

Well-dispersed nickel nanoparticles on the external and internal surface of SBA-15 for hydrocracking of pyrolyzed α -cellulose

Wega Trisunaryanti,^{*a} Endah Suarsih^a, Triyono^a and Iip Izul Falah^a

*Department of Chemistry, Universitas Gadjah Mada
Bulaksumur, DI Yogyakarta 55281*

Electronic Supplementary Information

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ESI 1 Original XRD patterns

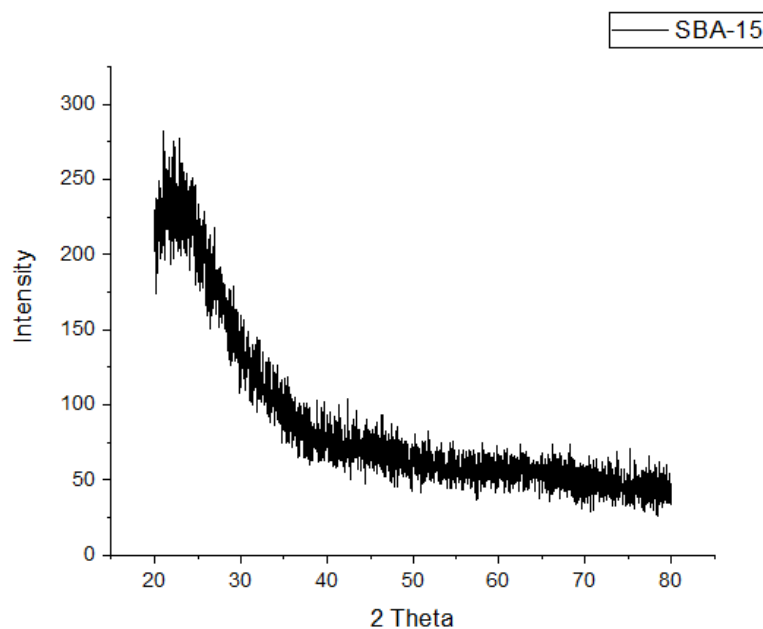


Figure 1 Wide angle XRD pattern of SBA-15

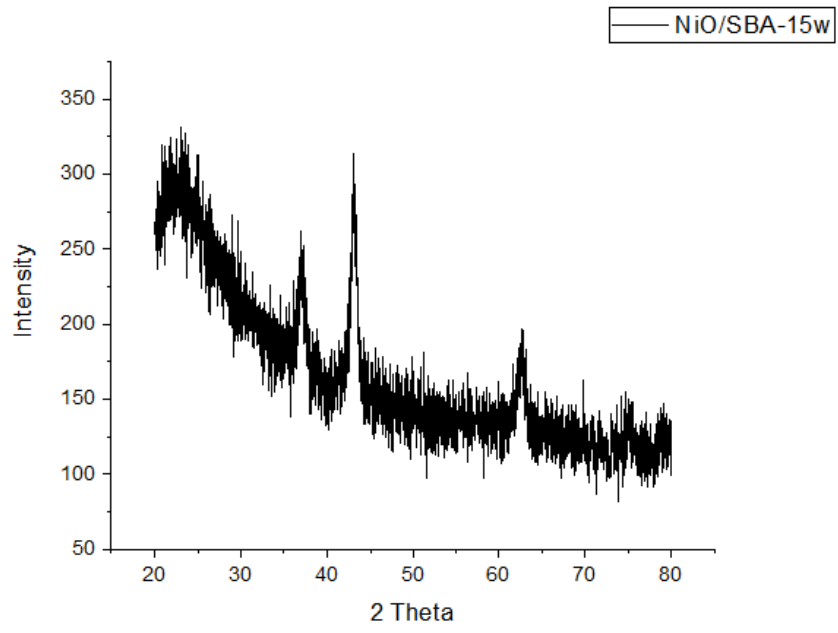


Figure 2 Wide angle XRD pattern of NiO/SBA-15w

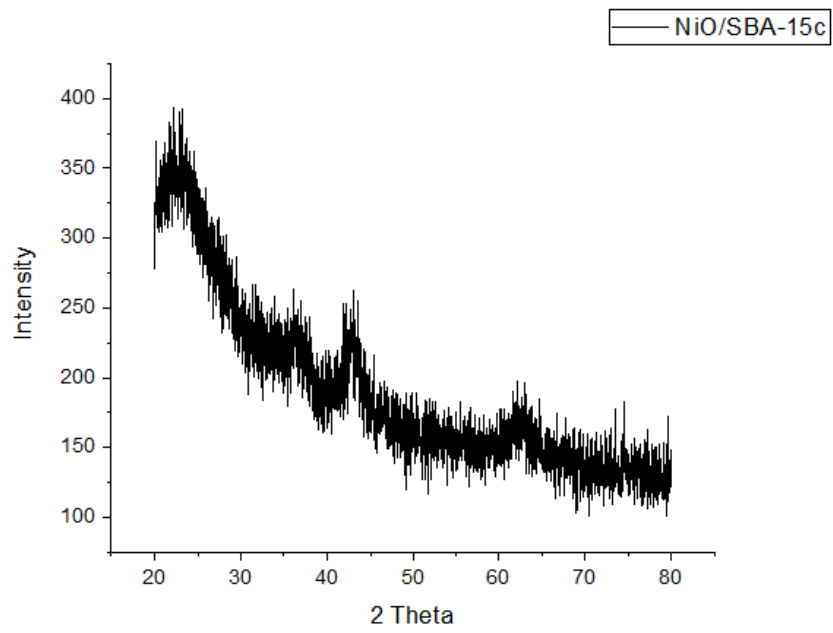


Figure 3 Wide angle XRD pattern of NiO/SBA-15c

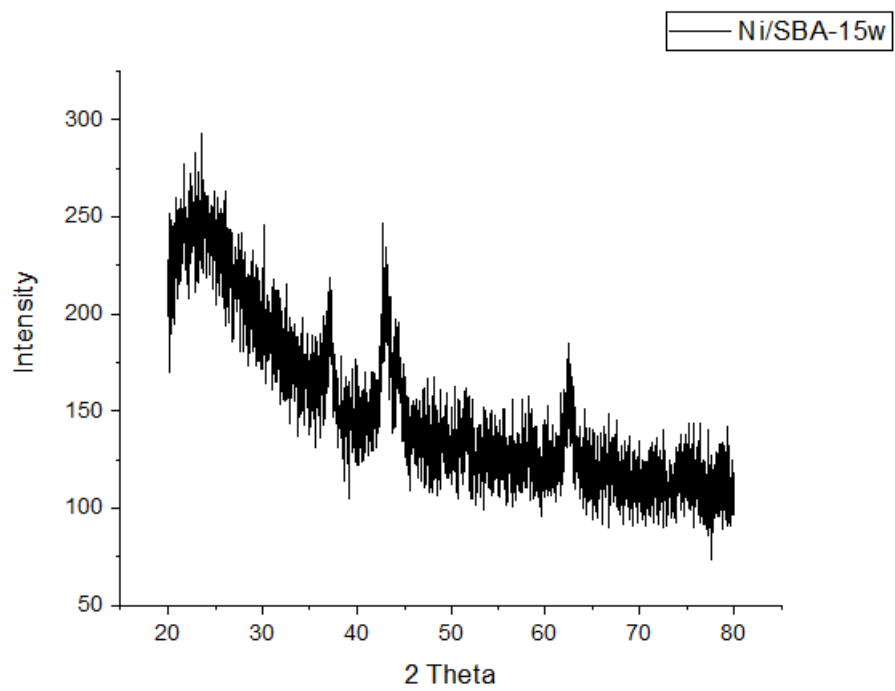


Figure 4 Wide angle XRD pattern of Ni/SBA-15w

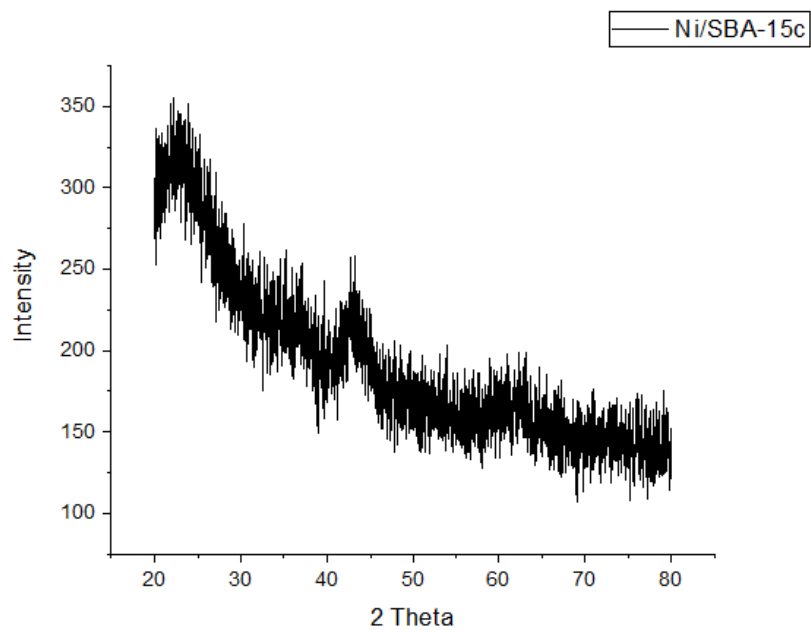
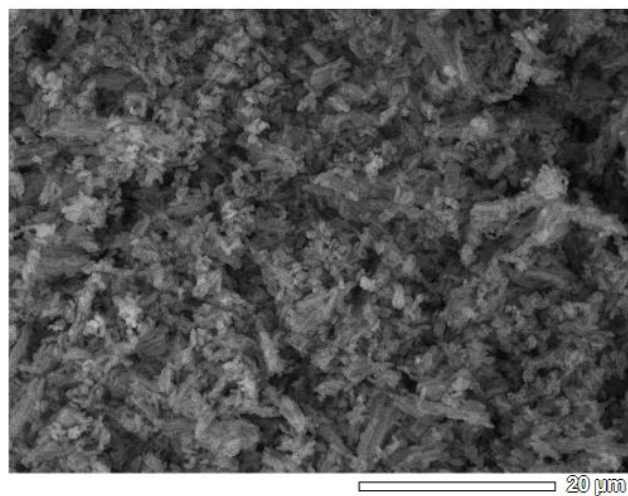
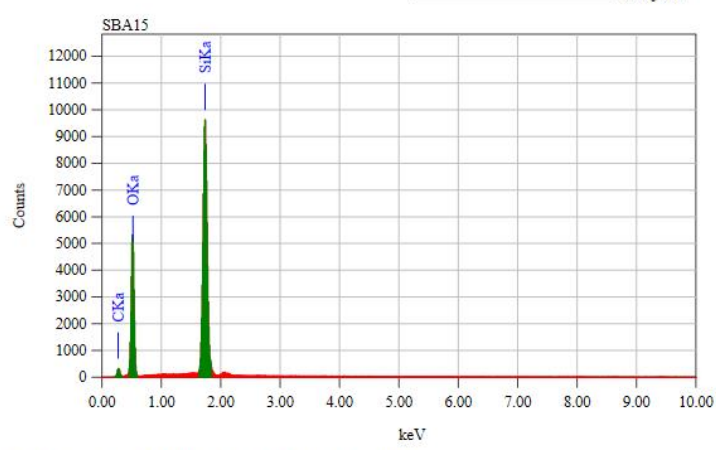


Figure 5 Wide angle XRD pattern of Ni/SBA-15c

ESI 2 Catalyst characterization using SEM-EDX



Title	: IMG1
Instrument	: 6510(LA)
Volt	: 15.00 kV
Mag.	: x 2,000
Date	: 2017/12/05
Pixel	: 1024 x 768

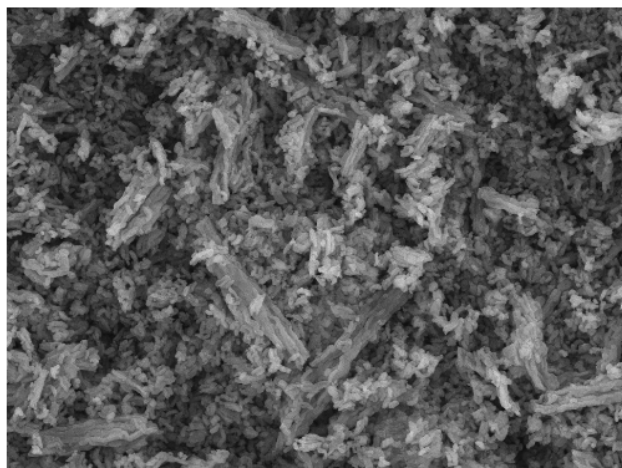


Acquisition Parameter	
Instrument	: 6510(LA)
Acc. Voltage	: 15.0 kV
Probe Current	: 1.00000 nA
PHA mode	: T3
Real Time	: 51.34 sec
Live Time	: 50.00 sec
Dead Time	: 2 %
Counting Rate	: 3089 cps
Energy Range	: 0 - 20 keV

ZAF Method Standardless Quantitative Analysis
