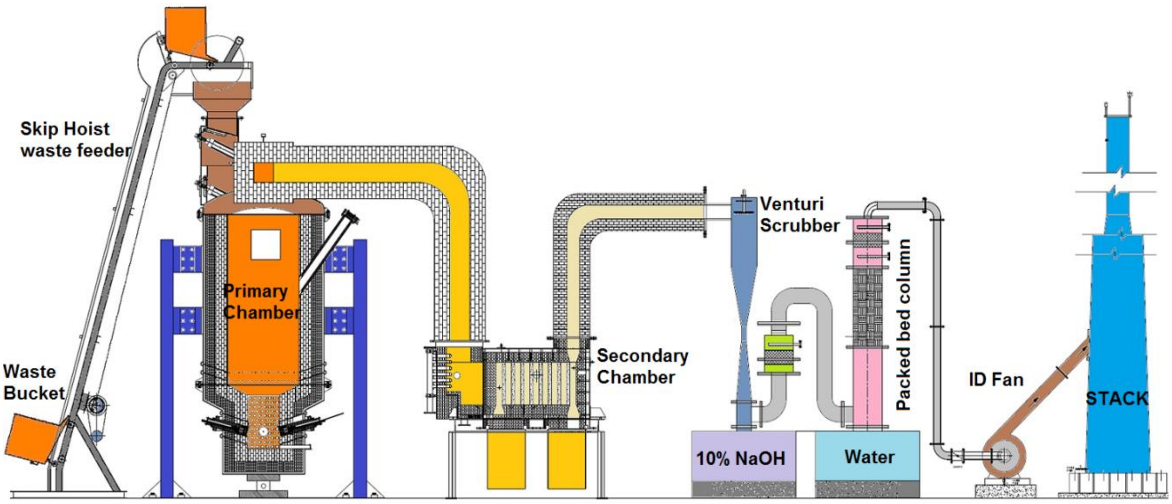
Introduction

Breaking of organic bonds using extremely hot air in an oxygen deficient environment, and conversion of the organic material into fuel gas (called syn gas, similar to CNG used in cars but consisting of mainly CO and H_2) is called gasification. Plasma gasification technology provides an attractive and universal means to treat most types of waste including municipal, nuclear and other solid wastes in an environment friendly manner. Usual low temperature burning has the issues of producing carcinogenic substances like dioxin, furan and other pollutants like NO_X and SO_X. Poor waste to gas conversion, high ash content in residue, slow process rate and no generation of fuel gas are some of the drawbacks of incineration. Gasification is different from incineration as no pollutant is generated and synthesized gas (syn gas) can be used as fuel for heat/electricity generation. The developed technology of Air Plasma Incinerator adopts a judicious combination of the two in which it does high temperature gasification at the bottom of the primary chamber and allows controlled burning of the produced syn-gas at the top to supply energy required for the process. The technique drastically reduces requirement of external supply of energy and mitigates waste in an environment friendly manner extracting energy from the waste itself. Achieved waste process rate in the developed system is of the order of 1-3 ton per day depending on the type of waste.

