	30.0	99.78
	40.0	99.91
1.0	10.0	85.47
	20.0	94.47
	30.0	97.83
	40.0	99.09
	50.0	99.59
	60.0	99.81
5.0	10.0	44.89

	20.0	75.56
	30.0	89.50
	40.0	95.52
	50.0	97.99
	60.0	99.05
	70.0	99.52
10.0	10.0	10.72
	20.0	56.04
	30.0	79.92
	40.0	91.12
	50.0	95.99
	60.0	98.09
	70.0	99.04
	80.0	99.50
15.0	10.0	7.272
	20.0	31.02
	30.0	62.53
	40.0	82.64
	50.0	93.99
	60.0	97.14
	70.0	98.57
	80.0	99.24
20.0	10.0	5.804
	20.0	10.33
	30.0	53.28
	40.0	78.54
	50.0	92.01
	60.0	96.18
	70.0	98.09
	80.0	98.99
	90.0	99.44
25.0	10.0	5.537
	20.0	5.537
	30.0	42.14
	40.0	74.50
	50.0	90.99
	60.0	95.23
	70.0	97.60
	80.0	98.74
	90.0	99.16
30.0	10.0	5.537
	20.0	5.537
	30.0	42.14
	40.0	74.50
	50.0	90.99
	60.0	95.23
	70.0	97.60
	80.0	98.74
	90.0	99.16

2.6 Table F: The mass flow rate of 1,2-benzenediol and 4-vinylphenol for (a) rice husk model and the mass flowrate of mnapthen, p-hydroquinone (C6H6O2), and methyl-salicylate (C8H8O3) for (b) forestry residue model at varying temperatures and pressure in the LVG stream of MD2 unit. **(for Figure 8)**

8 (a)

Pressure (Pa)	Temperature (°C)	Yield (wt.%)	
		1,2-benzenediol	4-Vinylphenol
0.10	10.0	8.274	0.271

	20.0	2.678	0.108
	30.0	0.925	0.046
	40.0	0.324	0.020
	50.0	0.095	0.007
1.00	10.0	57.11	3.167
	20.0	25.19	1.177
	30.0	9.358	0.486
	40.0	3.564	0.218
	50.0	1.419	0.103
	60.0	0.566	0.049
	70.0	0.195	0.020
	80.0	0.011	0.001
5.00	10.0	89.53	19.38
	20.0	70.22	7.008
	30.0	39.90	2.743
	40.0	17.38	1.170
	50.0	7.244	0.546
	60.0	3.114	0.271
	70.0	1.368	0.138
	80.0	0.579	0.067
	90.0	0.188	0.025
10.0	10.0	94.93	41.19
	20.0	84.05	15.46
	30.0	60.78	5.995
	40.0	32.21	2.496
	50.0	14.29	1.134
	60.0	6.272	0.558
	70.0	2.831	0.288
	80.0	1.289	0.151
	90.0	0.549	0.073
15.0	10.0	96.75	57.47
	20.0	89.35	24.59
	30.0	71.60	9.530
	40.0	43.81	3.938
	50.0	20.94	1.757
	60.0	9.388	0.854
	70.0	4.289	0.441
	80.0	1.998	0.235
	90.0	0.910	0.122
20.0	10.0	97.64	67.85
	20.0	92.11	33.71
	30.0	77.98	13.27
	40.0	52.62	5.467
	50.0	27.09	2.413
	60.0	12.45	1.159
	70.0	5.740	0.597
	80.0	2.706	0.319
	90.0	1.270	0.170
25.0	10.0	98.16	74.57
	20.0	93.80	42.12
	30.0	82.14	17.18
	40.0	59.35	7.066
	50.0	32.70	3.097
	60.0	15.45	1.473
	70.0	7.182	0.755
	80.0	3.413	0.405
	90.0	1.630	0.219
30.0	10.0	98.50	79.15
	20.0	94.93	49.44
	30.0	85.06	21.19
	40.0	64.58	8.722

	50.0	37.77	3.807
	60.0	18.35	1.795
	70.0	8.615	0.915
	80.0	4.119	0.491
	90.0	1.990	0.268

8 (b)