 Fitting Coefficient : 0.0675

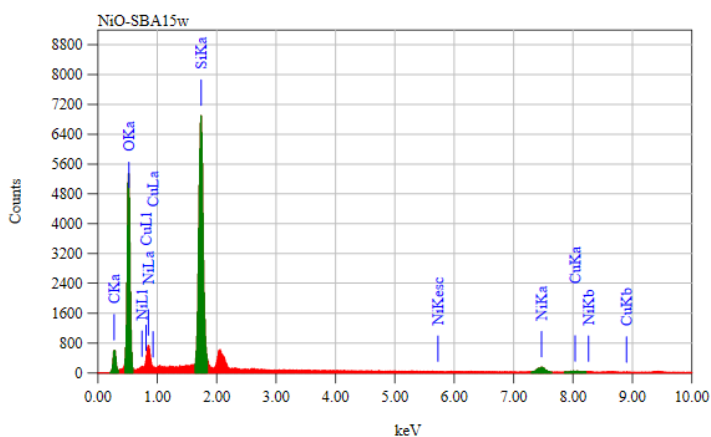
Element	(keV)	Mass%	Sigma	Atom%	Compound	Mass%	Cation	K
C K	0.277	11.19	0.13	16.72				2.0904
O K	0.528	54.93	0.28	61.62				62.2424
Si K	1.739	33.88	0.16	21.65				35.6673
Total		100.00		100.00				

Figure 6 SEM-EDX data of SBA-15



```

Title       : IMG1
-----
Instrument  : 6510(LA)
Volt       : 15.00 kV
Mag.      : x 2,000
Date      : 2017/12/05
Pixel     : 1024 x 768
  
```



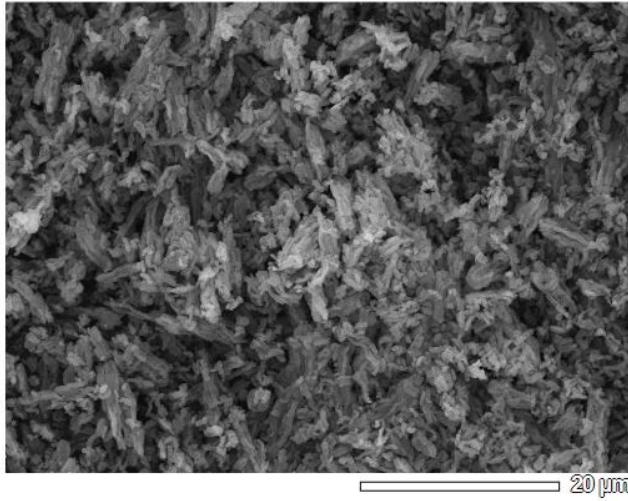
```

Acquisition Parameter
Instrument : 6510(LA)
Acc. Voltage : 15.0 kV
Probe Current: 1.00000 nA
PHA mode : T3
Real Time : 51.49 sec
Live Time : 50.00 sec
Dead Time : 2 %
Counting Rate: 3280 cps
Energy Range : 0 - 20 keV
  
```

ZAF Method Standardless Quantitative Analysis(Oxide)
 Fitting Coefficient : 0.0897
 Total Oxide : 24.0

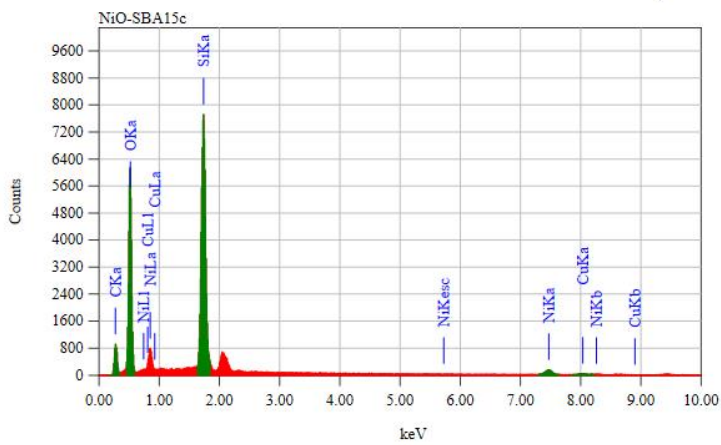
Element	(keV)	Mass%	Sigma	Mol%	Compound	Mass%	Cation	K
C K	0.277	22.32	0.20	59.88	C	22.32	0.00	9.6729
O		36.89						
Si K	1.739	29.80	0.35	34.20	SiO2	63.76	11.04	66.3028
Ni K	7.471	8.27	0.30	4.54	NiO	10.53	1.47	18.3397
Cu K	8.040	2.71	0.23	1.38	CuO	3.40	0.44	5.6846
Total		100.00		100.00		100.00	12.96	

Figure 7 SEM-EDX data of NiO/SBA-15w



```

Title      : IMG1
-----
Instrument  : 6510(LA)
Volt       : 15.00 kV
Mag.       : x 2,000
Date       : 2017/12/05
Pixel      : 1024 x 768
  