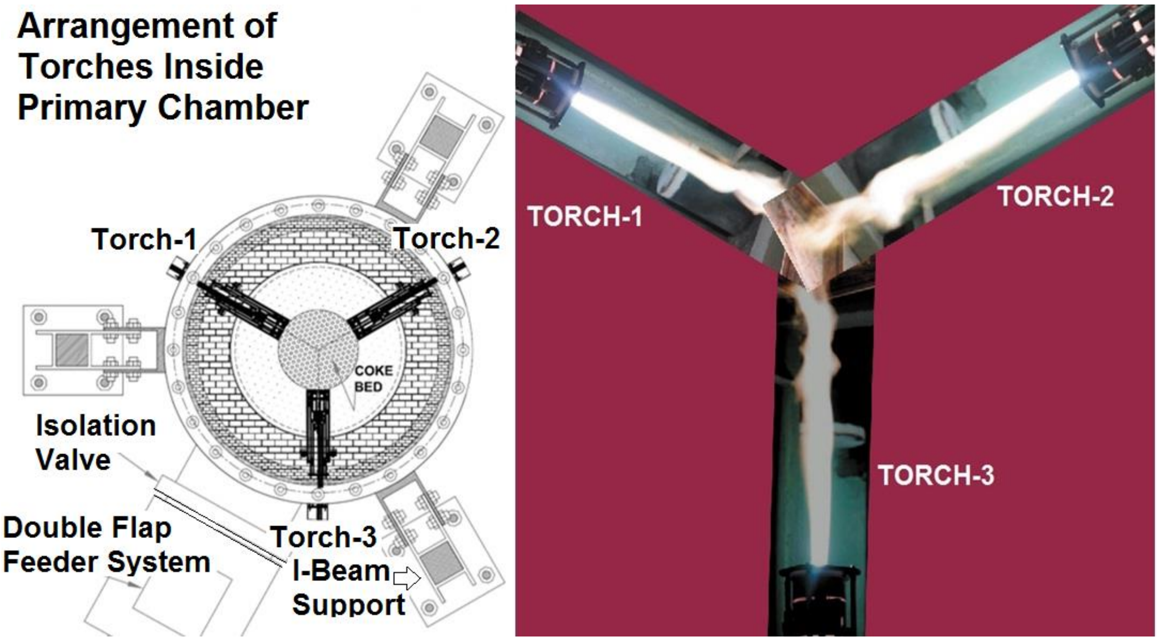
Components



Components of 60 kW Triple Torch Air Plasma Incinerator

The basic components of the unit include waste feeder unit, primary chamber, secondary chamber, venturi scrubber, packed bed column, id fan unit and a stack. Waste is fed from the side at the top of the primary chamber. The id fan unit maintains a negative pressure throughout the process zone and does not allow any synthesized gas to come out from the process chamber. Three air plasma torches oriented azimuthally 120 degree apart discharge inside a coke bed at the bottom of the primary chamber and form a highly uniform very high temperature process bed of temperature in excess of 1500 ^{o}C. A skip-hoist waste loader drops the wastes at the hopper which eventually reach the bottom of the primary chamber via mechanically interlocked double door compartments, a pusher and a heat blocker gate.

Air Plasma Torch Technology



Three plasma torches discharging inside coke bed of primary chamber

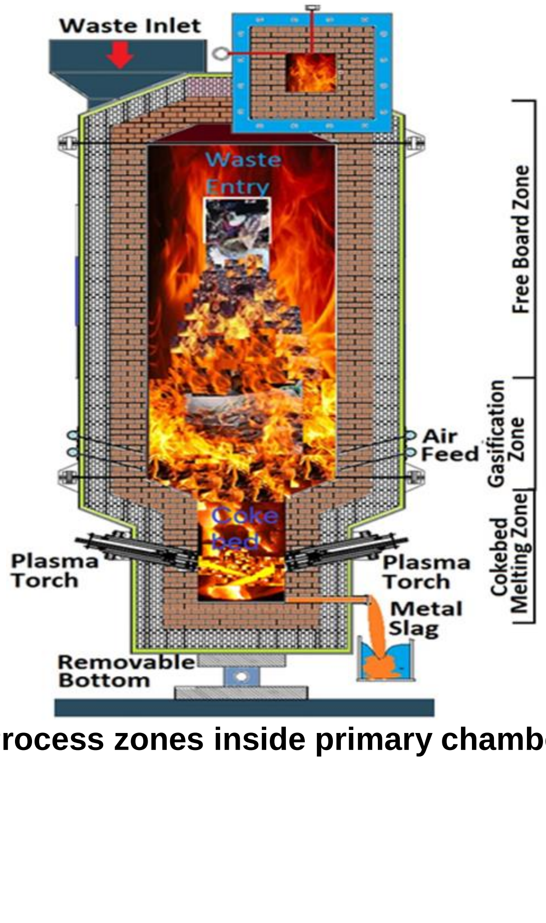
The primary prerequisite for processing waste (organic and inorganic) in an environment friendly manner using gasification technology is the 'availability of high temperature'. Higher the temperature better is the conversion of waste into fuel gas and lower is the harmful emission. Over the years it has been established that an arc plasma jet, a beam of huge concentrated thermal energy at very high temperature consisting of electrons, ions and neutrals, can meet the high temperature requirement of gasification process in a most convenient manner. Air plasma torches are the most suitable in this regard as they take air, freely available in environment and convert that into plasma jet. The offered technology uses three air plasma torches (Patent# 201721012999, Technology transferred), oriented azimuthally 120 degree apart, to produce beams in the form of an intensely luminous extremely hot radiating atmospheric pressure cylindrical plasma jet controlled in terms of its length, diameter, velocity and power content. The three plasma jets meet at the centre of a coke bed to produce uniformly heated very high temperature coke bed process zone for gasification. Low device cost, low operational cost, simple design, use of cheapest gas (air), high efficiency (>60%), high temperature (~8000 K at the anode exit) and ease of control are some of the key features of the air torch technology developed by BARC.