Pressure (Pa)	Temperature(°C)	Mnapthen (kg/hr)	P-Hydroquinone $C_6H_6O_2$ (kg/hr)	Methyl-Salicylate $C_8H_8O_3$ (kg/hr)
0.10	10.0	0.195	12.38	2.685
	20.0	0.095	4.079	1.030
	30.0	0.044	1.303	0.384
	40.0	0.011	0.220	0.076
1.0	10.0	2.910	122.8	36.43
	20.0	1.130	42.56	11.92
	30.0	0.550	15.46	4.740
	40.0	0.290	5.820	2.030
	50.0	0.140	2.040	0.810
	60.0	0.030	0.330	0.150
5.0	10.0	101.1	418.4	652.5
	20.0	10.76	202.2	95.57
	30.0	3.590	78.96	29.08
	40.0	1.680	30.97	11.58
	50.0	0.890	12.62	5.180
	60.0	0.470	5.060	2.330
	70.0	0.200	1.610	0.830
10.0	10.0	2403	536.0	5004
	20.0	53.22	345.0	350.4
	30.0	9.960	155.7	73.98
	40.0	3.870	62.77	25.81
	50.0	1.930	25.98	11.09
	60.0	1.050	11.01	5.160
	70.0	0.550	4.410	2.310
	80.0	0.180	1.150	0.670
15.0	10.0	4414.0	555.5	7204
	20.0	359.4	446.0	1317.
	30.0	21.07	224.9	141.5
	40.0	6.680	94.57	43.02
	50.0	3.100	39.48	17.55
	60.0	1.670	17.01	8.120
	70.0	0.910	7.230	3.810
	80.0	0.410	2.550	1.500
20.0	10.0	5526.5	562.0	8183
	20.0	1496.4	506.1	3381
	30.0	41.27	285.5	244.9
	40.0	10.28	126.0	63.78
	50.0	4.420	53.07	24.62
	60.0	2.310	23.04	11.20
	70.0	1.280	10.05	5.350
	80.0	0.640	3.940	2.330
	90.0	0.150	0.710	0.460
25.0	10.0	6206.1	565.2	8722
	20.0	2719.3	531.7	5033
	30.0	82.48	338.8	415.6
	40.0	14.91	156.7	88.77
	50.0	5.900	66.73	32.33
	60.0	3.000	29.11	14.42

	70.0	1.660	12.89	6.920
	80.0	0.870	5.340	3.170
	90.0	0.300	1.430	0.940
30.0	10.0	6660.1	567.0	9061
	20.0	6660.1	567.0	9061
	30.0	184.6	387.5	738.4
	40.0	20.89	186.4	118.9
	50.0	7.560	80.43	40.76
	60.0	3.730	35.21	17.78
	70.0	2.050	15.74	8.530
	80.0	1.110	6.750	4.020
	90.0	0.450	2.160	1.420

2.7 Table G: The mass flow rate of levoglucosan, at varying temperatures and pressure in the LVG stream of MD2 unit for (a) rice husk and forestry residue (b) models. **(for Figure 9)**

9 (a)

Pressure (Pa)	Temperature(°C)	Levoglucosan (kg/hr)
0.10	10.0	9594.5
	20.0	9551.9
	30.0	9374.8
	40.0	8710.9
1.0	10.0	9604.4
	20.0	9600.6
	30.0	9583.6
	40.0	9518.7
	50.0	9297.9
	60.0	8607.8
5.0	10.0	9605.0
	20.0	9604.5
	30.0	9601.7
	40.0	9589.6
	50.0	9546.6
	60.0	9411.5
	70.0	9021.4
10.0	10.0	9605.1
	20.0	9604.8
	30.0	9603.6
	40.0	9598.1
	50.0	9577.5
	60.0	9510.9
	70.0	9317.8
	80.0	8798.6
15.0	10.0	9605.1
	20.0	9605.0
	30.0	9604.2
	40.0	9600.8
	50.0	9587.6
	60.0	9543.9
	70.0	9416.1
	80.0	9072.3
20.0	10.0	9605.1

	20.0	9605.0
	30.0	9604.5
	40.0	9602.1
	50.0	9592.6
	60.0	9560.3
	70.0	9465.1
	80.0	9208.5
	90.0	8561.2
25.0	10.0	9605.1
	20.0	9605.0
	30.0	9604.6
	40.0	9602.8
	50.0	9595.5
	60.0	9570.1
	70.0	9494.5
	80.0	9290.0
	90.0	8774.5
30.0	10.0	9605.1
	20.0	9605.1
	30.0	9604.7
	40.0	9603.3
	50.0	9597.4
	60.0	9576.6
	70.0	9514.1
	80.0	9290.0
	90.0	8774.5

9 (b)

