Biomass to Power and Heat

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Possibilities of Multi-stage Gasification for Combined Heat and Power and Biochar Production

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Efficiency of electricity generation by various processes

$$\eta_{tot} = \eta_{CE} * \eta_{CU}$$

η_{CE} – cold gas efficiency which takes into account only the chemical energy of a gas

η_{CU} – eletrical efficiency of a cogeneration unit

η_{TOT} – overal eletricall efficiency

Type of power generation	Cold gas efficiency η_{CE}, %	Gas to electricity efficiency, η_{cu}, %	Overall el. efficiency η_t, %
1. Thermal plant with steam turbine (11 MW_e) (Zelený kotel, 33 MW_t), Plzeň	-	-	27,6
2. Thermal power plant (35 MW_e) (Biomass combustion, 105 MW_t), Hodonín	-	-	~ 33
4. Multi-stage (two-stage/twin-fire) gasifier GP750 (0,75 MW_e) TARPO spol. s r.o., AIR TECHNIC s.r.o., 2014	80–90	~ 36	~ 32*
5. Gasifier coupled with SOFC	~ 95	~ 45-65	~ 40-60

* Jenbacher AB, J316 GC (J320GC)

Principle of staged biomass gasification

Pyrolysis

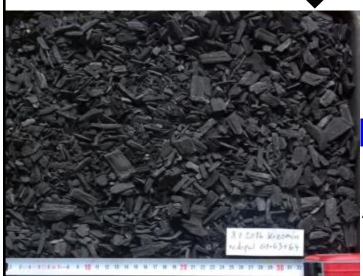
Partial oxidation of volatile matter

volatile matter

Volatile matter: H_2, H_2O, CO, CO_2, CH_4, hydrocarbons
Tar precursors

air

Biochar



heat

Tar definition according to the "Tar protocol" CEN/TS 15439: Tar is mixture of organic substances with boiling point higher than benzene (80,1 °C, 101,325kPa)

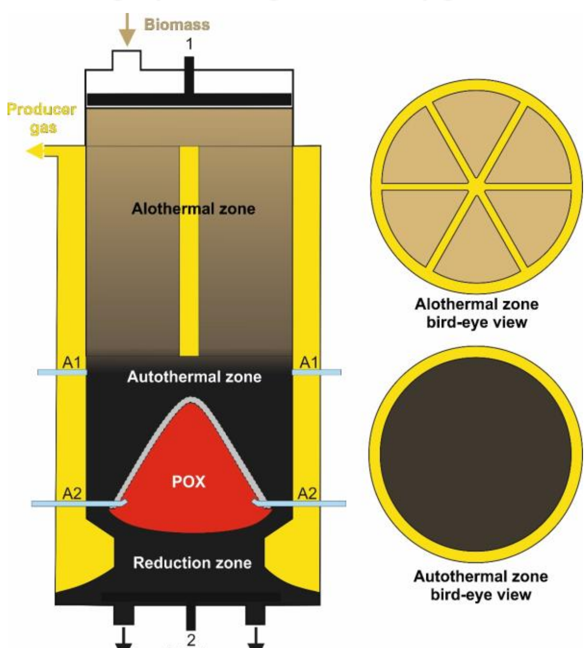
Gasification

tar free gas

CO, H_2, CH_4, CO_2, H_2O, N_2

biochar

Multi-stage (two-stage/twin-fire) gasifier GP750



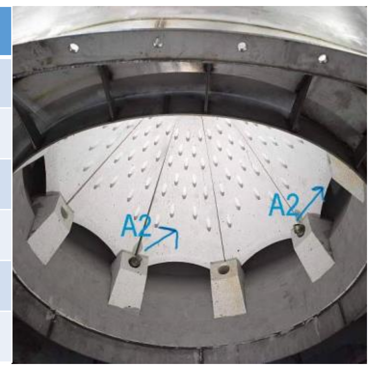
Basic description of GP750 gasifier

Gasifier	Dimensions of POX chamber		Volume	Flow*	Residence time*
	D,m	H,m	m^3	m^3/h	s
GP750	2,5	2,3	~4,0	~1300	~10