Environment Friendly Mitigation

High temperature of the coke bed immediately breaks all the organic bonds inside the waste material as soon as it interacts with the extremely hot coke bed at the bottom of the primary chamber. Released hydrogen atoms combine to form hydrogen gas. In presence of carbon in coke bed, controlled supply of oxygen through air converts carbon to carbon monoxide and strongly restricts formation of NO_x and SO_x. Formation of carcinogenic dioxin and furan is eliminated first by breaking associated bonds at high temperature coke bed, followed by fast quenching in the quencher unit above the venture scrubber. Particulates are efficiently separated in by the venturi scrubber and eventually deposited as slag at the bottom tank. Residual acidic gases are scrubbed in the spray column of alkaline solution sprayed at the top of the venturi. The cooled off gas is further scrubbed in the packed bed column using water before releasing to the stack.

Design Specialty of the Primary Chamber

The primary chamber is specially designed with an aim to run the system with maximum possible extraction of energy from the waste itself. It has three distinct zones: the very high temperature coke bed zone at the bottom, the gasification zone above it and the free board zone at the top. The chamber is equipped with equi-spaced air injection ports at various levels to facilitate extraction of energy through controlled burning of produced syn gas in the gasification zone. Continuous supply of energy through this mechanism not only has the potential to meet the requirement of energy in the process but also can generate additional energy to be utilized for other processes like generation of steam, production of electricity etc. Presence of plasma torches facilitates assured supply of external energy as and when required. Under self sustained mode with continuous feed, no supply of external energy is required for wastes like municipal solid waste (MSW).



