Biomass to Power and Heat

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Application of the GP750 Gasifier for Combined Heat and Power 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

Type of power generation	Cold gas efficiency η_{CE}, %	Gas to electricity efficiency, η_{cu}, %	Overall el. efficiency $\eta_{t'}$, %	Inst. costs thousands EUR/kW$_e$
1. Thermal plant with steam turbine (11 MW$_e$) (Zelený kotel, 33 MW$_t$), Plzeň	-	-	27,6	3,0
2. Thermal power station (35 MW$_e$) (Biomass combustion, 105 MW$_t$), Hodonín	-	-	~ 33	-
3. Two-stage gasifier prototype GP200 (0,2 MW$_e$) TARPO spol. s r.o., 2011	80–90	~ 32	~ 28*	3,3
4. Two-stage gasifier GP 750 (0,75 MW$_e$) TARPO spol. s r.o., AIR TECHNIC s.r.o., 2014	80–90	~ 36	~ 32**	3,7
5. Gasifier coupled with SOFC	~ 95	~ 45-65	~ 40-60	Very high

* Modified diesel engine: 6S160 ČKD Hořovice
** 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

char

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

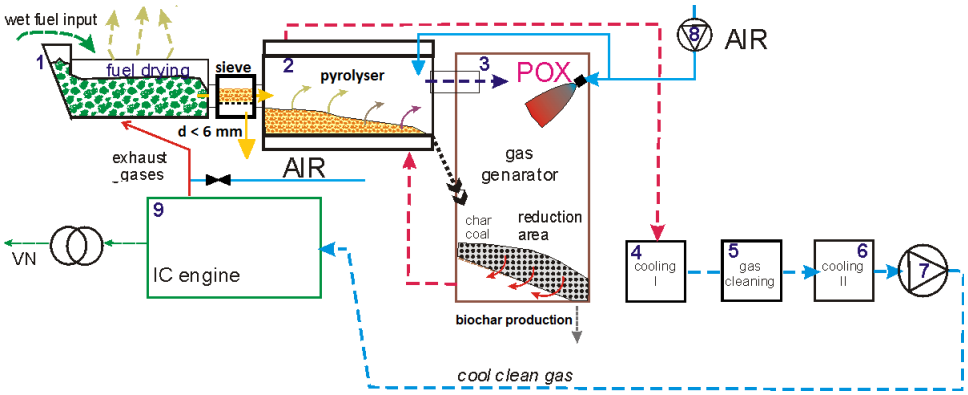
CO, H_2, CH_4, CO_2, H_2O, N_2

biochar

Installations of two-stage 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
Dobříš	Guascor, FBLD560	1xGP750	630 kWe	Experimental unit
Kněževes	ČKD, 2x6S160	2011- 2013, GP200	2x100 kW_e	2014 Replaced by pyrolysis unit
Odry	Jenbacher, 2xJ316	Since 2012 2xGP500	2x400KW_e	Operating at lower output: 2x400 kW_e
Olešnice	ČKD, 2x6S160	2013 GP200 03/2015 GP200XL	2x100 kW_e	Transformed to twin-fire

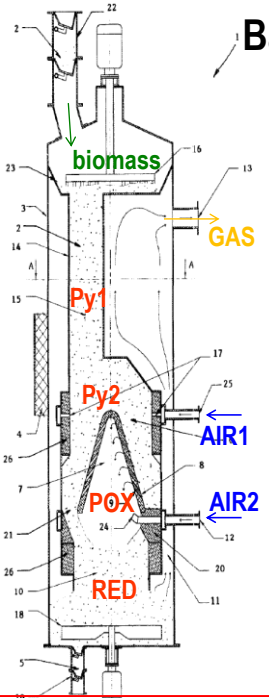
Principal scheme of the GP750 gasifier



Main parameters of GP750 unit used in Kozomín:

Nominal electric power	**710 kW**
Nominal wooden chips consumption (dry)	550 kg·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·kWh^{-1}**
Nominal electric output	**1,4 kWh·kg^{-1}**

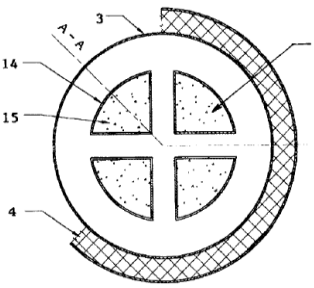
Basic description of GP750 gasifier



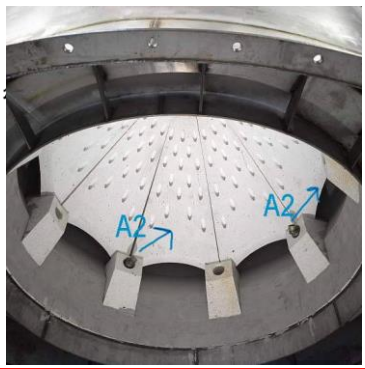
Gasifier	Dimensions of POX chamber		Volume	Flow*	Residence time*
	D,m	H,m	m^3	m^3/h	s
GP750	2,5	2,3	~4,0	~1300	~10