* Standard temperature and pressure

Nominal electric power	**710 kW**
Nominal wooden chips consumption (dry)	550 $kg \cdot h^{-1}$
Chips dimension	6 to 50 mm
Biomass moisture (dryer input)	up to 60 wt. %
Overall efficiency (calculated from LHV)	**32 %**
Nominal fuel (dry) consumption	**0,7 $kg \cdot kWh^{-1}$**
Nominal electric output	**1,4 $kWh \cdot kg^{-1}$**

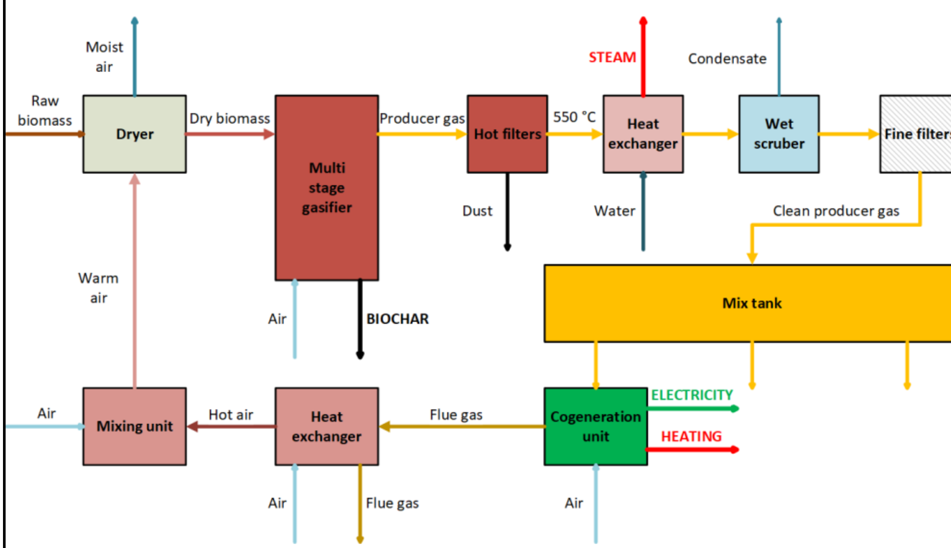
POX chamber



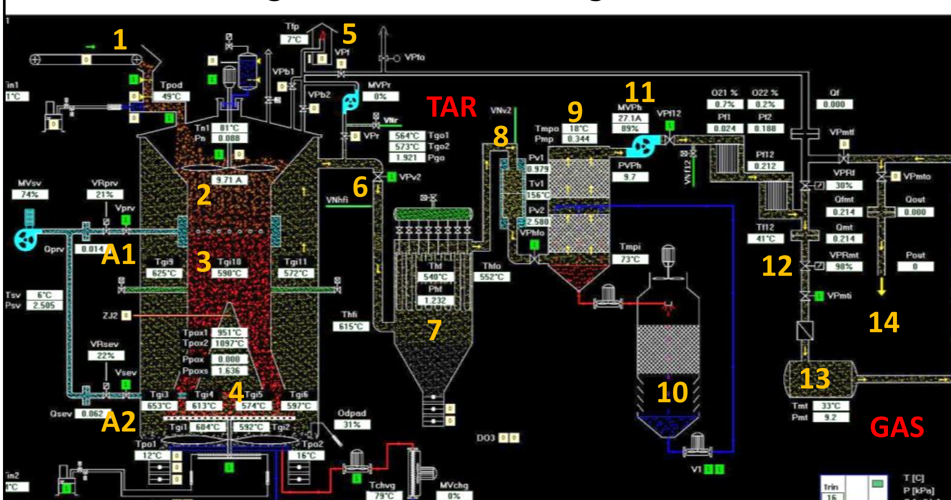
Installations of GP750 gasifiers

Locality	Engine type	Year of start-up Generator type	Installed power output	Current state
Kozomín	Jenbacher, 3xJ320	07/2014 5xGP750	2,1 MWe (3x710 kWe) 4,2 MW_t (gas)	Pilot operation of five GP750 units
Handlová	Guascor, FBLD560, FBLD480	06/2014 2xGP750	570 kW_e 430 kW_e	Operating from 4/2015

