MSW fired indirect combined cycle plant: A novel solution to waste management and power for India

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”A world in transformation”

Large-scale shifts in the global energy system :

- Rapid deployment of clean energy technologies
- Falling cost of renewables
- Solar, Wind, Hydro and Biomass lead the RE campaign

”The boom years for coal are over ” – **World Energy Outlook 2017**

”Global energy demand is 30% higher by 2040”– **WEO 2017**

We are on a hurried path of changes

Issues with Renewables

Diverse sources: Sun, air, water, biomass, geothermal

Equally diverse technologies for energy conversion

Varied resource mix at country or region levels

Different levels of development and maturation

Most technologies at low conversion efficiency

Technologies have different carbon emission implications

Not yet fit to cater to base load continuous generation

No uniform formula to decide right energy mix

Waste Conversion: Clean-Tech!

Waste conversion fits in well as a competing clean technology

Municipal Soloid Waste (MSW) is considered as local sources for a city or municipal area (self-sustaining too, in the sense that city keeps on generating resources on daily basis, generation volume predictable)

Traditional biomass conversion technologies like combustion and gasification, also apply to MSW. Besides that, MSW conversion has inherent disposal solution

Present work

Here we present the configuration, thermal design and analysis of a combined cycle plant, fuelled by segregated municipal solid waste (MSW).

Energy, exergy and environmental (3-E) analysis along with optimization study of the plant is carried out and reported.

Present work

We took the city named Chandanagar (22.87°N, 88.38°E), a highly populated municipal area, located near Kolkata and governed by a municipal corporation, as the case study.

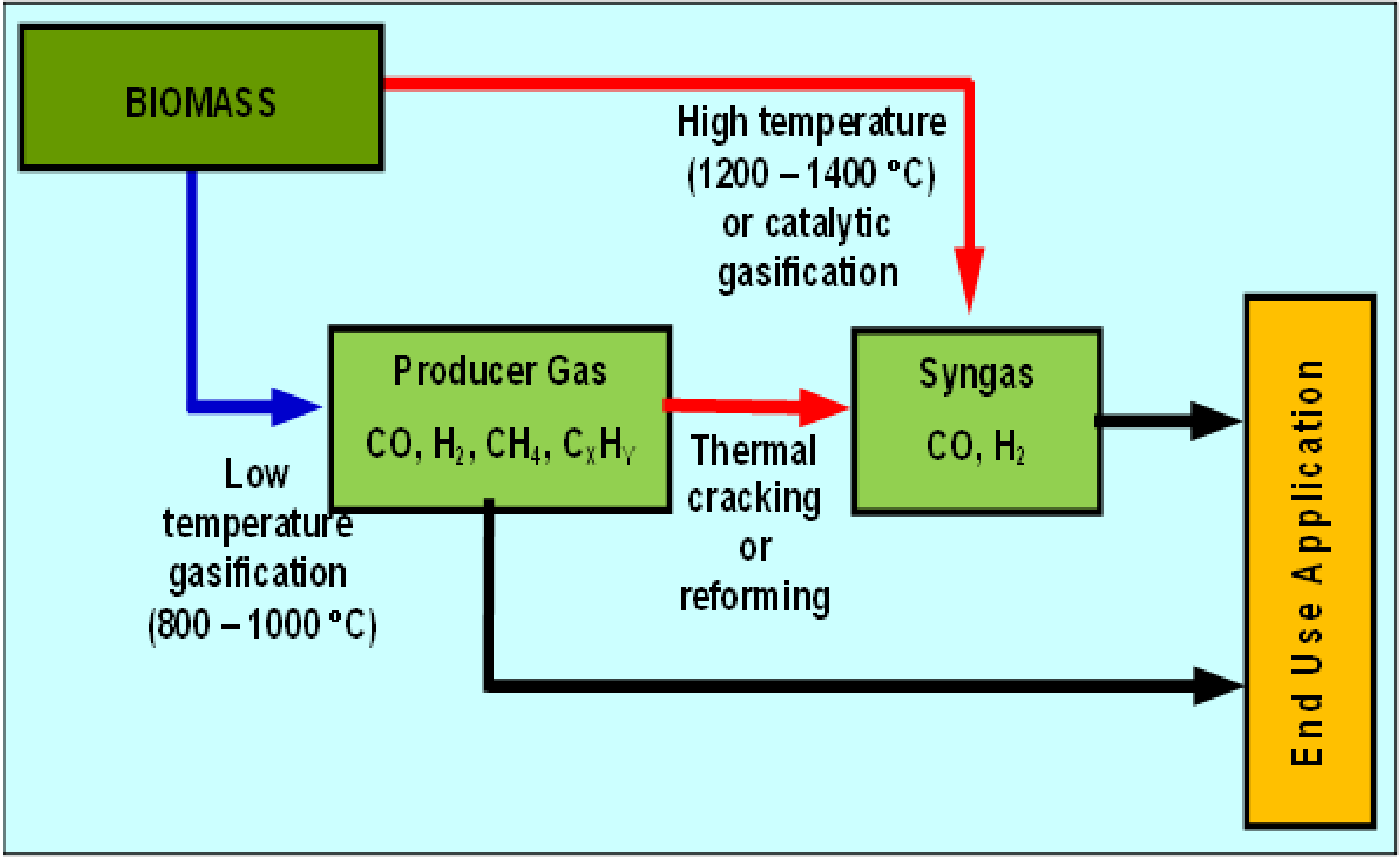
As per the report of the Chandanagar Corporation, about 46 tonnes of raw waste is generated on a daily basis (2017-2018)