* Standard temperature and pressure

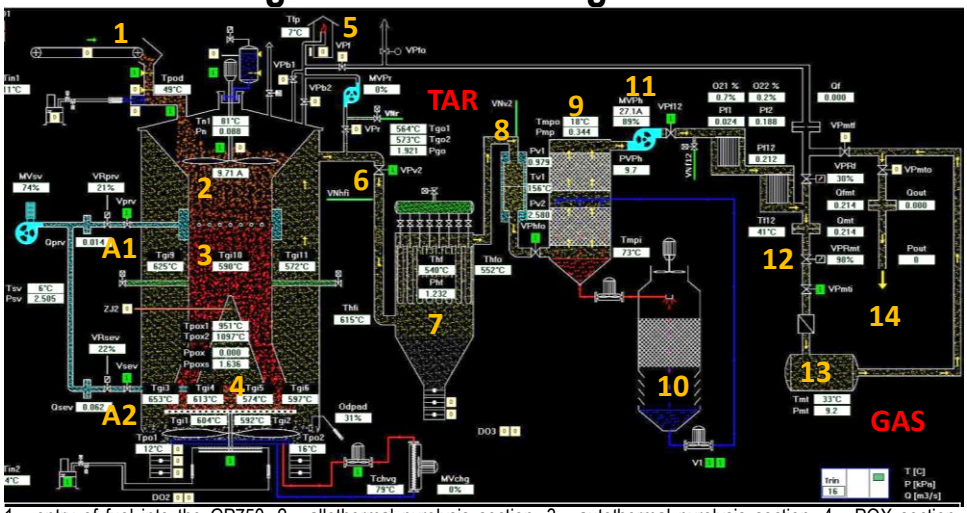
Pyrolysis zone



POX chamber



Technological flow sheet of gasification unit



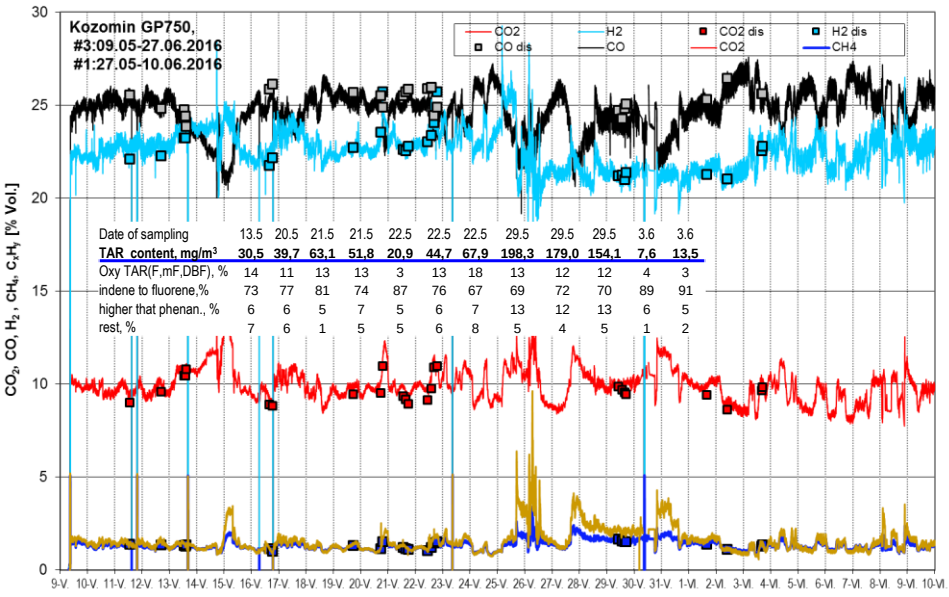
1 - entry of fuel into the GP750, 2 - allothermal pyrolysis section, 3 - autothermal pyrolysis section, 4 - POX section, 5 - combustion flare, 6 - gas output, 7 - candle filters, 8 - heat exchangers (gas/water), 9 - contact water cooling, 10 - cooling tower, 11 - gas blower, 12 - gas flow measurement , 13 - mix tank, 14 - pipe to IC motor.

A1- primary air supply, A2- secondary air supply

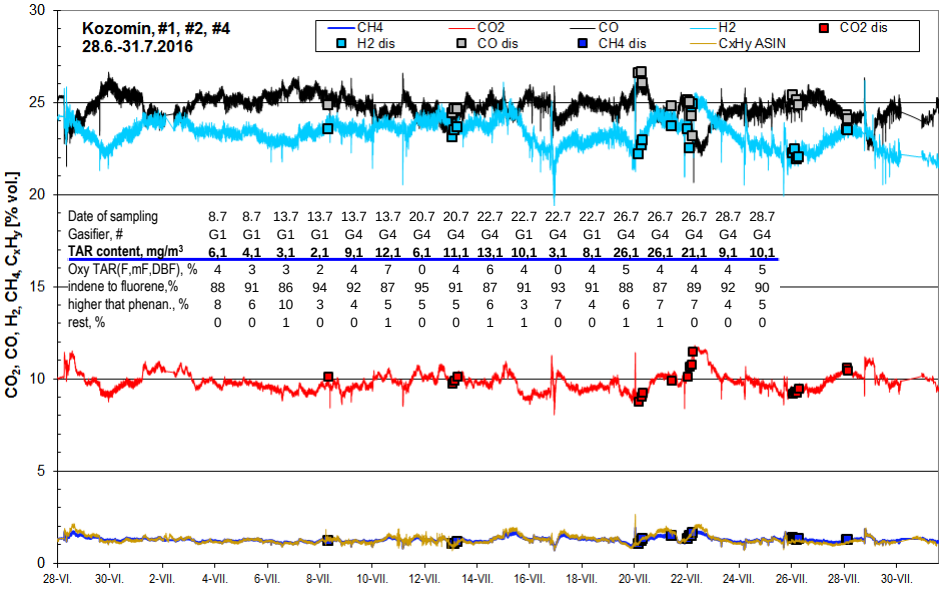
GAS - point for gas quality sampling (on-line, off-line), TAR - point for gas sampling according to the Tar Protocol