Combined heat and power plant Kozomín



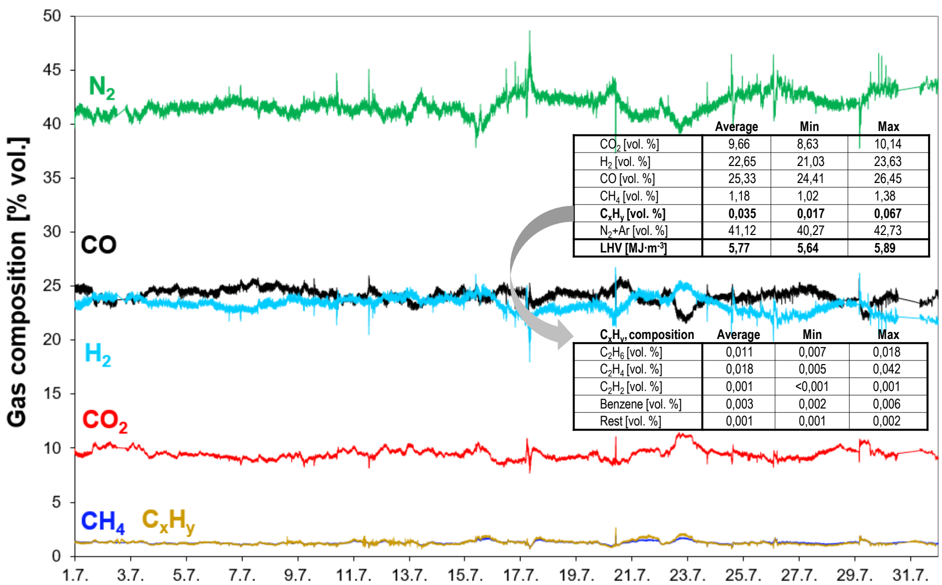
Technological flow sheet of gasification unit



1 - entry of fuel into the GP750, 2 - allothermal pyrolysis section, 3 - autothermal pyrolysis section, 4 - POX section, 5 - combustion flare, 6 - gas output, 7 - candle filters, 8 - heat exchangers (gas/water), 9 - contact water cooling, 10 - cooling tower, 11 - gas blower, 12 - gas flow measurement , 13 - mix tank, 14 - pipe to IC motor.
A1- primary air supply, A2- secondary air supply
GAS - point for gas quality sampling (on-line, off-line), TAR - point for gas sampling according to the Tar Protocol