Waste disposal

MSW Analysis

Proximate Analysis	**Ultimate Analysis**	**LHV theoretical**	**LHV actual**
C: 40-50 % H: 5.5-6.6 % O: 30-35 % N: 0.6-1.2 % S: 0.1-0.5 % Cl: 0.9-1.7 % Ash- Rest	Volatile matter: 50-80 % Fixed carbon: 10-18 % Ash: 6-12 % *Heavy metals* Cd:1 % Cr: <10 % Hg: 0.002% Pb: 39% As: <1% Se: <0.005%	14668.77 (kJ/kg)	13566.7 (kJ/kg)

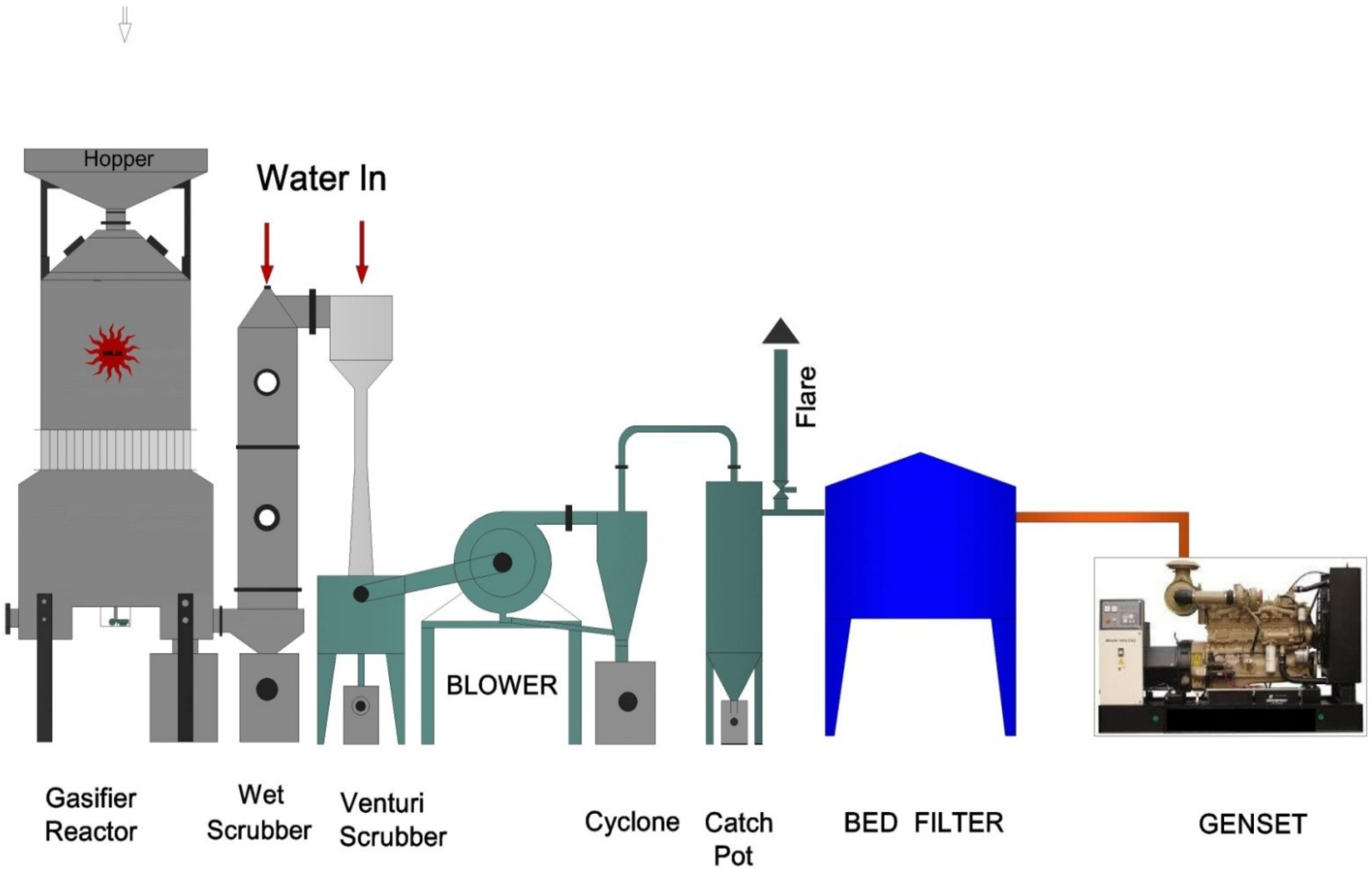
Gasification: A versatile route



Gasification

- A thermo-chemical process in which solid biomass is partially oxidized to yield combustible producer gas.
- Major components of producer gas: CH_4, H_2, CO, CO_2, H_2O and N_2.
- LHV of Producer gas 4-6 MJ/N m^3 (gasifying agent Air)
- LHV of Producer gas 12-18 MJ/N m^3 (gasifying agent Steam/Oxygen)

