

Supplementary content for

Evaluating Air Blown Gasification for Energy Recovery from Wastewater Solids: Impact of Biological Treatment and Point of Generation on Energy Recovery

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Simulation of power production with air-blown gasification

An ASPEN Plus ® model was developed to simulate an air-blown gasification system with electricity production using a reciprocating engine-generator (Fig. S1). Solids enter the system at 80% (wt) water content from an upstream centrifuge. The solids are dried in a direct-contact dryer where hot gases recycled from the syngas cooler and engine exhaust provide heat to evaporate water, drying the solids to 10% (wt) water content. Dried solids are briquetted and fed to the gasifier where they undergo a series of reactions (drying, pyrolysis, combustion, gasification). Air is introduced to the gasifier to combust a portion of the fuel, providing heat for the reactions. The quantity of air is determined dynamically by burning only the minimum amount of fuel solids to satisfy the gasifier energy balance. The syngas produced in the gasifier is cooled from the gasifier temperature of 850 °C to 150 °C by air in a heat exchanger. Cool syngas is cleaned by a bag filter (which is not modeled in detail) and a wet scrubber to filter particulates and condense tars. The cleaned gas is used to fuel a reciprocating internal combustion engine, which drives an induction alternator to produce electrical power. A utility burner is included to provide supplemental heat to the dryer by burning a portion of the syngas if energy in excess of that supplied by the recycled exhaust streams is necessary for drying. Dryer exhaust, containing recycled gases and evaporated water, is discharged to the surroundings at approximately 64 °C. Full details about system design, assumptions, modeling methods, and model validation can be found in Lumley et al. ¹

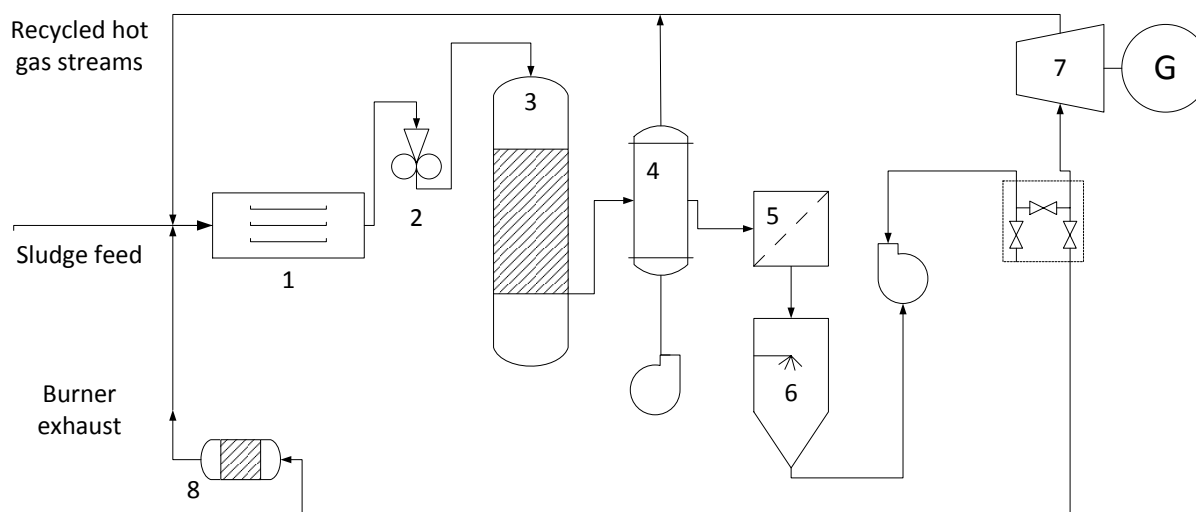


Fig. S1. Process schematic of Aspen Plus ® model of air blown gasification. Components of model include: 1. Dryer, 2. Briquetter, 3. Gasifier, 4. Syngas cooler, 5. Filter, 6. Scrubber, 7. Engine-generator, 8. Dryer heating burner.