Combined heat and power plant in Kozomín

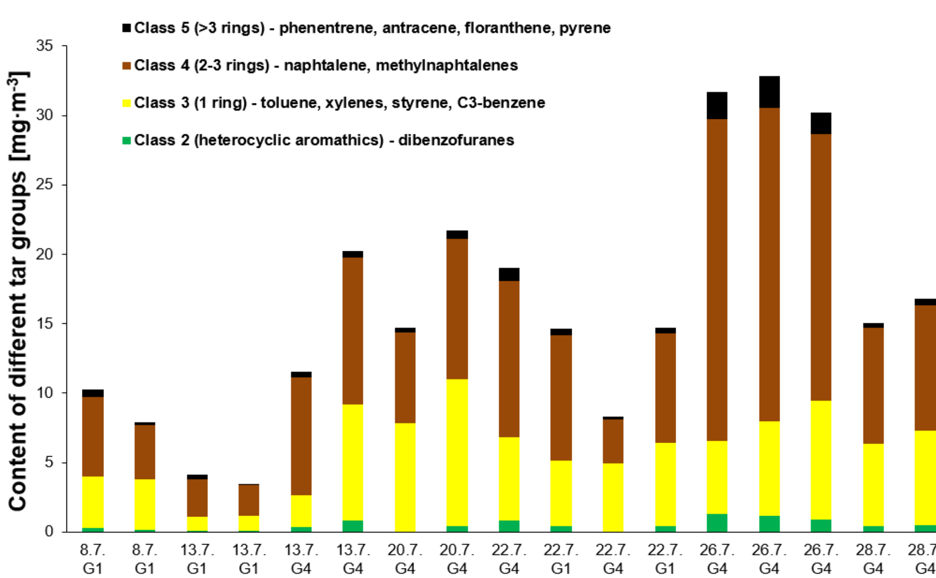
Gas composition July 2016



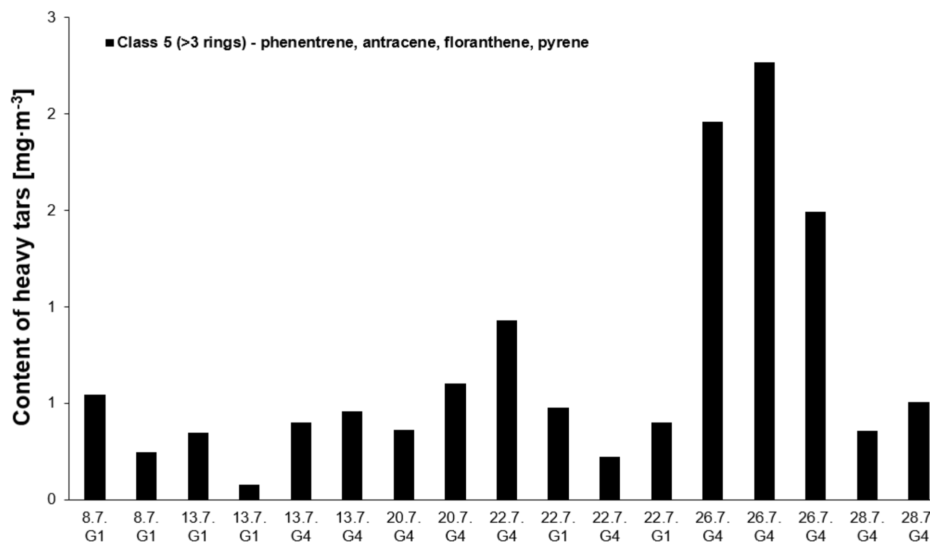
	Average	Min	Max
CO_2 [vol. %]	9,66	8,63	10,14
H_2 [vol. %]	22,65	21,03	23,63
CO [vol. %]	25,33	24,41	26,45
CH_4 [vol. %]	1,18	1,02	1,38
C_xH_y [vol. %]	**0,035**	**0,017**	**0,067**
N_2+Ar [vol. %]	41,12	40,27	42,73
LHV [$MJ \cdot m^{-3}$]	**5,77**	**5,64**	**5,89**

C_xH_y, composition	Average	Min	Max
C_2H_6 [vol. %]	0,011	0,007	0,018
C_2H_4 [vol. %]	0,018	0,005	0,042
C_2H_2 [vol. %]	0,001	<0,001	0,001
Benzene [vol. %]	0,003	0,002	0,006
Rest [vol. %]	0,001	0,001	0,002

Tar content July 2016



Content of heavy tars July 2016



Complex tar composition [mg·m3] (STP)