Gasifier-Gas Engine: A popular generation option



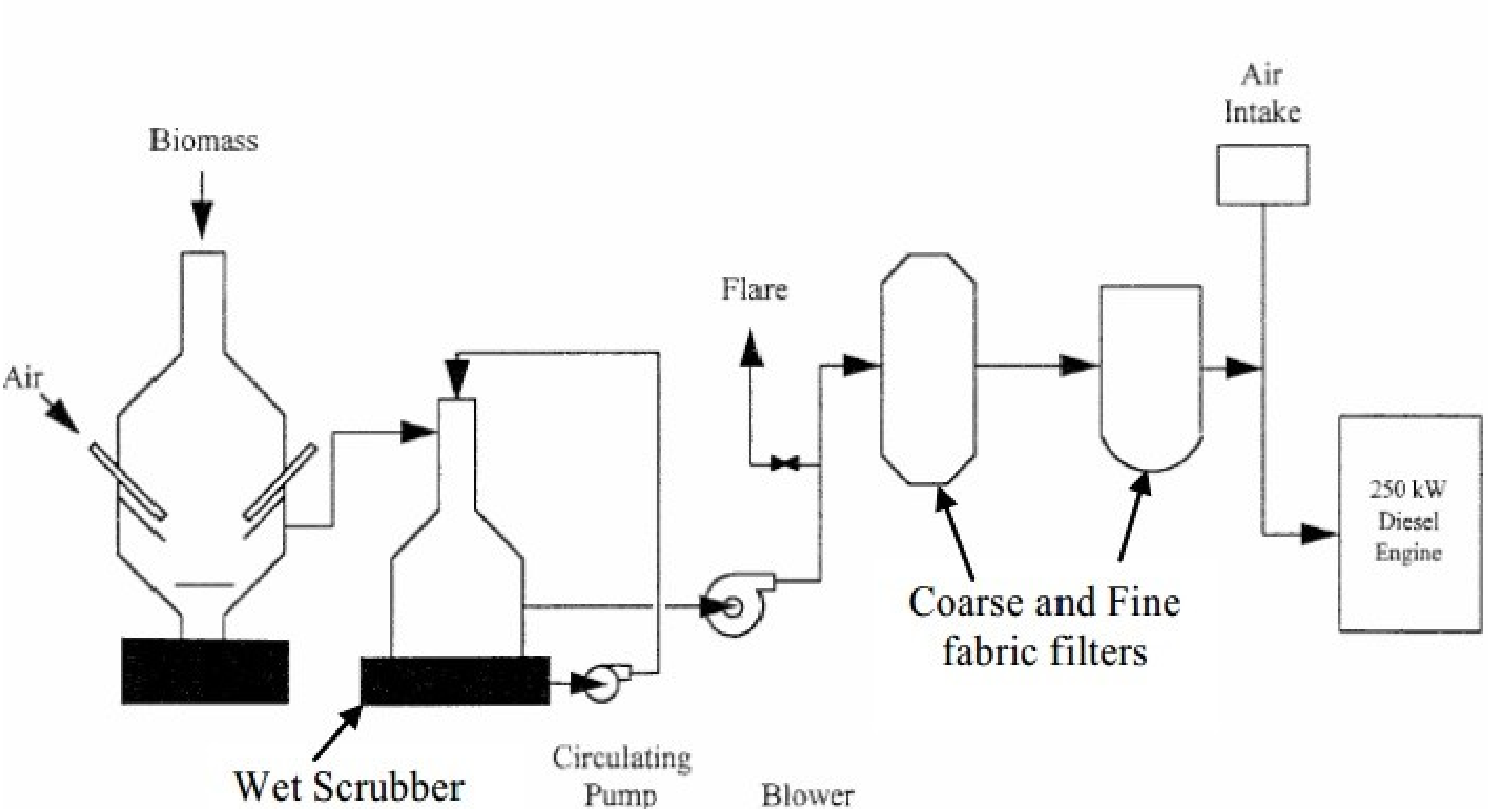
Disturbing Issues

Low Overall efficiency (16-20%).

Extensive gas cleaning and cooling requirement.

High cost of operation and maintenance.

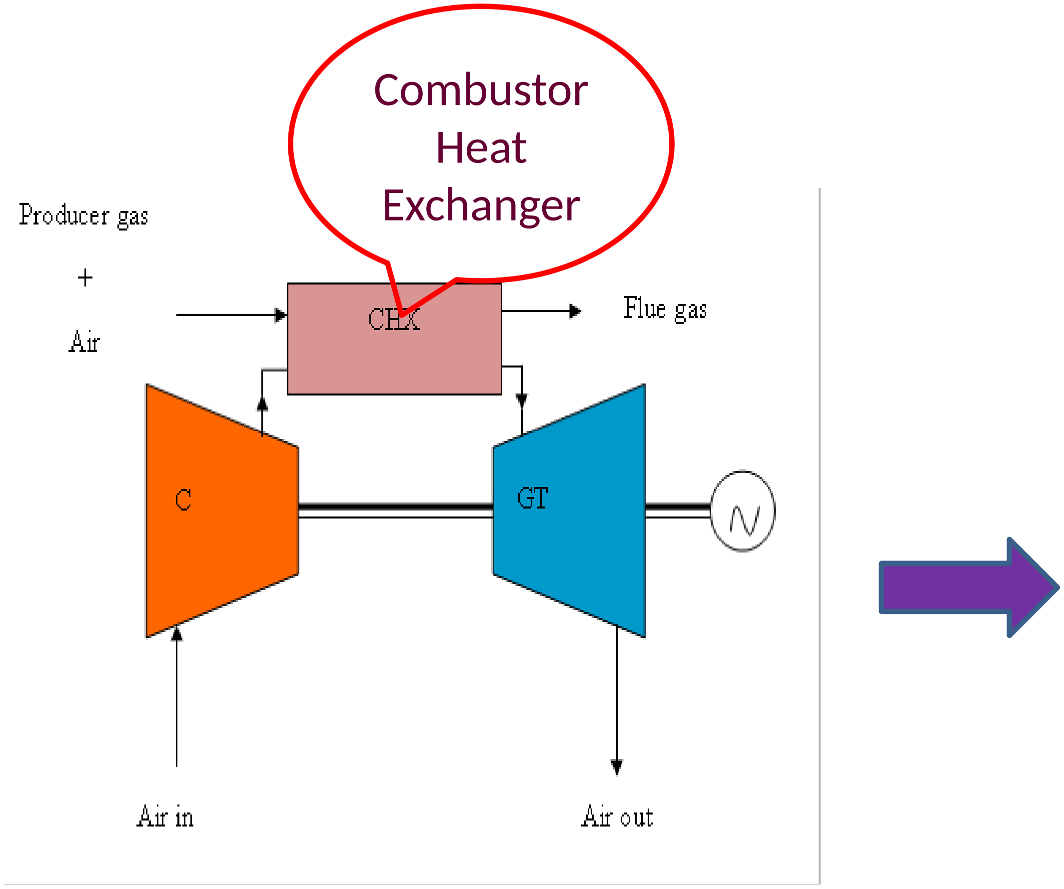
Gas Cleaning



Cleaning needs for ICE/GT

Impurities	*Unit*	*IC Engines*	*Gas Turbines*
Particulates (size)	mg/Nm3 (µm)	<50 (<10)	<30 (<5)
Tars	mg/Nm3	<100	<10.0-
Alkali metals	mg/Nm3	<0.1	<0.1
N species	ppm(v)	-	<50
S species	ppm(v)	<20	<20
Halides	ppm(v)	-	<1