Pressure (Pa)	Temperature(°C)	Levoglucosan (kg/hr)
0.10	10.0	947.2
	20.0	917.9
	30.0	796.5
	40.0	342.2
1.0	10.0	954.1
	20.0	951.3
	30.0	939.4
	40.0	894.7
	50.0	743.2
	60.0	270.8
5.0	10.0	954.6
	20.0	954.2
	30.0	952.0
	40.0	943.3
	50.0	913.4
	60.0	820.5
	70.0	553.1
10.0	10.0	954.7
	20.0	954.5
	30.0	953.5
	40.0	949.4
	50.0	934.7
	60.0	888.5
	70.0	755.8
	80.0	400.0
15.0	10.0	954.7
	20.0	954.6

	30.0	954.0
	40.0	951.4
	50.0	941.7
	60.0	911.2
	70.0	823.1
	80.0	587.2
20.0	10.0	954.7
	20.0	954.7
	30.0	954.3
	40.0	952.3
	50.0	945.2
	60.0	922.5
	70.0	856.7
	80.0	680.4
	90.0	236.8
25.0	10.0	954.7
	20.0	954.7
	30.0	954.4
	40.0	952.9
	50.0	947.3
	60.0	929.3
	70.0	876.8
	80.0	736.2
	90.0	382.7
30.0	10.0	954.7
	20.0	954.7
	30.0	954.5
	40.0	953.4
	50.0	948.7
	60.0	933.8
	70.0	890.2
	80.0	773.3
	90.0	479.6

2.8 Table H: The combined % recovery and % purity of levoglucosan (Optimal LVG) at different temperatures and pressures for (a) rice husk and (b) forestry residue models. **(for Figure 10)**

10 (a)

Pressure (Pa)	Temperature (°C)	Yield (wt.%)
		Levoglucosan
0.10	10.0	96.12
	20.0	98.18
	30.0	97.16
	40.0	90.53
	50.0	66.65
1.0	10.0	78.25
	20.0	89.14
	30.0	95.44
	40.0	97.38
	50.0	96.1
	60.0	89.33
	70.0	68.44
	80.0	8.08
5.0	10.0	65.79
	20.0	73.53
	30.0	83.49
	40.0	91.94

	50.0	95.91
	60.0	96.44
	70.0	93.23
	80.0	82.65
	90.0	54.51
10.0	10.0	59.8
	20.0	67.92
	30.0	76.25
	40.0	86.07
	50.0	93.04
	60.0	95.94
	70.0	95.58
	80.0	90.93
	90.0	77.59
15.0	10.0	56.31
	20.0	64.53
	30.0	72.4
	40.0	81.79
	50.0	90.29
	60.0	94.82
	70.0	95.87
	80.0	53.19
	90.0	84.93
20.0	10.0	54.33
	20.0	61.89
	30.0	69.83
	40.0	78.65
	50.0	87.92
	60.0	93.58
	70.0	95.67
	80.0	94.48
	90.0	88.47
25.0	10.0	53.13
	20.0	59.79
	30.0	67.86
	40.0	76.26
	50.0	85.62
	60.0	92.34
	70.0	95.28
	80.0	94.96
	90.0	90.49
30.0	10.0	52.34
	20.0	58.12
	30.0	66.21
	40.0	74.38
	50.0	83.75
	60.0	91.13
	70.0	94.79
	80.0	95.17
	90.0	91.78

10 (b)

Pressure (Pa)	Temperature (°C)	LVG (%)
0.10	10.0	97.63
	20.0	95.59
	30.0	83.24

	40.0	35.81
1.0	10.0	85.41
	20.0	94.13
	30.0	96.26
	40.0	92.86
	50.0	93.75
	60.0	92.71
5.0	10.0	44.88
	20.0	75.52
	30.0	89.24
	40.0	94.37
	50.0	93.75
	60.0	92.71
	70.0	89.64
10.0	10.0	10.72
	20.0	56.03
	30.0	79.82
	40.0	90.61
	50.0	93.97
	60.0	91.29
	70.0	78.41
	80.0	41.68
15.0	10.0	7.272
	20.0	31.02
	30.0	71.06
	40.0	86.52
	50.0	92.71
	60.0	92.94
	70.0	89.64
	80.0	76.13
20.0	10.0	5.804
	20.0	10.33
	30.0	53.26
	40.0	74.39
	50.0	87.49
	60.0	92.20
	70.0	90.56
	80.0	79.77
	90.0	49.82
25.0	10.0	5.537
	20.0	10.33
	30.0	53.26
	40.0	74.39
	50.0	89.32
	60.0	92.69
	70.0	89.64
	80.0	76.13
30.0	10.0	5.537
	20.0	5.537
	30.0	42.13
	40.0	74.39
	50.0	87.49
	60.0	92.20
	70.0	90.56
	80.0	79.77
	90.0	49.82