Combustion science in aid of conversion of lignaceous solid biofuels to gaseous fuels





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Background Importance for developed countries and developing countries What fuels, why?

- Single particle combustion and inferences for gasification
- Flame propagation in particle beds
- Producer gas Combustion features for engine applications
- Power Gasifiers and Gasifier Stoves

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Part of the inspiration for this talk –

Proceedings of the Combustion Institute, volume 28, 2000/pp 1-10.

HOTTEL LECTURE

SUPERSONIC FLIGHT AND COOKING OVER WOOD-BURNING STOVES: CHALLENGES TO THE COMBUSTION COMMUNITY

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Background

Importance for developing and developed countries

Renewable fuels need to be used sooner or later *– sooner* for the developing countries (including parts of South America) and *later* for Europe and *even later* for the North Americas.

Why? - Oil importing countries have large impetus to gain from the economy of biofuels

Rich countries can afford to work with expensive renewable & "fashionable" technologies (like SPV) and ignore cheaper options for a long time.

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International compulsions of GHG reduction will be imposed on populated developing countries

Thus it is better for us in India to do research to help ourselves rather than wait till other countries do research and transfer technologies at high cost.

At IISc, a 300 man-year effort has gone into solid biofuelto-gas field in a unique laboratory, on *fundamental research*, technology development, field testing and improvements in design over the last 20 years.

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What fuels and why?

Agro-fuels

Rice husk and Rice straw – for India, China, S-E Asia Other straws, Sugarcane trash (& Bagasse), Peanut shells,

----- These are light (~100 kg/m³), fine sized (a few mm), high ash (5 to 20 %), highly alkaline ash – Potassium from the fertilizer application, Moisture problem not serious (because of thin walls)

----- Coconut shells, Cotton stalk, mustard stalk, weeds like Ipomia, Parthenium (properties like woody fuels)

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Aim

Convert these into gaseous fuels through thermo-chemical conversion process – gasification process – and enable them to be used for electricity generation through reciprocating engines/gas turbines or heat applications – cooking, industrial drying or melting all with highest possible efficiency and little emissions, keeping cost as low as is possible.

Just what is this technology?

Get all biomass into solid form -

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Biomass

Coconut Shells

Coffee Husk



Dry Grass





Marigold Pellets



Paper Trash



Rice Husk



Pine Needles



Saw Dust





– Sugar Cane Thrash



Use them in a vertical cylindrical reactor Introduce air at appropriate places to create the correct thermal profile for the conversion of lingo-cellulosic material to char and reactive gases that react further with red hot char to result in "producer gas" which when cleaned and cooled is equivalent of any combustible gas like natural gas.



Biomass + Air \longrightarrow Products (Partial) + Char, N₂ + Heat (Upward propagation of flame front) \rightarrow A

Char + Air Heat CO_2 , H_2O + Char, N_2 – Heat

Char + CO_2 , H_2O , $N_2 \rightarrow CO$, H_2 , CH_4 , $N_2 \rightarrow B$

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Schematic of Wood Gasifier for Power Generation application



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Summary of the results on the tests of the gasifier

IISc Gasifier System at Chatel-St-Denis Switzerland.



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IISc Gasifier based power generation system deployed in Chile



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Quality of the gas demanded of the gasifier

For woody biomass:

Cold gasification efficiency ~ 80 % + Composition (%) – CO~20, H_2 ~ 18, CH_4 ~1.5, CO2 ~ 12, rest N₂ (Calorific value – 4.5 to 5 MJ/n.m³)

Particulates and Tar ~ as low as possible – 50 mg/m³ or less, Liquid effluents must be treatable with moderate cost.