Replace Fired Engine/GT with indirect Heating



No fired GT

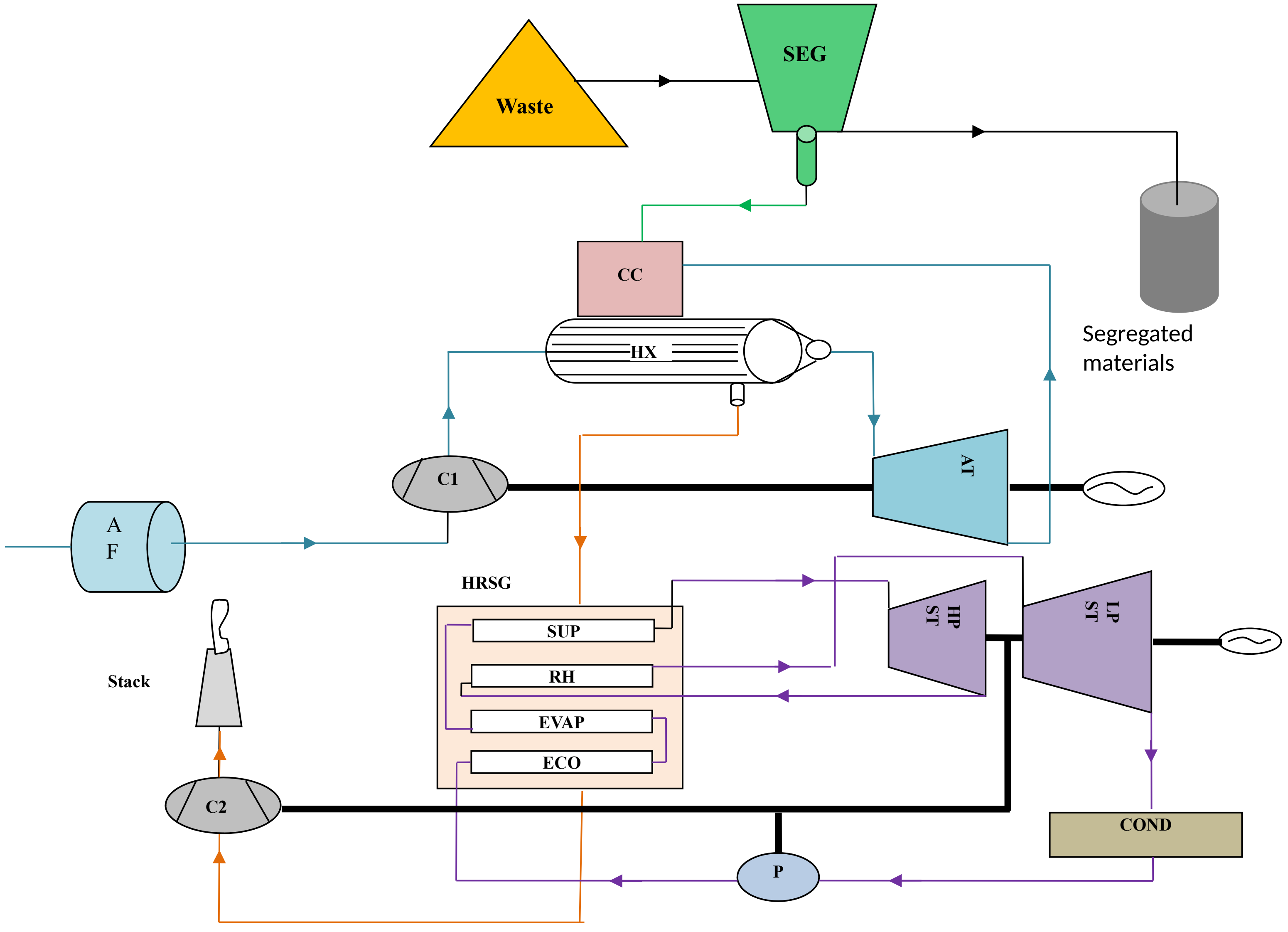
No corrosion and erosion , particulate deposition : GT safe

No need of gas cooling & cleaning

Clean GT exhaust; recyclable

Operates on low-cost and dirt fuels

Externally Fired Combined Cycle



MSW Combined Cycle: Model

Net power output from the plant is calculated as

$$W_{net} = \{(W_{GT} - W_{C1})\eta_{gen1} + (W_{HPST} + W_{LPST} - W_{P})\eta_{gen2}\} - W_{C1}.\eta_{gen3}$$