```



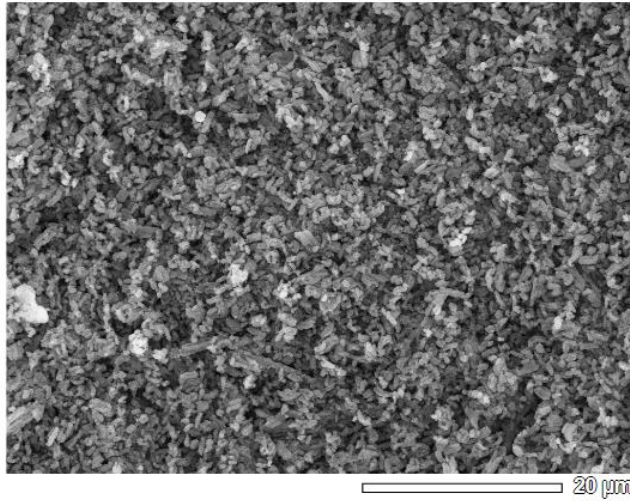
```

Acquisition Parameter
Instrument  : 6510(LA)
Acc. Voltage : 15.00 kV
Probe Current: 1.000000 nA
PHA mode   : T3
Real Time  : 51.69 sec
Live Time  : 50.00 sec
Dead Time  : 3 %
Counting Rate: 3690 cps
Energy Range : 0 - 20 keV
  
```

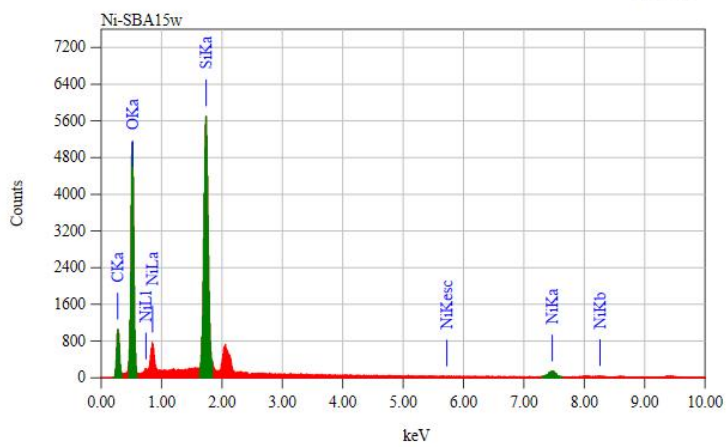
ZAF Method Standardless Quantitative Analysis(Oxide)
Fitting Coefficient : 0.0911
Total Oxide : 24.0

Element	(keV)	Mass%	Sigma	Mol%	Compound	Mass%	Cation	K
C	0.277	26.76	0.04	65.48	C	26.76	0.00	12.5272
O		34.86						
Si	1.739	28.22	0.19	29.52	SiO2	60.36	11.06	64.7687
Ni	7.471	7.70	0.14	3.86	NiO	9.80	1.45	17.4505
Cu	8.040	2.45	0.14	1.14	CuO	3.07	0.43	5.2535
Total		100.00		100.00		100.00	12.94	

Figure 8 SEM-EDX data of NiO/SBA-15c



Title : IMG1
 Instrument : 6510(LA)
 Volt : 15.00 kV
 Mag. : x 2,000
 Date : 2017/12/05
 Pixel : 1024 x 768

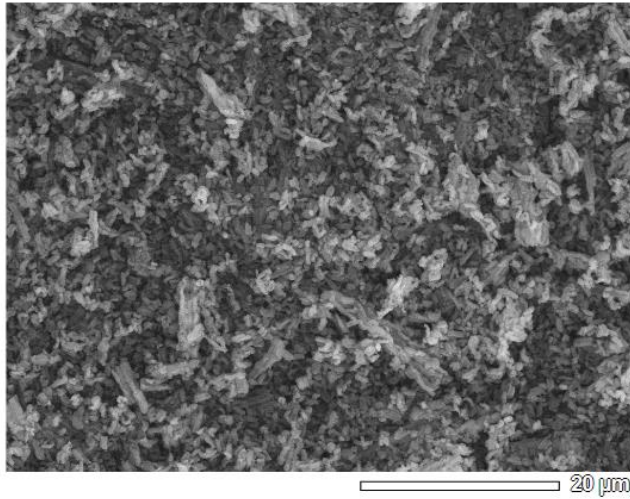


Acquisition Parameter
 Instrument : 6510(LA)
 Acc. Voltage : 15.0 kV
 Probe Current: 1.00000 nA
 PHA mode : T3
 Real Time : 51.43 sec
 Live Time : 50.00 sec
 Dead Time : 2 %
 Counting Rate: 3181 cps
 Energy Range : 0 - 20 keV

ZAF Method Standardless Quantitative Analysis
 Fitting Coefficient : 0.1089

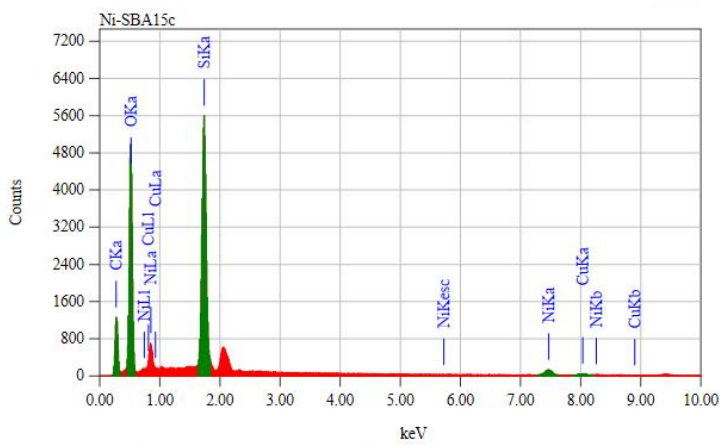
Element	(keV)	Mass%	Sigma	Atom%	Compound	Mass%	Cation	K
C K	0.277	22.05	0.03	31.11				6.8333
O K	0.525	52.29	0.10	55.39				63.5668
Si K	1.739	19.37	0.07	11.69				22.3965
Ni K	7.471	6.29	0.10	1.82				7.2034
Total		100.00		100.00				

Figure 9 SEM-EDX data of Ni/SBA-15w



```

Title      : IMG1
-----
Instrument  : 6510(LA)
Volt       : 15.00 kV
Mag.       : x 2,000
Date       : 2017/12/05
Pixel      : 1024 x 768
  
```



```

Acquisition Parameter
Instrument  : 6510(LA)
Acc. Voltage : 15.00 kV
Probe Current: 1.00000 nA
PHA mode   : T3
Real Time  : 51.36 sec
Live Time  : 50.00 sec
Dead Time  : 2 %
Counting Rate: 3099 cps
Energy Range : 0 - 20 keV
  
```

ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.1032

Element	(keV)	Mass%	Sigma	Atom%	Compound	Mass%	Cation	K
C	0.277	24.44	0.15	34.37				8.2354
O	0.525	49.98	0.26	52.77				61.2895
Si	1.739	17.70	0.11	10.65				21.1955
Ni	7.471	5.61	0.17	1.61				6.7199
Cu	8.040	2.26	0.14	0.60				2.5596
Total		100.00		100.00				

Figure 10 SEM-EDX data of Ni/SBA-15c

ESI 3 Catalysts characterization using Gas Adsorption Analyzer

Quantachrome NovaWin - Data Acquisition and Reduction
for NOVA instruments
©1994-2010, Quantachrome Instruments
version 11.0



Analysis		Report	
Operator: Lab Instrument TK - ITB	Date: 2015/06/26	Operator: Lab Instrument TK - ITB	Date: 6/26/2015
Sample ID: SBA-15	Filename:	C:\QCdata\Physisorb\lstn_C_20150625_1_SBA-15.qps	
Sample Desc:	Comment:	Ridwan Pratama Putra / TK ITB	
Sample weight: 0.0138 g	Sample Volume: 0.01619 cc		
Outgas Time: 3.0 hrs	Outgas Temp: 300.0 C		
Analysis gas: Nitrogen	Bath Temp: 77.3 K		
Press. Tolerance: 0.100/0.100 (ads/des)	Equil time: 60/60 sec (ads/des)	Equil timeout: 120/120 sec (ads/des)	
Analysis Time: 610.2 min	End of run: 2015/06/26 1:22:42	Instrument: Nova Station C	
Cell ID: 99		F/W version: 0.00	

BJH Pore Size Distribution Desorption

Data Reduction Parameters Data

<u>t-Method</u>	Calc. method: de Boer		
<u>BJH/DH method</u>	Moving pt. avg.: off	Ignoring P-tags below 0.35 P/Po	
<u>Adsorbate</u>	Nitrogen	Temperature	77.350K
	Molec. Wt.: 28.013 g	Cross Section:	16.200 Å ²
	Contact Angle: 0.0 degrees	Surf. Tension:	8.850 erg/cm ²
		Liquid Density:	0.808 g/cc