Time	14:12	16:33	10:45	12:33	14:49	17:00	14:38	9:58	11:04	12:18	13:30	10:05	12:03	14:10	11:17	13:20	13:20
Date	08.07.	08.07.	13.07.	13.07.	13.07.	13.07.	20.07.	20.07.	22.07.	22.07.	22.07.	22.07.	26.07.	26.07.	26.07.	28.07.	28.07.
Gasifier	G1	G1	G1	G1	G4	G4	G4	G4	G4	G1	G4	G1	G4	G4	G4	G4	G4
Benzene	6,78	7,95	1,39	2,13	4,02	12,39	18,23	20,55	8,86	5,72	14,41	9,47	10,40	12,32	14,74	16,43	16,87
Toluene	2,03	2,08	0,42	0,55	1,42	5,81	6,07	7,67	3,82	2,52	3,88	3,58	2,97	4,00	5,54	4,32	4,96
m+p+o-xylene+ethylbenzene+phenyacetylene	1,18	1,17	0,36	0,33	0,59	1,88	1,33	1,99	1,44	1,09	0,81	1,34	0,93	1,21	1,46	1,02	1,19
Styrene	0,31	0,26	0,12	0,13	0,19	0,61	0,43	0,76	0,57	0,69	0,25	0,86	0,76	0,99	1,09	0,37	0,57
C3-benzene summ	-	-	-	-	0,02	0,02	0,01	0,06	0,11	0,12	-	-	0,24	0,07	0,12	0,12	0,03
Indene+Indane	0,20	0,12	0,08	0,06	0,05	0,02	-	0,13	0,09	0,27	-	0,21	0,36	0,50	0,40	0,09	0,06
Rest	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
BTX summ	**10,30**	**11,46**	**2,28**	**3,15**	**6,25**	**20,71**	**26,07**	**31,04**	**14,81**	**10,14**	**19,36**	**15,24**	**15,31**	**18,61**	**22,94**	**22,26**	**23,63**
Phenol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Methylphenols	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dibenzofuranes	0,26	0,14	0,09	0,06	0,36	0,83	-	0,39	0,82	0,44	-	0,39	1,30	1,16	0,87	0,41	0,47
Oxugenates summ*	**0,26**	**0,14**	**0,09**	**0,06**	**0,36**	**0,83**	**-**	**0,39**	**0,82**	**0,44**	**-**	**0,39**	**1,30**	**1,16**	**0,87**	**0,41**	**0,47**
Nitrogenates	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Naphtalene	5,11	3,58	2,52	2,05	8,11	9,84	6,38	9,50	10,23	7,75	3,04	7,05	20,51	19,74	16,80	8,00	8,66
Methylnaphthalenes	0,33	0,15	0,17	0,15	0,21	0,38	0,12	0,47	0,59	0,88	0,11	0,59	1,36	1,37	1,25	0,22	0,25
Alkylnaphthalenes (Alkyl >=C2)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Biphenyl	0,12	0,04	-	-	0,17	0,23	-	0,12	0,24	0,19	-	0,12	0,39	0,44	0,34	0,06	-
Acenaphthylene	0,07	0,04	-	-	-	0,12	-	-	0,19	0,08	-	0,05	0,71	0,76	0,65	0,08	0,12
Acenaphthene	0,06	0,07	0,03	0,04	-	-	-	-	-	0,12	-	0,09	0,12	0,20	0,16	-	-
Fluorene	0,07	0,04	-	-	-	-	-	-	-	0,04	-	-	0,06	0,12	-	-	-
PAH with M/Z=165,166	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenentrene	0,19	0,14	0,11	0,03	0,13	0,23	0,16	0,25	0,36	0,14	0,09	0,18	0,60	0,80	0,78	0,25	0,29
Anthracene	0,20	0,11	0,10	0,05	0,21	0,24	0,20	0,23	0,31	0,14	0,13	0,18	0,72	0,62	0,42	0,11	0,22
Methylphenatrenes+4H Cyclopenta[def]phenanthrene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenylnaphthalenes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Fluoranthene[2]	0,06	-	0,05	-	0,02	0,04	-	0,08	0,06	0,03	-	0,03	0,17	0,23	0,16	-	-
Pyrene[3]	0,09	-	0,04	-	0,02	0,08	-	0,05	0,03	0,05	-	0,02	0,18	0,27	0,14	-	-
Benzofluorenes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Methylfluoranthene+methylpyrene	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PAH (4 rings, m/z=226,228)**	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PAH (5 rings, m/z=252) ***	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PAH (6 rings, m/z=276)****	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rest (TAR)	-	-	0,04	-	0,02	0,12	-	-	0,17	0,12	-	-	0,29	0,35	-	-	-
Summ TAR (without BTX)	**6,75**	**4,42**	**3,23**	**2,44**	**9,30**	**12,13**	**6,86**	**11,21**	**13,09**	**10,24**	**3,36**	**8,90**	**26,76**	**26,56**	**21,97**	**9,21**	**10,06**
TAR (Tar protocol)	10,28	7,93	4,13	3,45	11,53	20,46	14,70	21,70	19,03	14,66	8,31	14,68	31,67	32,84	30,17	15,04	16,82