Overall electrical efficiency of the plant is calculated as

$$\eta_{overall} = W_{net} / m_{waste}.LHV_{waste}$$

Annualized electricity delivered ($MW_e h$) by the plant is determined as

$$P_{annual} = W_{net}.CUF.8760.(1 - L_{distribution\ network})/1000$$

CUF represents Capital Utilization Factor (taken as 0.5, as the plant operating hour is 12 h a day basis)

MSW Combined Cycle: Model

Exergetic efficiency of the plant as well for the plant components is calculated as:

$$\eta_{ex} = \frac{Ex_{product}}{Ex_{fuel}}$$

The specific fuel exergy is given by

$$Ex_{waste} = \beta . LHV_{waste} \qquad \beta = \frac{1.044 + 0.016(H/C) - 0.34493(O/C).(1 + 0.0531.H/C)}{1 - 0.4124.(O/C)}$$

Environmental performance of the plant is evaluated via determining the specific CO_2 emission as well as the sustainability index (SI).

$$\xi_{CO_2} = \frac{N_{CO_2}.44.3600}{W_{net}} \qquad SI = \frac{1}{(1 - \eta_{exergetic,plant})}$$

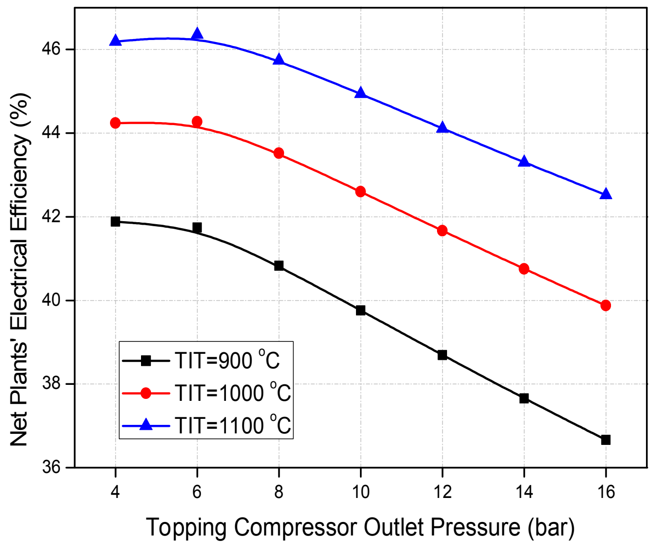
Parametric Assumptions

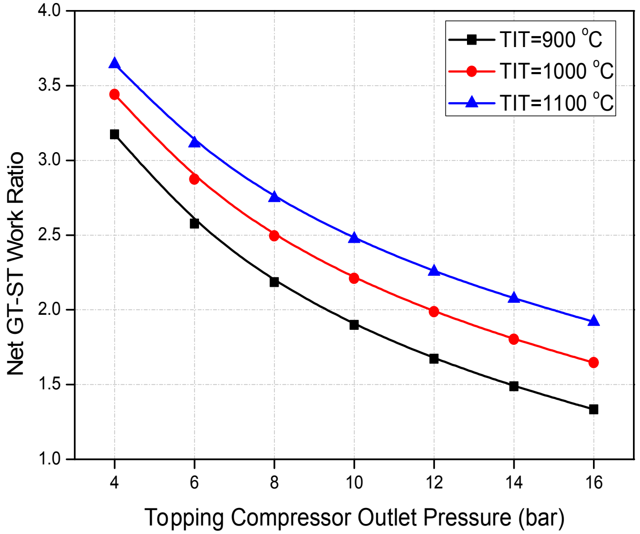
Component	Parameter/s	Value	Ref
CC	Operating pressure (bar)	1.013	*Mondal & Ghosh 2017 [21]*
	Pressure drop (bar)	0.05	*Datta et al., 2009 [22]*
HX	Pressure drop at air side	3 % of inlet pressure	*Datta et al., 2009 [22]*
	Pressure drop at gas side	1.5% of inlet pressure	
C1	Isentropic efficiency (%)	87	*Mondal & Ghosh 2017 [21]*
C2	Isentropic efficiency (%)	90	
GT	Isentropic efficiency (%)	86	
	Mechanical Efficiency (%)	95	
HPST	Isentropic efficiency (%)	85	*Mondal & Ghosh 2017 [21]*
	Inlet pressure (bar)	18	
	Inlet temperature (^{o}C)	320	
LPST	Isentropic efficiency (%)	85	
	Inlet pressure (bar)	5 (18% of HP)	
	Inlet temperature (^{o}C)	300	
HRSG	Pinch point temperature difference of the Evaporator (^{o}C)	10	*Mondal & Ghosh 2017 [21]*
Cond.	ST exhaust pressure (bar)	0.1	*Mondal & Ghosh 2017 [21]*
P	Isentropic efficiency (%)	85%	
Other assumptions			
Environmental damage cost due to CO_2 emission		0.0145 $/kg	*Jana & De, 2015 [23]*
Environmental damage cost due to land filling		12.8 Euro/t of waste	*Rabl et al., 2008 [9]*
Plant operating hours		12h-a day basis	
Loss in transmission line		5%	