BJH Pore Size Distribution Desorption Data

Diameter	Pore Volume	Pore Surf Area	dV(d)	dS(d)	dV(logd)	dS(logd)
[Å]	[cc/g]	[m ² /g]	[cc/Å/g]	[m ² /Å/g]	[cc/g]	[cc/g]
34.1276	4.5095e-03	5.2855e+00	1.1921e-03	1.3973e+00	9.3585e-02	1.0969e+02
38.3303	8.4665e-03	9.4149e+00	8.5600e-04	8.9328e-01	7.5458e-02	7.8745e+01
43.1983	1.9111e-02	1.9272e+01	2.0818e-03	1.9277e+00	2.0683e-01	1.9152e+02
48.7520	1.3488e-01	1.1426e+02	1.9314e-02	1.5846e+01	2.1653e+00	1.7766e+03
56.1444	4.5515e-01	3.4243e+02	3.6433e-02	2.5957e+01	4.7003e+00	3.3487e+03
65.8539	8.2864e-01	5.6930e+02	3.5141e-02	2.1345e+01	5.3171e+00	3.2296e+03
77.7776	8.7347e-01	5.9235e+02	3.3908e-03	1.7438e+00	6.0579e-01	3.1155e+02
94.5308	8.9808e-01	6.0276e+02	1.2131e-03	5.1333e-01	2.6304e-01	1.1130e+02
121.7391	9.2242e-01	6.1076e+02	7.1312e-04	2.3431e-01	1.9858e-01	6.5248e+01
174.1200	9.4635e-01	6.1626e+02	3.3880e-04	7.7832e-02	1.3395e-01	3.0772e+01
315.6733	9.7743e-01	6.2019e+02	1.4627e-04	1.8535e-02	1.0218e-01	1.2947e+01
1252.8006	1.0223e+00	6.2163e+02	2.7023e-05	8.6281e-04	6.4743e-02	2.0672e+00

BJH desorption summary

Surface Area = 621.628 m²/g
Pore Volume = 1.022 cc/g
Pore Diameter Dv(d) = 56.144 Å

Figure 11 BJH pore size distribution desorption of SBA-15

Analysis		Report	
Operator:nova	Date:2017/11/29	Operator:nova	Date:11/29/2017
Sample ID: NiO-w	Filename:	C:\QCdata\Physisorb\NiO-w.qps	
Sample Desc:	Comment:	Endah	
Sample weight: 0.0408 g	Sample Volume: 0.01196 cc	Sample Density: 3.41 g/cc	
Outgas Time: 3.0 hrs	Outgas Temp: 300.0 C		
Analysis gas: Nitrogen	Bath Temp: 77.3 K		
Press. Tolerance: 0.050/0.050 (ads/des)	Equil time: 120/120 sec (ads/des)	Equil timeout: 240/240 sec (ads/des)	
Analysis Time: 903.9 min	End of run: 2017/11/29 9:04:57	Instrument: Nova Station A	
Cell ID: 81		F/W version: 0.00	

BJH Pore Size Distribution Desorption

Data Reduction Parameters Data

t-Method	Calc. method: de Boer		
BJH/DH method	Moving pt. avg.: off	Ignoring P-tags below 0.35 P/Po	
Adsorbate	Nitrogen	Temperature	77.350K
	Molec. Wt.: 28.013 g	Cross Section:	16.200 Å²
	Contact Angle: 0.0 degrees	Surf. Tension:	8.850 erg/cm²
		Liquid Density:	0.808 g/cc

BJH Pore Size Distribution Desorption Data

Diameter	Pore Volume	Pore Surf Area	dV(d)	dS(d)	dV(logd)	dS(logd)
[Å]	[cc/g]	[m²/g]	[cc/Å/g]	[m²/Å/g]	[cc/g]	[cc/g]
36.0180	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00
42.8584	7.4683e-03	6.9702e+00	1.0472e-03	9.7736e-01	1.0310e-01	9.6228e+01
52.8999	1.4615e-01	1.1184e+02	1.0708e-02	8.0969e+00	1.2978e+00	9.8131e+02
67.2608	7.3224e-01	4.6038e+02	3.7163e-02	2.2101e+01	5.7291e+00	3.4071e+03
90.3016	7.9354e-01	4.8754e+02	2.0226e-03	8.9593e-01	4.1658e-01	1.8453e+02
133.3832	8.2719e-01	4.9763e+02	6.0246e-04	1.8067e-01	1.8229e-01	5.4668e+01
267.2283	8.5817e-01	5.0226e+02	1.4624e-04	2.1890e-02	8.5056e-02	1.2732e+01
966.1222	8.7349e-01	5.0290e+02	1.2919e-05	5.3489e-04	2.4673e-02	1.0215e+00

BJH desorption summary

Surface Area = 502.898 m²/g
Pore Volume = 0.873 cc/g
Pore Diameter Dv(d) = 67.261 Å

Figure 12 BJH pore size distribution desorption of NiO/SBA-15w

Analysis		Report	
Operator:nova	Date:2017/11/29	Operator:nova	Date:11/29/2017
Sample ID: NiO-c	Filename:	C:\QCdata\Physisorb\NiO-c.qps	
Sample Desc:	Comment:	Endah	
Sample weight: 0.0416 g	Sample Volume: 0.0122 cc	Sample Density: 3.41 g/cc	
Outgas Time: 3.0 hrs	Outgas Temp: 300.0 C		
Analysis gas: Nitrogen	Bath Temp: 77.3 K		
Press. Tolerance: 0.050/0.050 (ads/des)	Equil time: 120/120 sec (ads/des)	Equil timeout: 240/240 sec (ads/des)	
Analysis Time: 909.4 min	End of run: 2017/11/29 9:10:24	Instrument: Nova Station B	
Cell ID: 82		F/W version: 0.00	

BJH Pore Size Distribution Desorption

Data Reduction Parameters Data

t-Method	Calc. method: de Boer		
BJH/DH method	Moving pt. avg.: off	Ignoring P-tags below 0.35 P/Po	
Adsorbate	Nitrogen	Temperature	77.350K
	Molec. Wt.: 28.013 g	Cross Section:	16.200 Å²
	Contact Angle: 0.0 degrees	Surf. Tension:	8.850 erg/cm²
		Liquid Density:	0.808 g/cc

BJH Pore Size Distribution Desorption Data

Diameter	Pore Volume	Pore Surf Area	dV(d)	dS(d)	dV(logd)	dS(logd)
[Å]	[cc/g]	[m²/g]	[cc/Å/g]	[m²/Å/g]	[cc/g]	[cc/g]
35.8452	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00
43.5776	9.4980e-03	8.7183e+00	1.0826e-03	9.9373e-01	1.0826e-01	9.9375e+01
53.5912	1.3559e-01	1.0283e+02	1.1204e-02	8.3626e+00	1.3775e+00	1.0281e+03
66.3248	7.1368e-01	4.5147e+02	4.0673e-02	2.4530e+01	6.1877e+00	3.7318e+03
88.6192	7.8602e-01	4.8413e+02	2.3816e-03	1.0750e+00	4.8117e-01	2.1718e+02
132.4104	8.2151e-01	4.9485e+02	6.2035e-04	1.8740e-01	1.8616e-01	5.6237e+01
289.3866	8.5754e-01	4.9983e+02	1.4034e-04	1.9398e-02	8.7018e-02	1.2028e+01
880.4192	8.9006e-01	5.0131e+02	3.5147e-05	1.5968e-03	6.4125e-02	2.9134e+00

BJH desorption summary

Surface Area = 501.305 m²/g
Pore Volume = 0.890 cc/g
Pore Diameter Dv(d) = 66.325 Å

Figure 13 BJH pore size distribution desorption of NiO/SBA-15c

Analysis		Report	
Operator:nova	Date:2017/11/29	Operator:nova	Date:11/29/2017
Sample ID: Ni-w	Filename:	C:\QCdata\Physisorb\Ni-w.qps	
Sample Desc:	Comment:	Endah	
Sample weight: 0.0455 g	Sample Volume: 0.01334 cc	Sample Density: 3.41 g/cc	
Outgas Time: 3.0 hrs	Outgas Temp: 300.0 C		
Analysis gas: Nitrogen	Bath Temp: 77.3 K		
Press. Tolerance: 0.050/0.050 (ads/des)	Equil time: 120/120 sec (ads/des)	Equil timeout: 240/240 sec (ads/des)	
Analysis Time: 914.8 min	End of run: 2017/11/29 9:15:51	Instrument: Nova Station C	
Cell ID: 83		F/W version: 0.00	

BJH Pore Size Distribution Desorption

Data Reduction Parameters Data

t-Method	Calc. method: de Boer		
BJH/DH method	Moving pt. avg.: off	Ignoring P-tags below 0.35 P/Po	
Adsorbate	Nitrogen	Temperature	77.350K
	Molec. Wt.: 28.013 g	Cross Section:	16.200 Å²
	Contact Angle: 0.0 degrees	Surf. Tension:	8.850 erg/cm²
		Liquid Density:	0.808 g/cc