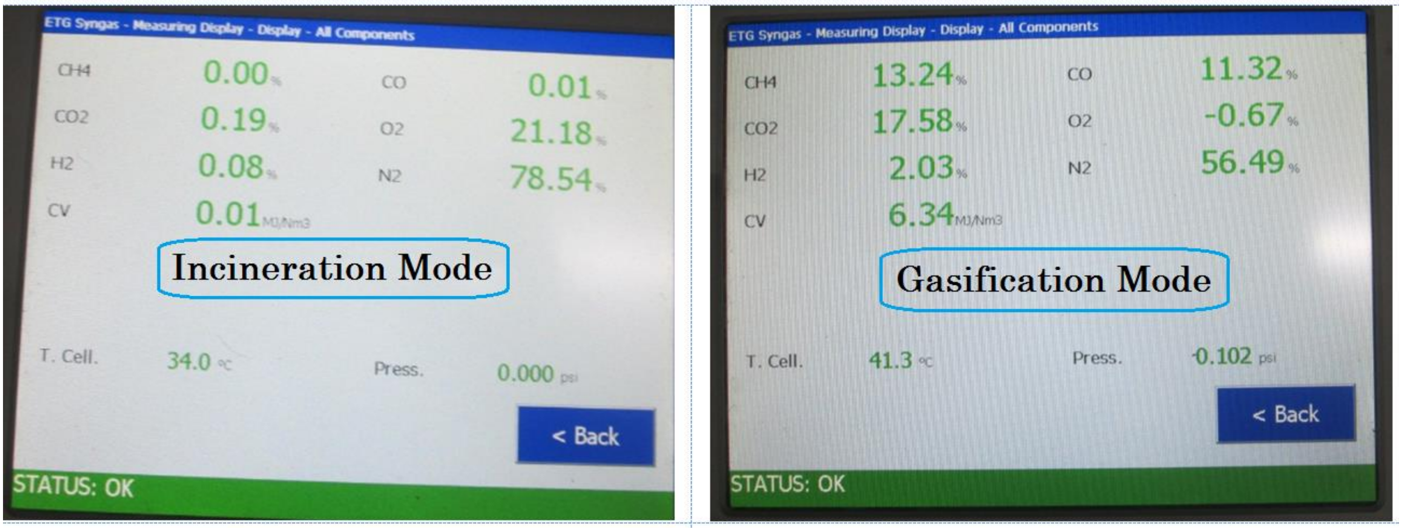
Process zones inside primary chamber

Advantages

1. **Oxygen starved environment**: Limits production of harmful gases like NO_x, SO_x, CO_2
2. **High temperature plasma and sudden quenching:** Gives ability to break chemical bonds. Does not allow formation of Dioxin & Furan. Makes it suitable for hazardous waste
3. **Very high solid to gas conversion efficiency:** Due to vigorous reaction in presence of species in atomic and ionic state. Very little amount of residue. Reduced landfill.
4. **Faster conversion:** Higher the temperature better is the concentration of active species (atoms and ions). Faster is the reaction.
5. **Syn gas:** Produced high quality fuel gas (CO + H_2) under gasification mode can run gas engine and produce electricity from waste.
6. **Low carbon foot print:** No burning of fossil fuel
7. **High energy density:** **Compact reactor**
8. **Relatively low device and peripheral cost**: Reduced installation cost.
9. **Low operational cost:** Light weight portable compact device: easier handling.
10. **Low maintenance cost:** Simpler design, easier maintenance
11. **Longer plasma jet (>300 mm):** better plasma waste interaction volume.
12. **Low gas flow requirement (~20 slpm in each torch):** Reduced cost of gas delivery and effluent gas treatment.

Emission Features

The system can be operated in both incineration and gasification mode. Under incineration mode the measured emission of harmful gases like CO, SO_X, NO_X are found well with the permissible limit by CPCB. The syngas generation mode in the system gets activated once all the external air inlet ports are closed. Obtained syn gas (total of CH_4, CO and H_2) quality meets the energy content of more than 6.3 MJ/Nm^3.



Safe emission in Incineration mode and good syngas quality in gasification mode

Tech Specs

1. Plasma torch

Diameter	Length	Plasma exit bore	Weight	Coolant connector	Gas connector	Electrical connector type
96 mm	250 mm	15 mm	4.5 kg	1/4 inch BSP	1/4 inch BSP	Plate type with central bore (10 mm)
No. of gas connectors	No. of elec. connectors	Current supply	Anode elec. connection		Cathode elec. Connection	Coolant connection
3	4	Dc: 50A to 300 A	Negative of DC Supply		Ground of DC supply	Source: looped Constrictor: separate Anode: separate
Cathode type	Anode type	Cathode cooling	Anode cooling		Constrictor cooling	Maximum coolant temperature
Button type Hafnium in copper matrix	Electrolytic copper	Forced water jet cooling	Annular channel flow		Annular channel flow	50