Base Case Performance

Parameter	Unit	Value
Net GT output	kWe	2327.31
ST1+ST2 output	kWe	913.28
Net GT-ST work ratio	----	3.44
Net electrical efficiency	%	44.236
Annualized electricity delivered	MWh	12498.73
Electrical specific CO_2 emission	kg/kWh	0.96
Sustainability index	----	1.62
Environmental damage cost due to CO2 emission from the plant	$/Y	168845.6
Environmental damage cost due to land filling	$/Y	247148.8
Environmental savings compared to land filling	$/Y	78303.2

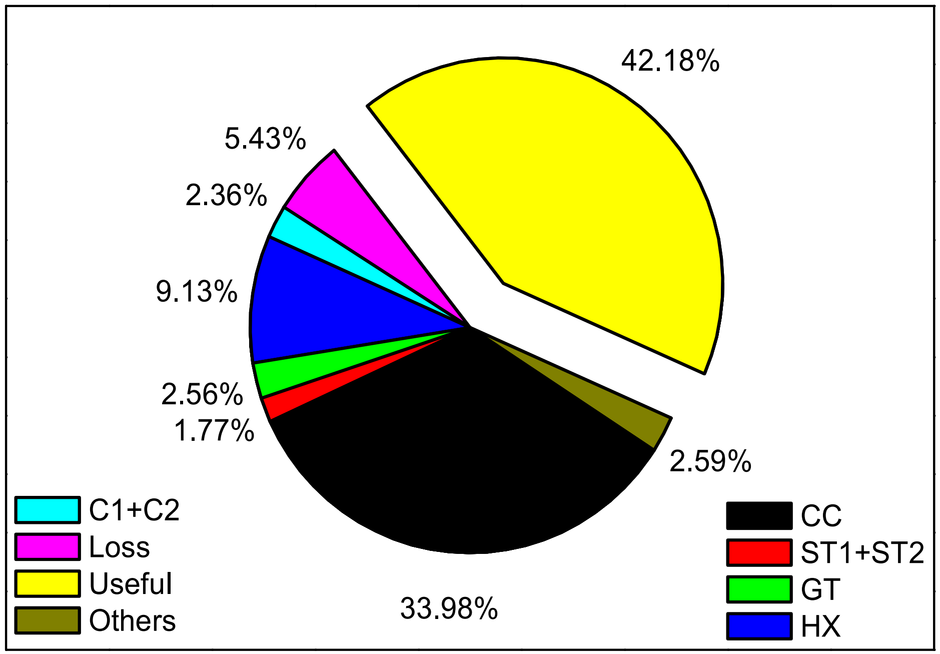
Parametric performance





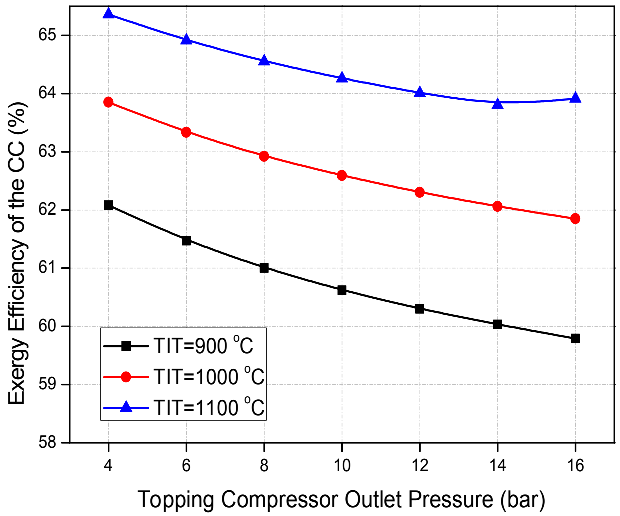
Energetic performance at varying pressure ration of GT