BJH Pore Size Distribution Desorption Data

Diameter	Pore Volume	Pore Surf Area	dV(d)	dS(d)	dV(logd)	dS(logd)
[Å]	[cc/g]	[m²/g]	[cc/Å/g]	[m²/Å/g]	[cc/g]	[cc/g]
36.0143	4.6368e-02	5.1500e+01	7.0797e-03	7.8632e+00	5.8547e-01	6.5026e+02
43.0673	8.7351e-02	8.9564e+01	5.4235e-03	5.0372e+00	5.3644e-01	4.9824e+02
52.8868	2.2592e-01	1.9437e+02	1.1469e-02	8.6743e+00	1.3905e+00	1.0517e+03
66.6482	8.0232e-01	5.4030e+02	3.7331e-02	2.2405e+01	5.7031e+00	3.4228e+03
89.8172	8.7436e-01	5.7239e+02	2.3316e-03	1.0384e+00	4.7741e-01	2.1262e+02
105.6458	8.7436e-01	5.7239e+02	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00

BJH desorption summary

Surface Area = 572.386 m²/g
Pore Volume = 0.874 cc/g
Pore Diameter Dv(d) = 66.648 Å

Figure 14 BJH pore size distribution desorption of Ni/SBA-15w

Analysis		Report	
Operator:nova	Date:2017/11/30	Operator:nova	Date:11/30/2017
Sample ID: Ni-c	Filename:	C:\QCdata\Physisorb\Ni-c.qps	
Sample Desc:	Comment:	Endah	
Sample weight: 0.0471 g	Sample Volume: 0.013812 cc	Sample Density: 3.41 g/cc	
Outgas Time: 3.0 hrs	Outgas Temp: 300.0 C		
Analysis gas: Nitrogen	Bath Temp: 77.3 K		
Press. Tolerance: 0.050/0.050 (ads/des)	Equil time: 120/120 sec (ads/des)	Equil timeout: 240/240 sec (ads/des)	
Analysis Time: 681.1 min	End of run: 2017/11/30 5:28:11	Instrument: Nova Station A	
Cell ID: 81		F/W version: 0.00	

BJH Pore Size Distribution Desorption

Data Reduction Parameters Data

<u>t-Method</u>	Calc. method: de Boer		
<u>BJH/DH method</u>	Moving pt. avg.: off	Ignoring P-tags below 0.35 P/Po	
<u>Adsorbate</u>	Nitrogen	Temperature	77.350K
	Molec. Wt.: 28.013 g	Cross Section:	16.200 Å ²
	Contact Angle: 0.0 degrees	Surf. Tension:	8.850 erg/cm ²
		Liquid Density:	0.808 g/cc

BJH Pore Size Distribution Desorption Data

Diameter	Pore Volume	Pore Surf Area	dV(d)	dS(d)	dV(logd)	dS(logd)
[Å]	[cc/g]	[m ² /g]	[cc/Å/g]	[m ² /Å/g]	[cc/g]	[cc/g]
36.0393	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00	0.0000e+00
43.5066	4.4517e-03	4.0929e+00	5.3974e-04	4.9624e-01	5.3907e-02	4.9562e+01
53.4530	6.7699e-02	5.1422e+01	5.4313e-03	4.0643e+00	6.6583e-01	4.9825e+02
66.7117	5.7706e-01	3.5683e+02	3.4249e-02	2.0536e+01	5.2391e+00	3.1413e+03
89.7024	6.2815e-01	3.7961e+02	1.6421e-03	7.3224e-01	3.3574e-01	1.4971e+02
135.7293	6.5471e-01	3.8744e+02	4.3591e-04	1.2847e-01	1.3391e-01	3.9465e+01
292.7839	6.8119e-01	3.9106e+02	1.0457e-04	1.4287e-02	6.5864e-02	8.9983e+00
859.5996	6.8942e-01	3.9144e+02	9.3467e-06	4.3493e-04	1.6751e-02	7.7946e-01

BJH desorption summary

Surface Area = 391.443 m²/g
Pore Volume = 0.689 cc/g
Pore Diameter Dv(d) = 66.712 Å

Figure 15 BJH pore size distribution desorption of Ni/SBA-15c

ESI 4 Characterization of liquid product using GC-MS

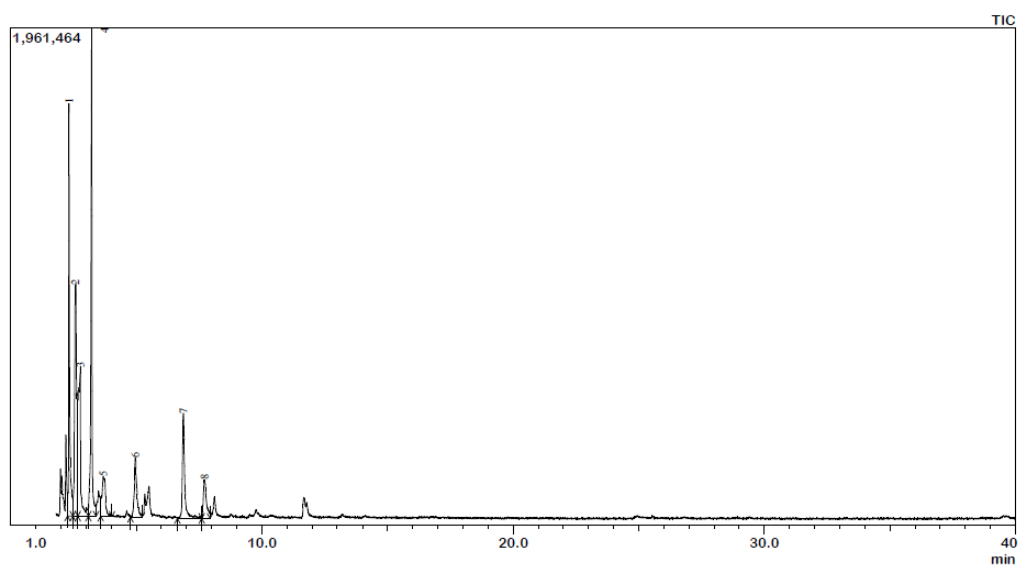


Figure 16 Chromatogram of pyrolyzed α -cellulose

Table 1 Composition of Pyrolyzed α -cellulose

Peak #	R.time	Area	Area (%)	Name	Molecular Formula
1	2.3180	4204868	15.41	Formic acid	CH ₂ O ₂
2	2.5670	5671987	20.78	2,3-Butanedione	C ₄ H ₆ O ₂
3	2.7710	4095677	15.01	Acetic acid	C ₂ H ₄ O ₂
4	3.2190	6169920	22.61	1-hydroxy-2-Propanone	C ₃ H ₆ O ₂
5	3.6790	1510617	5.53	Oxirane (butoxymethyl)	C ₇ H ₁₄ O ₂
6	4.9600	1672250	6.13	1-Hydroxy-2-Butanone	C ₄ H ₈ O ₂
7	6.8740	2696886	9.88	2-Furancarboxaldehyde	C ₅ H ₄ O ₂
8	7.7130	1271932	4.66	2-Furanmethanol	C ₅ H ₆ O ₂