2. Power Supply

Type & Line supply	Open circuit voltage	Maximum current	Ripple	Control knobs	Indicator
Constant current supply: Electrical line Supply: 400V(±10%), 200A 50Hz(±5%), 3 phase AC	200 V	300 A	<5% of supply current	1. Current control 2. Shut down 3. Emergency stop	1. Fault indicator 2. Line supply status 3. Load current 4. Load voltage

3. Air Supply System

Capacity	Discharge pressure	Filter
275 cfm of air at a pressure of 8 bar.	Work: 7 bar Max: 10 bar	Oil content <2 ppm Moisture content < 1ppm

4. Coolant Supply System

Type	Capacity	Inlet & outlet temperature	Control and display
Outdoor, weather proof, Industrial process cooling system	200 liter per minute at 7 kg/cm^2 of pressure	Inlet: 30-50 C Outlet: 15-30 C	1. Set temperature 2. Coolant temperature 3. Compressor status

5. Arc Ignition, Control and Monitoring System

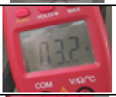
HF ignition	Spectrometer	RTD sensor	Coolant Flow meter	Gas flow meters
3 kV 3 MHz	Spectral range: 400 nm to 480 nm Resolution: 0.05nm	Range:0-100 C Accuracy: 0.1C	Range: 0-30 lpm Accuracy 0.25 lpm	Range: 0-100 lpm Accuracy: 2.5 slm

Capacity, Investment & Unit Cost of Production

[* Figures given are only indicative and for a rough estimate only. Actual cost may vary depending on market rate.]

Sl.	Subsystem	Component	Subcomponents	Cost (Rs.)
1	Plasma Torch	Plasma source	Hafnium cathode	7000.00
			Cathode holder	5000.00
			Gas Injection ring	3000.00
			Teflon core	7000.00
			SS housing	4000.00
			Copper nozzle	5000.00
			Brass cup for nozzle housing	5000.00
			Electrical and flow tubing	5000.00
			Copper shroud gas injection ring with distributor cavity	6000.00
		Constrictor	Constrictor with coolant channel, electrical and flow connectors	15,000.00
		Anode	Do	15,000.00
		Teflon rings	O-rings with machined grooves 4 Nos.	10,000.00
		SS-Holder plates	2 Nos.	4,000.00
		Holding studs	4 No s with bolts	2,000.00
			Plasma source cost (per torch)	93,000.00
			Total Source cost for three torches (Rs.)	279,000.00
2.			IGBT Power supply (300A, 200V,400V- OCV)x3	36,00,000.00
3.	Air supply system		Air compressor	12,00,000.00
			Electrical networking and star-delta-starter configuration	15,000.00
			Gas supply lining (SS-304, 1 inch NB pipe)	1,00,000.00
			Total cost of air supply system	13,15,000.00
4.	Chilled water supply system		Chiller unit	15,00,000.00
			Water piping (SS 304 2 inch NB) with thermal insulation	5,00,000.00
			Total cost of coolant supply system	20,00,000.00
5.	Ignition and control system		RF ignitor (3 kV, 3 MHz x3)	75,000.00
			Thermocouple, pressure sensor, control consol, mounting, display and wiring	15,00,000.00
			Gas flow meters (4 Nos.)	40,000.00
			Water flow meters (3 Nos.)	45,000.00
			RTD sensors with mounting (4 nos.) and display	40,000.00
			Total cost ignition and control system	17,00,000.00
			Total cost primary chamber	25,00,000.00
			Total cost secondary chamber	15,00,000.00
			Total cost venturi scrubber	14,00,000.00
			Total cost packed bed column	11,00,000.00
			Total cost i.d. fan unit	6,00,000.00
			Total cost stack (fabrication & installation)	10,00,000.00
			Net Unit Cost	1,69,94,000.00 (~1.7 Crore)