Combined heat and power plant in Kozomín

Gas composition June 2016



Gas composition July 2016



Date of sampling	8.7	8.7	13.7	13.7	13.7	13.7	20.7	20.7	22.7	22.7	22.7	22.7	26.7	26.7	26.7	28.7	28.7
Gasifier, #	G1	G1	G1	G1	G4	G4	G4	G4	G4	G1	G4	G1	G4	G4	G4	G4	G4
TAR content, mg/m³	**6,1**	**4,1**	**3,1**	**2,1**	**9,1**	**12,1**	**6,1**	**11,1**	**13,1**	**10,1**	**3,1**	**8,1**	**26,1**	**26,1**	**21,1**	**9,1**	**10,1**
Oxy TAR(F,mF,DBF), %	4	3	3	2	4	7	0	4	6	4	0	4	5	4	4	4	5
indene to fluorene,%	88	91	86	94	92	87	95	91	87	91	93	91	88	87	89	92	90
higher that phenan., %	8	6	10	3	4	5	5	5	6	3	7	4	6	7	7	4	5
rest, %	0	0	1	0	0	1	0	0	1	1	0	0	1	1	0	0	0

Effects of fuel properties on operation of GP750

Proximate and ultimate analysis of selected fuels

fuel properties	Handlová, 2014	Kozomín, 2015	Kozomín*), 2016	Kozomín, 2016
moisture, W^a	5.00	14.00	2.61	2.89
ash, A^d	1.08	2.78	1.03	0.98
volatile matter, V^d	79.75	78.80	78.84	78.21
fixed carbon, F_c^d	19.17	18.42	20.14	20.81
Q_i^a	16.94	14.72	16.71	17.23
Q_i^{daf}	18.16	18.02	17.40	17.99
ultimate analysis, ^{d}				
C	49.58	50.28	48.62	48.40
H	6.30	6.15	5.88	6.08
N	0.50	0.27	0.23	0.19
O	42.52	40.48	44.24	44.34
S	0.02	0.04	0.01	0.01

*)chips stored for long period in the open air

Mass and energy balance during long time operation

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·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·kWh^{-1}]	0,728	0,673	0,690	0,687	0,760	0,735
Overall efficiency [%]	**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**

Quality of different biochar samples produced by GP750

	Wooden chips			Biochar		
Related to dry sample	Hardwood	Softwood	Mix	Hardwood	Softwood	Mix
Combustible [wt.]	99,0	99,6	99,2	82,8	83,5	68,0
Ash content [wt.]	1,03	0,379	0,795	17,2	16,5	32,0
Volatile matter [wt.]	82,9	83,5	83,4	4,48	2,95	4,90
Fixed carbon [wt.]	16,1	16,1	15,8	78,3	80,6	63,1
Higher heating value [MJ·kg^{-1}]	19,0	19,2	19,3	27,9	27,3	21,0
Lower heating value [MJ·kg^{-1}]	17,7	17,9	18,0	27,8	27,2	20,9
Specific surface area (S_{BET}) [m^2·g^{-1}]	-	-	-	600	659	401
Specific mesopore area [m^2·g^{-1}]	-	-	-	238	261	-
Volume of micropores [mm^3·g^{-1}]	-	-	-	188	205	-

- Produced biochar does not contain any organic pollutants due to long residence time (several hours) in the high temperature zone (t > 600 °C)
- Textural properties of produced biochar are not dependent on a particle distribution
- Average specific surface area S_{BET} = 600 m^2·g^{-1}
- High volume of micropores assure good water retention abilities
- All samples of produced biochar fulfil requirements of the European biochar certificate

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/m³	**1000-2000**	**1300-2000**	**<5**	**0,5-2,0**	**5,0-40**	**20-200**
LHV (15 °C), MJ/m³	6,3	5,7	5,6	5,9	5,9	5,8

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 $mg \cdot m^{-3}$), HHV = 6,5 $MJ \cdot m^{-3}$ (Power production >32 % Netto).
- Gas treatment consists of: hot candle ceramic filters for particles removal and water scrubber for cooling < 40 °C.
- **High biochar quality (500-900 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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