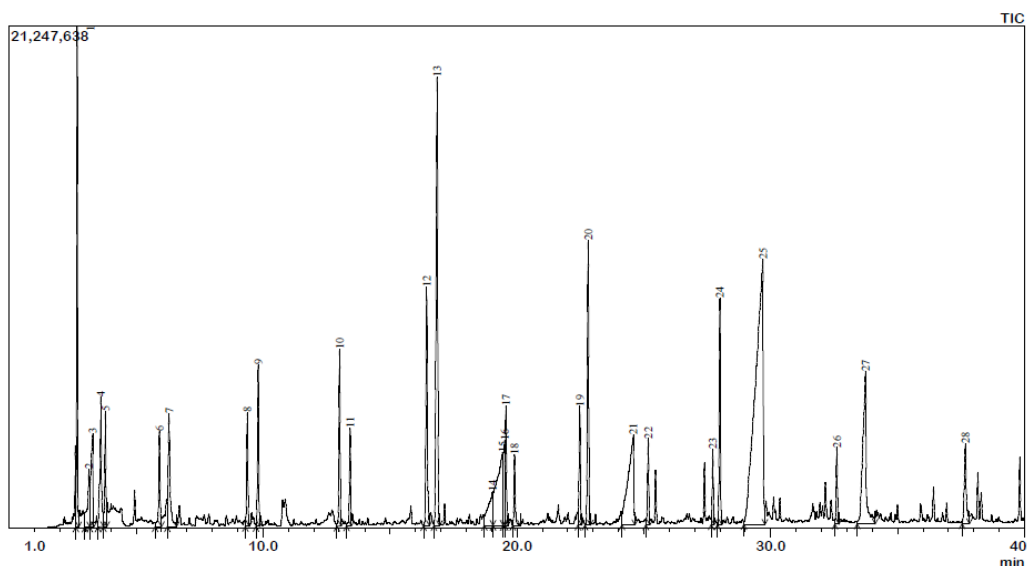


Figure 17 Chromatogram of hydrocracking liquid product with no catalyst

Table 2 Compositions of hydrocracking liquid product with no catalyst

Peak #	R.time	Area	Area (%)	Name	Molecular Formula
1	2.674	44348656	4.61	Hexane	C ₆ H ₁₄
2	3.139	12849517	1.34	Benzene	C ₆ H ₆
3	3.288	21626619	2.25	Acetic acid	C ₂ H ₄ O ₂
4	3.605	23343723	2.43	1-Heptanol	C ₇ H ₁₆ O
5	3.786	14442683	1.5	Heptane	C ₇ H ₁₆
6	5.917	15203284	1.58	1-Octene	C ₈ H ₁₆
7	6.292	26063881	2.71	2-Furancarboxaldehyde	C ₅ H ₄ O ₂
8	9.379	15331107	1.59	1-Nonene	C ₉ H ₁₈
9	9.81	21513058	2.24	Nonane	C ₉ H ₂₀
10	13.015	23959665	2.49	1-Decene	C ₁₀ H ₂₀
11	13.423	13233467	1.38	Decane	C ₁₀ H ₂₂
12	16.447	38749069	4.03	1-Undecene	C ₁₁ H ₂₂
13	16.857	83410605	8.67	Dodecane	C ₁₂ H ₂₆
14	19.043	18039188	1.87	6-Dodecanone	C ₁₂ H ₁₈ O
15	19.436	50960032	5.3	Decanal	C ₁₀ H ₂₀ O
16	19.52	15027160	1.56	Octanoic acid	C ₈ H ₁₆ O ₂
17	19.57	14892929	1.55	1-Dodecanol	C ₁₂ H ₂₆ O
18	19.909	10387174	1.08	Dodecane	C ₁₂ H ₂₆
19	22.477	16751172	1.74	1-Tridecene	C ₁₃ H ₂₆
20	22.811	42679952	4.44	Tetradecane	C ₁₄ H ₃₀
21	24.589	57784646	6.01	Decanoic acid	C ₁₀ H ₂₀ O ₂
22	25.175	12849282	1.34	1-Tridecene	C ₁₃ H ₂₆
23	27.716	10220151	1.06	1-Tridecene	C ₁₃ H ₂₆
24	27.998	31775704	3.3	Nonadecane	C ₁₉ H ₄₀
25	29.692	234309295	24,35	Dodecanoic acid	C ₁₂ H ₂₄ O ₂
26	32.606	10676555	1,11	Octadecane	C ₁₈ H ₃₈
27	33.736	62485364	6,49	Tetradecanoic acid	C ₁₄ H ₂₈ O ₂
28	37.671	19177174	1,99	Pentadecanoic acid	C ₁₅ H ₃₀ O ₂

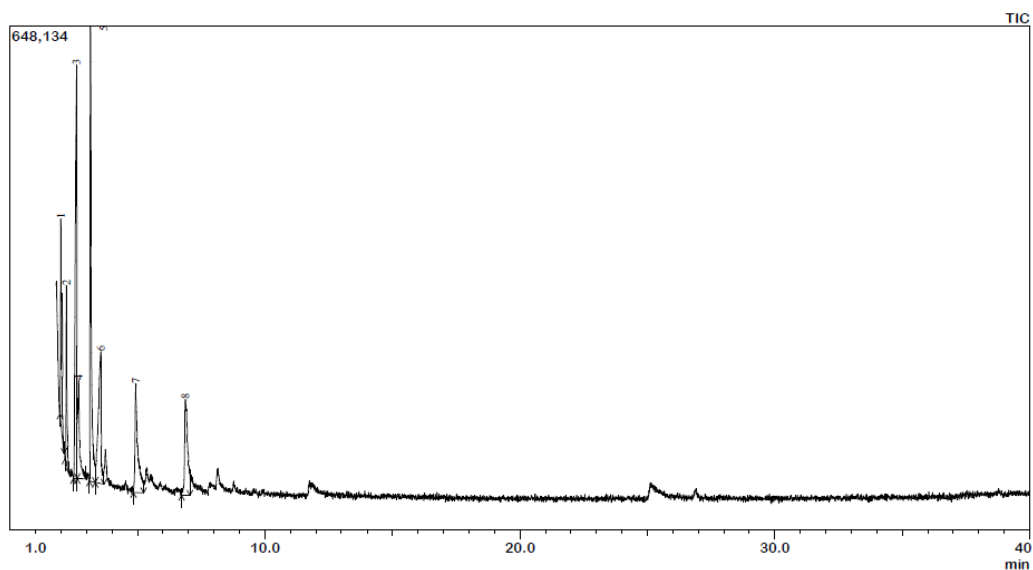


Figure 18 Chromatogram of hydrocracking liquid product with SBA-15

Table 3 Compositions of hydrocracking liquid product with SBA-15

Peak #	R.time	Area	Area (%)	Name	Molecular Formula
1	1.992	790824	8.37	Formaldehyde	CH ₂ O
2	2.207	513928	5.44	2-Propanone	C ₃ H ₆ O
3	2.605	2080643	22.01	Acetic acid	C ₂ H ₄ O ₂
4	2.688	640723	6.78	Propanoic acid	C ₃ H ₆ O ₂
5	3.152	1922726	20.34	1-hydroxy-2-Propanone	C ₃ H ₆ O ₂
6	3.558	1352436	14.31	Propanoic acid	C ₃ H ₆ O ₂
7	4.931	1084382	11.47	1-HYDROXY-2-BUTANONE	C ₄ H ₈ O ₂
8	6.876	1066032	11.28	2-Cyanomethyl-tetrahydrofuran	C ₆ H ₉ NO

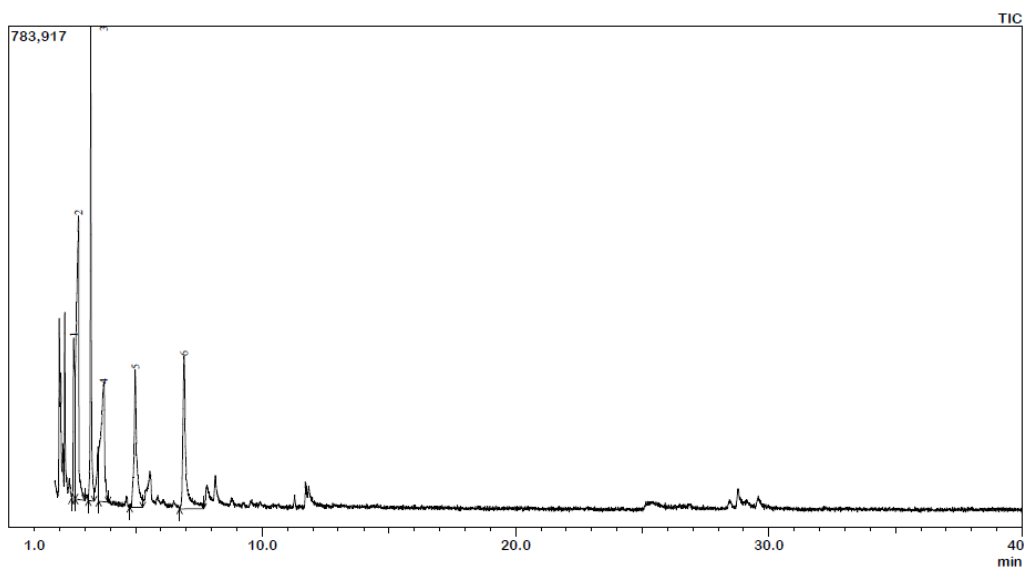


Figure 19 Chromatogram of hydrocracking liquid product with NiO/SBA-15w

Table 4 Compositions of hydrocracking liquid product with NiO/SBA-15w

Peak #	R.time	Area	Area (%)	Name	Molecular Formula
1	2.552	1049932	9.04	2,3-Butanedione	C ₄ H ₆ O ₂
2	2.743	3006366	25.89	Acetic acid	C ₂ H ₄ O ₂
3	3.225	2047609	17.63	1-hydroxy-2-Propanone	C ₃ H ₆ O ₂
4	3.728	1934012	16.65	Propanoic acid	C ₃ H ₆ O ₂
5	4.984	1623171	13.98	1-HYDROXY-2-BUTANONE	C ₄ H ₈ O ₂
6	6.911	1951691	16.81	2-Furancarboxaldehyde	C ₅ H ₄ O ₂