Energy Consumption Rate under Full Load

Sl No	Particulars	Voltage (V_L)	Current (I_L)	P. F.	Power (KW) $1.732*V_L*I_L*P.F.$	No of Devices	Hrs of Opera -tion	Energy Consumed (KWh) Unit (X) per day	Image
1	Chillier (30Tr)	415	72.7	0.8	**41.8**	01	8	334.4	
2	Air Compressor	415	66.3	0.8	**38.12**	01	8	304.96	
3	Small Chillier (10Tr)	415	22.1	0.8	**12.7**	01	8	101.6	
4	Blower	415	24.4	0.8	**14.03**	01	8	112.24	
5	Packed bed Pump	415	3.2	0.8	**1.84**	01	8	14.72	
6	Venturi Pump	415	9.9	0.8	**5.6**	01	8	44.8	
7	Plasma Torch (P/S @160V*135A	415	41.1	0.8	**26.63**	03	2	159.78	
8	Total		239.7		**140.99**			**1072.5 /Day**	

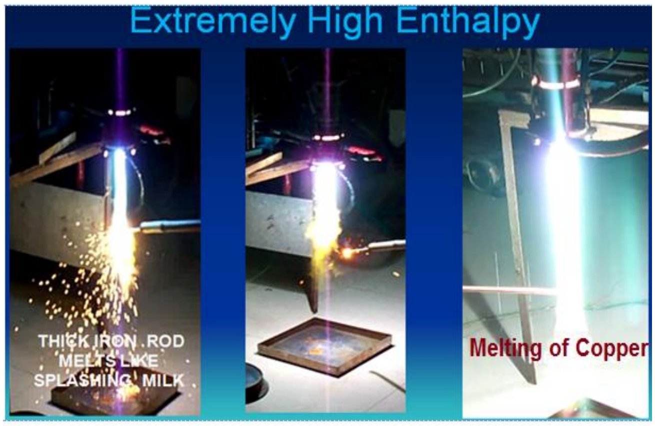
Notes.

1. Depending on chilling requirement, the usual power consumption rate during operation will be less, once steady state reaches in the system.

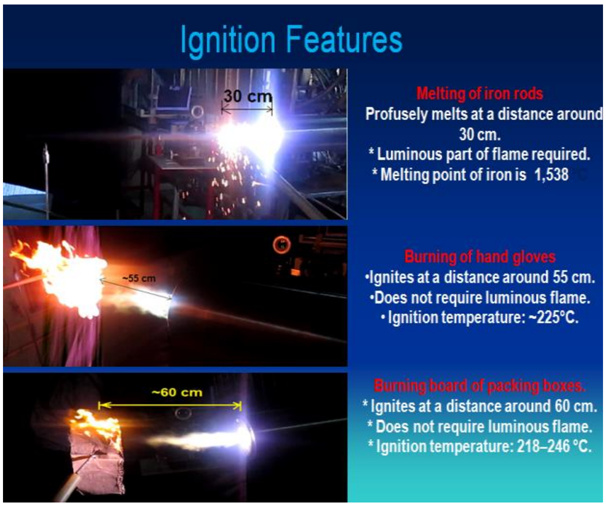
2. The Power consumption by air compressor will depend on the air flow requirement. For lower flow rate, the compressor may stay in idle condition and the power consumption rate will be reduced.

3. Once coke bed reaches very high temperature (>1500K) through plasma discharge, the power coming from the waste found to be sufficient to run the system with requisite efficacy. The plasma power input may be stopped at that time. The energy consumption rate may be directly reduced by 75 kW under steady state operation with continuous waste feed.