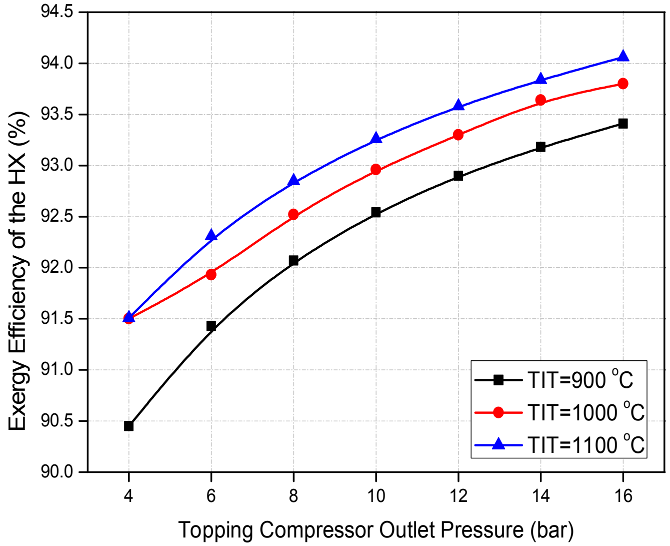
Parametric performance



Exergy destruction and useful exergy

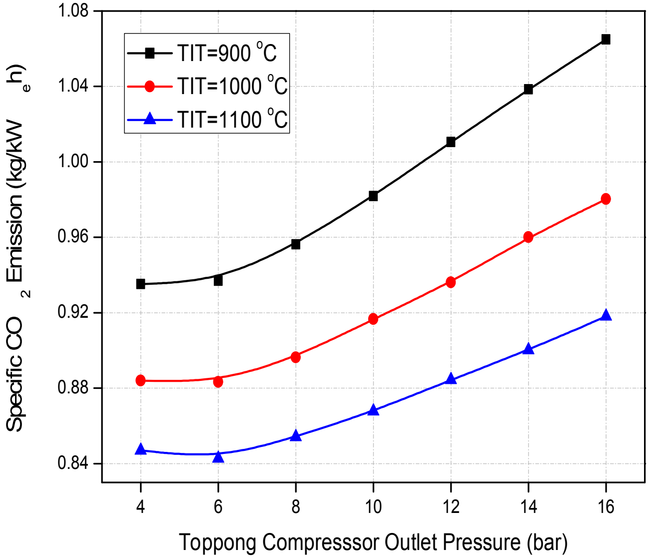
Parametric performance

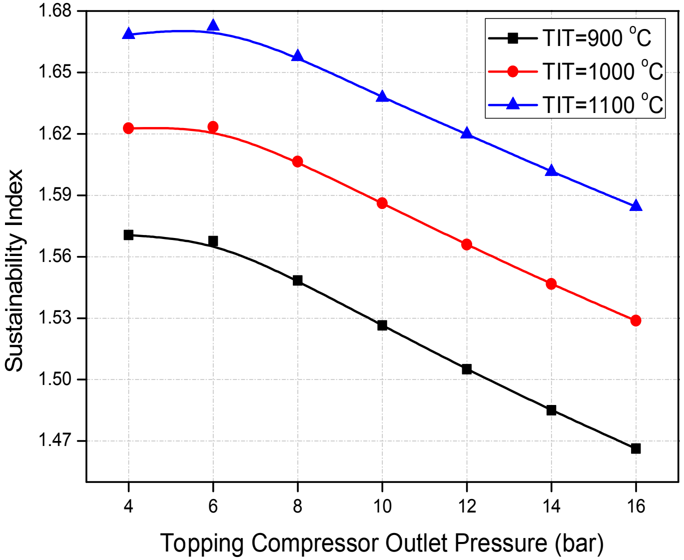




Energetic performance of CC and HX varying pressure ration og GT

Parametric performance





Environmental performance: Specific CO_2 emission as well as the sustainability index (SI).

Conclusion

The study confirms that, such kind of small scale off-grid plant can be beneficial for both sustainable MSW management as well as generation of electricity from MSW to meet the utility power need of the city.

It is observed that, the plant can produce 3 MWe net electrical output at an overall efficiency value of about 44% giving annual production of about 12500 MWh. The specific CO_2 emission is 0.96 kg/kWh and SI value is 1.62 at base case.

Furthermore it is observed that, annual environmental damage saving is about 78303$ at base case.

Thank you

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