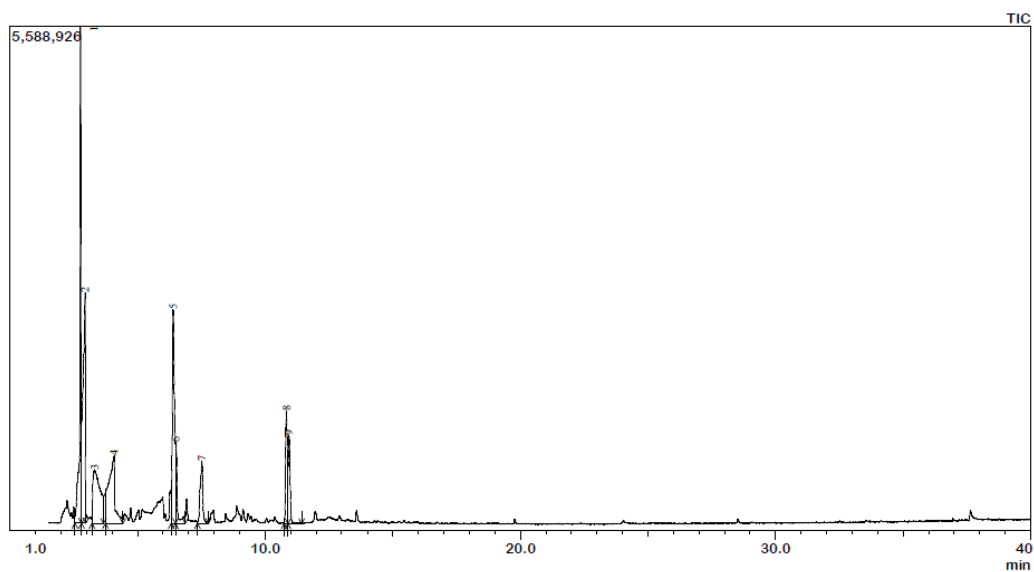


Figure 20 Chromatogram of hydrocracking liquid product with NiO/SBA-15c

Table 5 Compositions of hydrocracking liquid product with NiO/SBA-15c

Peak #	R.time	Area	Area (%)	Name	Molecular Formula
1	2.762	15800431	17.55	3-methyl-Pentane	C ₆ H ₁₄
2	2.943	15854468	17.61	Acetic acid	C ₂ H ₄ O ₂
3	3.315	11498201	12.77	1-hydroxy- 2-Propanone	C ₃ H ₆ O ₂
4	4.082	12965236	14.4	Propanoic acid	C ₃ H ₆ O ₂
5	6.392	13832871	15.37	2-Furancarboxaldehyde	C ₅ H ₄ O ₂
6	6.497	3915768	4.35	1,2-Bis(vinyloxy)ethane	C ₆ H ₁₀ O ₂
7	7.516	4983590	5.54	Acetol acetate	C ₅ H ₈ O ₃
8	10.829	6086867	6.76	3,3-Dimethyl-2-butanone	C ₆ H ₁₂ O
9	10.931	5071794	5.63	TRIMETHYLSILYL	C ₁₄ H ₂₀

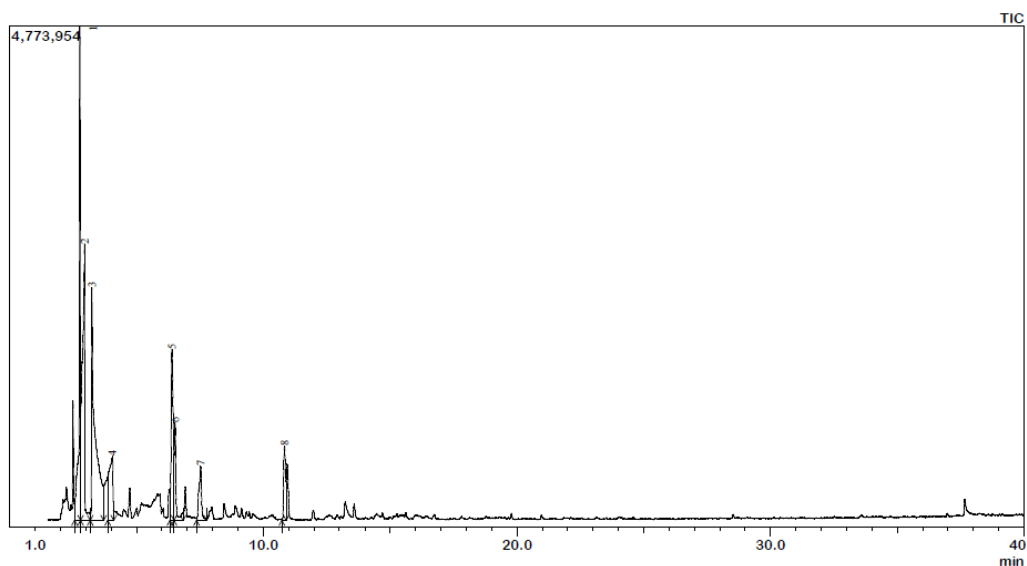


Figure 21 Chromatogram of hydrocracking liquid product with Ni/SBA-15w

Table 6 Compositions of hydrocracking liquid product with Ni/SBA-15w

Peak #	R.time	Area	Area (%)	Name	Molecular Formula
1	2.762	14062415	17.62	Ethanedioic acid	C ₁₀ H ₁₈ O ₄
2	2.948	17647297	22.11	Acetic acid	C ₂ H ₄ O ₂
3	3.24	20546243	25.74	1-hydroxy-2-Propanone	C ₃ H ₆ O ₂
4	4.053	6729774	8.43	Propanoic acid	C ₃ H ₆ O ₂
5	6.399	9329816	11.69	2-Furancarboxaldehyde	C ₅ H ₄ O ₂
6	6.516	4113419	5.15	2-(ethenyloxy)-Propane	C ₅ H ₁₀ O
7	7.524	3775825	4.73	Acetol acetate	C ₅ H ₈ O ₃
8	10.832	3602735	4.51	3,3-Dimethyl-2-butanone	C ₆ H ₁₂ O

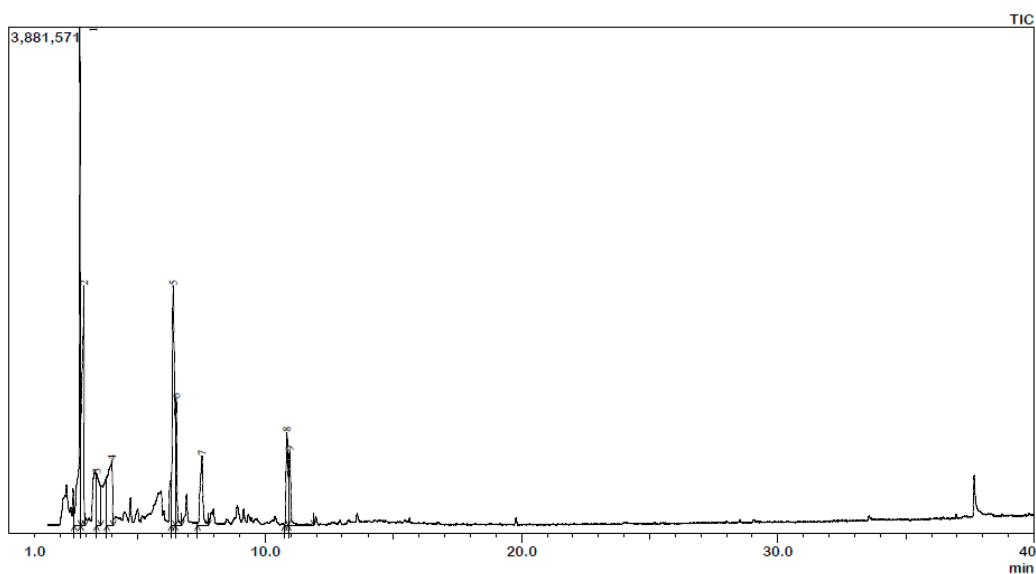


Figure 22 Chromatogram of hydrocracking liquid product with Ni/SBA-15c

Table 7 Compositions of hydrocracking liquid product with Ni/SBA-15c

Peak #	R.time	Area	Area (%)	Name	Molecular Formula
1	2.766	10765262	19.43	3-methyl-Pentane	C ₆ H ₁₄
2	2.919	9960407	17.98	Acetic acid	C ₂ H ₄ O ₂
3	3.415	3593105	6.49	1,4-DIBUTOXYBUTANE	C ₁₂ H ₂₆ O ₂
4	4.019	5930568	10.7	Propanoic acid	C ₃ H ₆ O ₂
5	6.407	11044880	19.94	2-Furancarboxaldehyde	C ₅ H ₄ O ₂
6	6.518	3651060	6.59	2,3,6-TRIMETHYLPHENYLBUTAN-2-ONE-D5	C ₁₃ H ₁₃ D ₅ O
7	7.526	4026237	7.27	Acetol acetate	C ₅ H ₈ O ₃
8	10.841	3425758	6.18	3,3-Dimethyl-2-butanone	C ₆ H ₁₂ O
9	10.945	3005578	5.42	ETHYLHEXATHIADAMANTANE	C ₆ H ₈ S ₆