STP Standardt temperature and preassuree (t = 0 °C, p = 101,325 kPa)
- Below detection limit
[1] This category includes rest of BTX group and alkylbenzenes.
[2] Fluoranthene together with acephenan*trylene, which eluates right after it* (Mr=202)
[3] Pyrene together with aceanthrylene, which elutes near before it (Mr=202)

*** Benzofuran,dibenzofurans,methylbenzofuranes,naphtylbenzofuran**
**** Benzo[c]phenantrene, benzo[ghi]fluoranthene,3,4-Dihydrocyclopenta(cd)pyrene (acepyrene),cyclopenta[cd]pyrene, benzo[a]anthracene,chrysenr,naphtacene**
***** benzo[j]fluoranthene,benzo[k]fluoranthene,benzo[e]pyrene,benzo[a]pyrene,perylene**
****** indeno[1,2,3-cd]pyrene,dibenzo[a,h]anthracene,benzo[ghi]perylene,Dibenzo[def,mno]chrysene and other PAH with m/r=278,302**

Typical gas composition from downdraft and staged gasifiers

Gasifier type	Downdraft Imbert 100 kW_{el}	GP300 200 kW_{el}	Viking DTU 75 kW_{th}	Staged gasifier		
				GP200	**GP500**	**GP750**
Biomass moisture, wt.	<10	<10	35-45	<10	<10	<10
CO	25,5	24,6	19,6	26,7	25,0	25,3
H_2	17,2	16,4	30,5	23,0	22,3	22,7
CH_4	***3,0***	***2,2***	***1,2***	***1,1***	***2,0***	***1,3***
CO_2	9,6	9,6	15,4	8,0	9,5	9,7
N_2	***43,5***	***46,1***	***33,2***	***40,6***	***41,1***	***40,9***
Other	1,2	1,1	0,1	0,6	0,2	0,1
Tar content, mg/m^3	**1000-2000**	**1300-2000**	**<5**	**0,5-2,0**	**5,0-40**	**20-200**
LHV (15 °C), MJ/m^3	6,3	5,7	5,6	5,9	5,9	5,8

Mass and energy balance during long time operation of Kozomín CHP

Operation period (2016)	July	August	September	October	November	December
Wet fuel consumption [tons]	1733	1427	1395	1530	1376	1390
Average water content [wt. %]	40,0	38,2	38,5	40,5	41,3	42,7
Dry fuel consumption [tons]	**1039**	**882**	**858**	**911**	**808**	**796**
LHV of wet fuel [$MJ \cdot kg^{-1}$]	9,7	10,1	10,0	9,7	9,5	9,3
Biochar production [tons]	**38,1**	**45,2**	**26,4**	**25,7**	**29,4**	**26,2**
Biochar yield (compared to dry fuel) [wt. %]	3,7	5,1	3,1	2,8	3,6	3,3
Electric production [MWh]	**1427**	**1309**	**1244**	**1327**	**1063**	**1083**
Dry fuel consumption [$kg \cdot kWh^{-1}$]	0,728	0,673	0,690	0,687	0,760	0,735
Overall efficiency (brutto) [%]	**30,6**	**32,9**	**32,1**	**32,4**	**29,3**	**30,3**
Overall efficiency (w/o biochar) [%]	**32,4**	**35,7**	**33,7**	**33,8**	**31,0**	**32,0**

Conclusion

- **GP750 gasifier is capable to simultaneously produce gas and biochar**
- Most suitable fuel for realisable operation are wooden chips with size 6–50 mm.
- Gas quality produced by GP750 is suitable for different types of IC engines.
- GP750 produces low tar gas (typically below 50 mg·m^{-3}), HHV = 6,5 MJ·m^{-3} (Power production >32 % brutto).
- **High biochar quality (500-700 m^2/g).**
- Gas quality and biochar production depends on:
  - fuel properties (size distribution, moisture content, ash content),
  - operating parameters (ratio of primary and secondary air, frequency of grating, temperature in POX chamber).

Thank you for attention

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