The results from bulk solid analysis of all the samples collected at the WRFs are summarized in Table S1. The results of proximate and HHV are summarized in Table S2. And results of the model simulations for the three WRF feedstocks are summarized in Table S3.

Table S1. Summary of information about WWRFs included in the study. Design flow may exceed actual operating flows. Site 02 retains solids in the primary clarifier to increase the generation of organic acids, which are then used as carbon source for denitrification. Site 06 includes anaerobic pretreatment of high-strength wastewater followed by high-purity oxygen biological treatment, and aerobic stabilization of biological treatment solids. Site 01 is a decentralized, research WRF. Industrial discharges to municipal WWRFs contribute less than 10% of plant flows for the plants sampled.

Plant	01	02	03	04	05	06	07
Design Flow ML/d (mgd)	0.026 (0.007)	7.6 (2.0)	11.3 (3.0)	32.1 (8.5)	832 (220)	19 (5.0)	189 (50)
Preliminary Treatment	Coarse screen	Grit removal	Grit removal	Grit removal	Grit removal	Grit removal	Grit removal
Primary Treatment	Influent coarse screening	Clarification	None	Influent fine screening	Clarification	Clarification	Clarification
Biological System	SBMBR	Bardenpho	Extended aeration	Activated sludge	Activated sludge	Pure oxygen, Anaerobic	Trickling filter/ solids contact
Stabilization	None	Aerobic	Aerobic	Anaerobic	Anaerobic	Aerobic	Anaerobic
Disposal Method	City sewer	Land app.	Land app.	Land app.	Land app.	Compost	Land app.
Samples	PCS, WAS	AES, DWS	FOG, AES	PCS, WAS, ANS, DWS	PCS, ANS	PCS, AES, ANS, DWS	GCS, ANS, DWS

Table S2. Bulk analysis of each sample collected per Standard Methods 2450. Total suspended solids (TSS), volatile suspended solids (VSS) and fixed suspended solids (FSS) were conducted on samples with water content exceeding 99%. Total solids (TS), volatile solids (VS) and fixed solids (FS) were conducted on samples that could not be filtered with reasonable effort. In most cases TS exceeded 10%, with the exception of solids produced using dissolved air flotation (DAF).

Sample ID	TSS mg/L	VSS mg/L	FSS mg/L	TS %	VS %	FS %
WAS-01	8,767	7,353	1,413		83.9	16.1
PCS-01	10,422	9,405	1,017		90.3	9.7
AES-02	17,307	12,799	4,508		74.3	25.7
SCS-02	20,027	15,421	4,606		77.0	23.0
DWS-02				12.4	79.9	20.1
DDS-02 ¹				84.6	56.9	43.1
AES-03	10,781	9	1,883		82.5	17.5
SCS-03	13,128	11	1,973		85.0	15.0
DWS-03				19.0	83.8	16.2
FOG-03				11.4	85.8	14.2
PCS-04				11.9	93.4	6.6
DAF-04				4.8	81.8	18.2
DWS-04				20.0	76.2	23.8
WAS-04	9,505	8,254	1,251		87.4	12.6
PCS-05	48,697	42,845	5,852		84.3	15.7
ANS-05	22,451	14,973	7,478		67.5	32.5
APS-05 ²	37,557	32,294	5,262		86.0	14.0
DWS-05				20.2	76.9	23.1
DAF-05				5.2	86.3	13.7
WAS-07	5,452	4,380	1,072		80.2	19.8
ANS-07	24,568	16,721	7,847		68.1	31.9
PCS-07	1,589	1,208	381		76.4	23.6
GCS-07				34.6	83.8	16.2
DAF-07				5.9	85.3	14.7
DWS-07				18.1	69.6	30.4

Notes:

1. Solid sources: WAS – waste activated sludge; PCS – Primary clarifier solids including thickened primary solids; AES – aerobically digested solids; SCS – Secondary clarifier solids; DWS – dewatered solids (centrifuged); DDS – air dried solids (dried for more than 12 months); FOG – Fats, oils & grease; DAF – solids thickened by dissolved air flotation; ANS – anaerobically digested solids; APS – solids from acid phase of anaerobic digestion; and GCS – Grit chamber solids.