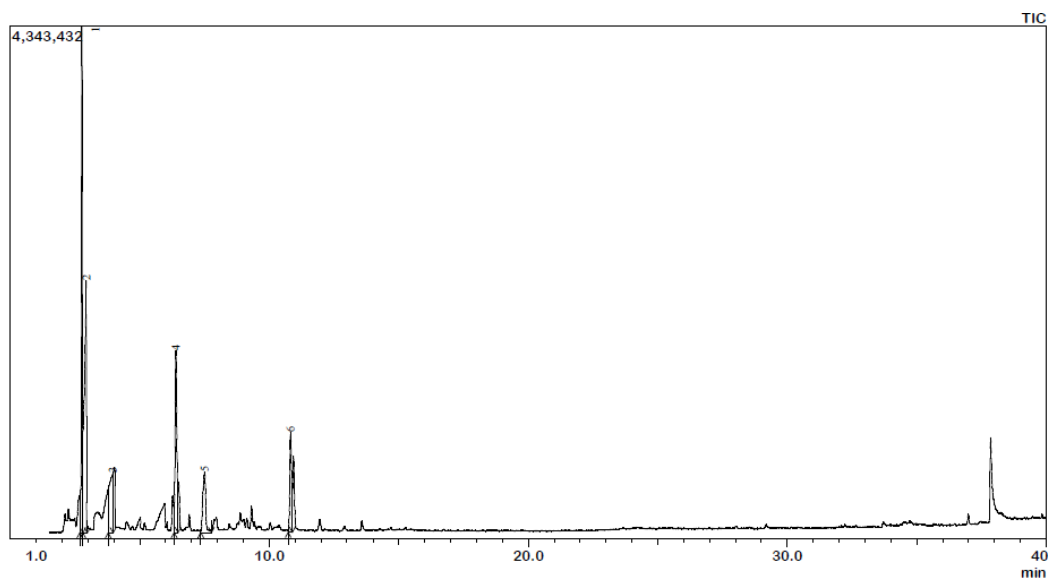


Figure 23 Chromatogram of double step hydrocracking liquid product with Ni/SBA-15w

Table 8 Compositions of double step hydrocracking liquid product with Ni/SBA-15w

Peak #	R.time	Area	Area (%)	Name	Molecular Formula
1	2.765	9530787	22.88	Hexane	C ₆ H ₁₄
2	2.929	11561914	27.76	Acetic acid	C ₂ H ₄ O ₂
3	3.953	5057059	12.14	1-methyl-4-(pent-1-en-4-on-2-yl) cyclohexene	C ₁₂ H ₁₈ O
4	6.393	7483106	17.97	2-Furancarboxaldehyde	C ₅ H ₄ O ₂
5	7.501	3959156	9.51	Acetol acetate	C ₅ H ₈ O ₃
6	10.822	4058390	9.74	3,3-Dimethyl-2-butanone	C ₆ H ₁₂ O

ESI 5 Catalysts characterization using TEM

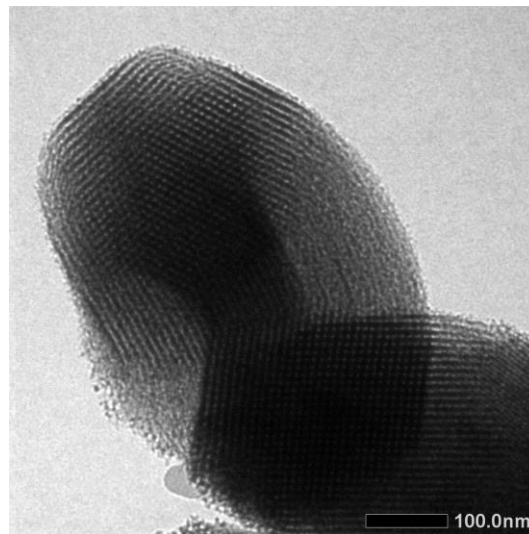


Figure 24 TEM image of SBA-15

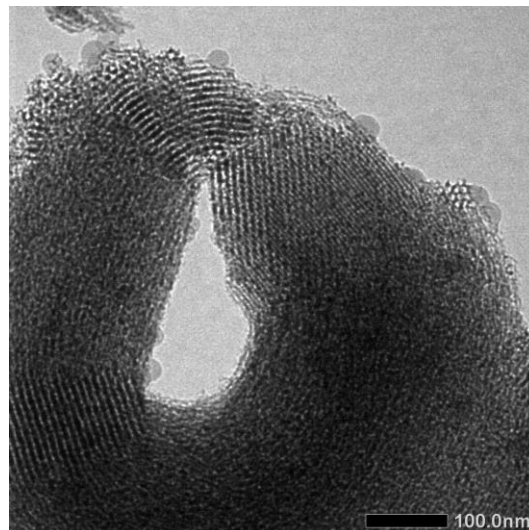


Figure 25 TEM image of NiO/SBA-15c

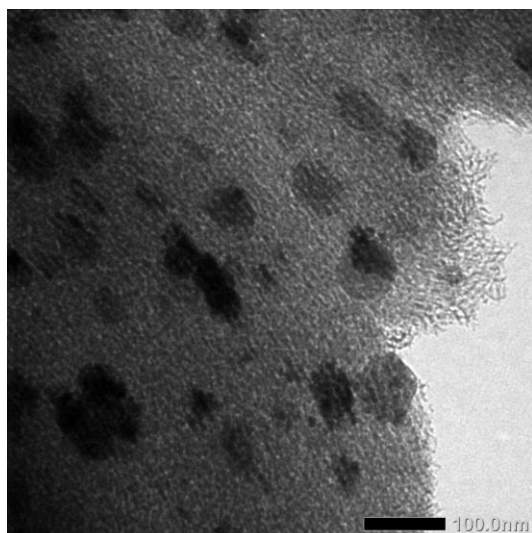


Figure 26 TEM image of NiO/SBA-15w

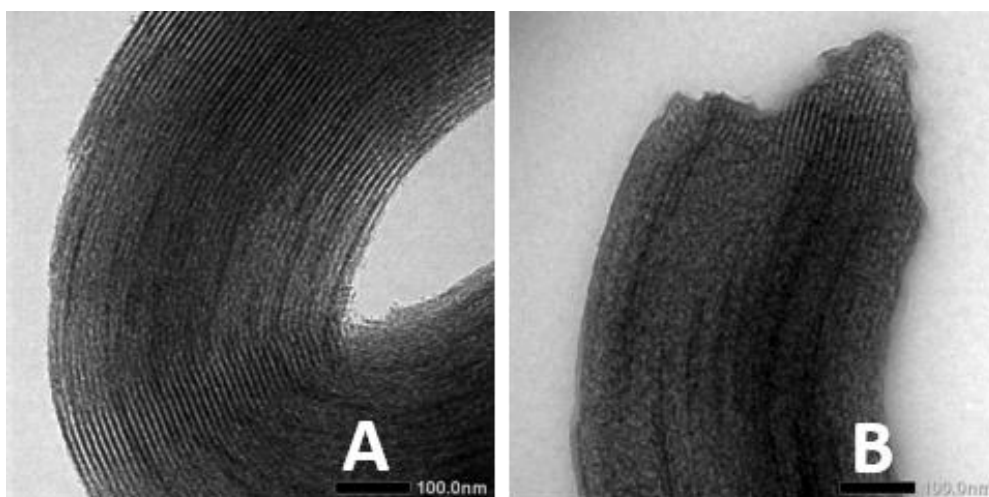


Figure 27 TEM image of Ni/SBA-15c (A) before and (B) after hydrocracking of pyrolyzed α -cellulose

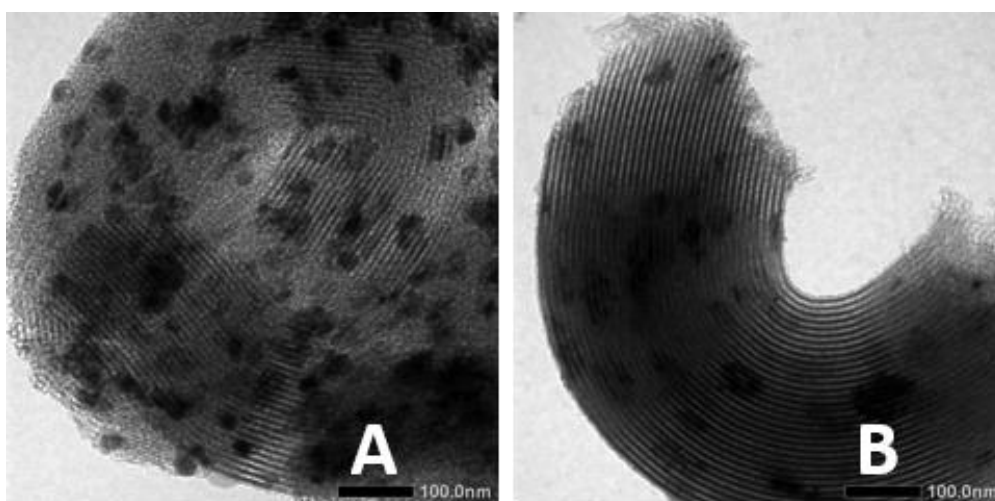


Figure 28 TEM image of Ni/SBA-15w (A) before and (B) after hydrocracking of pyrolyzed α -cellulose