Process & Operational Features-I

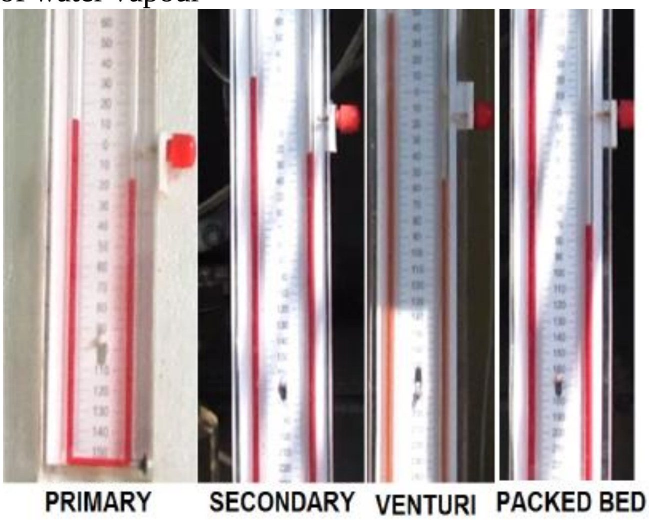


Iron melts instantaneously and splashes like milk; copper melts and even evaporates instantaneously

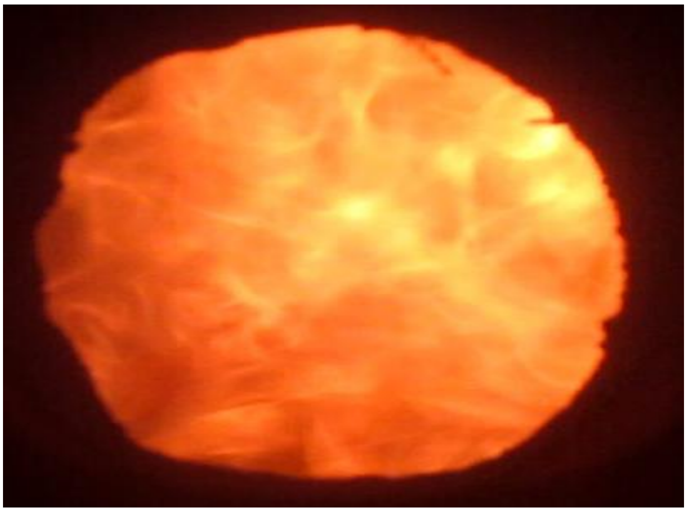


Clean emission from stack: Only faint white stream of water vapour

The extremely hot coke bed with bed temperature >1500°C



Negative pressure maintained at different units



Fast plasma gasification as waste interacts with extremely hot coke bed

Process & Operational Features-II

Mitigation of NO_x

No_x is generated by breaking of air in the region above 1600K. Only a cylinder of radius<5mm in arc jet possess this → Only 20% of air volume can produce NO_x → Temperature in core is 20 times higher than ambient, reducing NOx further through reaction → Sticking O to CO and H further reduces NOX due to lack of O

After getting mixed with 8000m³/hr of air at exhaust blower, net calculated No_x =0.05 ppm in exhaust [<<Permissible limit]

Mitigation of HC, CO, H_2, CO_2

Off gas is burnt in secondary chamber and gets converted into (99.99%):

$$HC \dashrightarrow H_2O + CO_2$$
$$CO \dashrightarrow CO_2$$
$$H_2 \dashrightarrow H_2O$$

▪Design basis of the KOH Scrubber assumes exhaust CO_2 concentration as 10ppm.

▪Considering natural value of CO_2 concentration in ambient air as ~400 ppm, ground level emission is permitted

Formation of Dioxin and Furan takes place in the temperature zone 200-600C. The zone is avoided by sudden quenching of syn-gas from ~1200 ºC to 50 ºC in the ventury scrubber. Also, the system generates least amount of fly ash to act as catalyst for formation of Dioxin and Furan.

Safety Aspects

- Operation at negative pressure, allows no syn-gas to reach outside.
- Dual gate feeder unit prohibits release of obnoxious gas
- Suction hood on top of scrubber and secondary chamber takes care of release of syn gas if any
- Inline temperature sensors at multiple locations monitors thermal health
- Pressure sensor for chamber and duct monitors process health
- Continuous area motoring for NOx, CO, CO2, HC for safe operation
- No thermal runway. Automatic trip for any electrical instability, as arc characteristics do not support.
- Coolant flow is interlocked with the power supply through flow switch