Table S3. Results of heat value, ultimate, and proximate analyses of 17 samples. Analysis was completed by a commercial, certified laboratory using ASTM protocol. All values are on dry weight basis.

Parameter	HHV ¹	LHV ²	Ash ³	Volatile Material ⁴	Fixed C ⁵	C	O (calc) ⁶	H	N	S
Units ⁷	BTU/lb	BTU/lb	%wt.	%wt.	%wt.	%wt.	%wt.	%wt.	%wt.	%wt.
GCS-07	7,396	6,829	21.82	69.29	8.89	44.08	23.60	6.12	3.61	0.77
FOG-03	10,357	9,610	11.39	81.49	7.12	55.62	20.11	8.05	4.18	0.65
PCS-01	8,345	7,745	8.73	86.46	4.81	46.91	35.51	6.46	2.02	0.37
PCS-04	10,067	9,363	5.73	88.07	6.20	52.42	30.96	7.60	2.74	0.55
PCS-05	8,496	7,848	8.15	81.16	10.69	48.88	31.30	7.00	3.56	1.11
Ave	8,969	8,319	7.54	85.23	7.23	49.40	32.59	7.02	2.77	0.68
SD	954	906	1.59	3.62	3.07	2.79	2.53	0.57	0.77	0.39
SCS-02	7,647	7,059	19.68	71.52	8.80	42.61	23.09	6.34	7.31	0.97
DAF-04	7,359	6,781	19.12	72.34	8.54	43.42	22.87	6.24	6.97	1.38
WAS-01	7,729	7,183	17.15	70.64	12.21	41.24	26.63	5.59	8.03	1.36
WAS-04	7,258	6,681	16.70	72.82	10.48	43.60	24.13	6.22	8.17	1.18
Ave	7,498	6,058	18.2	71.84	11.06	39.93	21.65	5.73	7.82	1.04
SD	225	698	1.5	0.96	3.74	1.73	1.93	0.54	0.33	0.46
AES-02	7,068	6,511	22.45	68.33	9.22	40.46	22.50	6.01	7.65	0.93
DWS-07	6,499	5,986	23.66	61.45	14.89	38.88	23.72	5.54	7.36	0.84
DWS-02	6,816	6,246	20.26	69.81	9.93	42.05	22.57	6.15	8.03	0.94
DWS-04	7,216	6,651	22.87	70.75	6.38	40.67	20.66	6.09	7.87	1.84
Ave	6,900	6,349	22.31	67.59	10.11	40.52	22.36	5.95	7.73	1.14
SD	14	294	1.46	4.21	3.54	1.30	1.27	0.28	0.29	0.47

Notes:

1. High Heating value: assumes heat lost due to formation of water vapor in combustion is recovered.
2. Low Heating Value: includes loss of heat due to water vapor formed as part of combustion.
3. Ash is measured as residue remaining after burning the sample at 750 °C.
4. Volatile matter is determined by burning the sample at 950 °C.
5. Fixed carbon is calculated by subtracting the sum (expressed as percentages) of moisture, ash, and VM from 100.
6. Oxygen content is calculated by subtracting the sum of the percentages of ultimate analysis elements and the ash content from 100.
7. All values are dry weight basis.

References

1. Lumley, N. P. G.; Ramey, D. F.; Prieto, A. L.; Braun, R. J.; Cath, T. Y.; Porter, J. M., Techno-economic analysis of wastewater sludge gasification: A decentralized urban perspective. *Bioresour Technol.* **2014**, *161*, 385-394.