Enable use of the same gasifier for all solid biomass since agro-residues are seasonal



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Calorific Value (gas) vs Wood Species



Calorific Value of Producer Gas

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Composition vs Moisture in wood



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Gasification Efficiency vs Moisture in Wood



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Tar Composition for the High Pressure Gasifier (CFBG) of Vernamo, Sweden



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Tar Composition for the ambient pressure Gasifier of IISc design



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Nox Emissions from Gasifier Based Furnace and US

Emission Standard

Size	NO, g/MJ	Particulates
Large > 250 X 10 ⁶ kJ/h	0.09	0.014
Small < 250 X 10 ⁶ kJ/h	-	0.068
Furnace in lab	0.07	-

Single particle combustion and inferences for gasification

The fuel used is usually cylindrical of dimensions between 5 to 50 mm, dia and length comparable.

A series of studies were initiated (1984 to 1998) on

Biomass sphere flaming combustion

- b. Biomass char glowing combustion in $O_2 N_2$ environment
- c. Char sphere conversion with mixtures of CO_2 , H_2O , O_2 and
- N₂. Aim: Spherical geometry is clean; mathematics will be simpler.

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Measuring Conversion time / wt loss time, etc..



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Conversion time vs Diameter



Reactant - Steam

t_c ~ d₀^{1.2} at 1280 K t_c ~ d₀^{1.33} at 1388 K

 $t_{c}/\rho = d^{T/1080} \exp[-3.26 + 15470 (1/T - 1/1270)]$

Behaviour differs from that of C - O_2 and C - CO_2 reaction

- departs from d²law.
- Increase in exponent at high temperature is an indication of higher reactivity and shift towards diffusion controlled.

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Comparison of Conversion time with diameter Reactants : (a) CO₂ (b) F₂O (c) air (d) O₂



$t_{b} \sim d_{0}^{1.03}$	CO ₂	Kinetic and diffusion dependence
$t_b \sim d_0^{1.2 - 1.3}$	H₂O	Kinetic and diffusion dependence
$t_{b} \sim d_{0}^{1.9}$	air	diffusion limited
$t_b \sim d_0^2$	O ₂	diffusion limited

Conversion time for char reaction with

1. CC 2 is 3-4 times that of H 2O

2. H₂O is comparable to air at d_p > 8 mm

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Char conversion time vs ambient reactant mole fraction

Reactants :



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Single Particle Conversion – Experiments and Results



Burn time for different particle diameters in air at 300 & 100K and the experi--mental data of Simmons and Ragland(1986) (Dashed lines indicates trends) *CGPL, Dept. of Aerospace Engg., IISc (...30)*

A simple Analysis of Extension

Heat release rate at the surface = Heat taken away by connection + Heat loss by radiation

$$A_{s}\delta_{f}e^{-E/RT_{s}}F\bar{Y}_{ox} = \dot{m}c_{p}(T_{s}-T_{o}) + A_{s}\varepsilon\tau(T_{s}^{4}-T_{0}^{4})$$
$$\bar{Y}_{ox} = (T_{s}-T_{o})/(T_{ad}-T_{o})$$
$$\delta_{f}[(T_{s}-T_{o})/(T_{ad}-T_{o})]e^{-E/RT_{s}}F = \dot{m}''c_{p}(T_{s}-T_{o}) + \varepsilon\tau(T_{s}^{4}-T_{0}^{4})$$

Radiation is a small fraction of the heat transfer.

$$\dot{m} = Kr_s;$$

$$\dot{m}'' \approx \frac{x_{o\infty}}{4400} \frac{1}{r_s}$$

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r _s , mm	$T_{s, cr, nt}$ $T_{s} > T_{s, crit}$
4	803
3	825
2	843
1	900

$$r_s < \frac{1}{-dT_s/dr_s} \cdot \frac{1}{(E_s/RT_s^2)}$$

For < 1 mm Extinction occurs.

Combustion Experiments with

a) Rice Husk

b) Sawdust with 20% Silica

c) Pulverised Rice Husk

d) Sawdust

e) Spheres- Wood and Rice Husk Briquette

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Rice Husk

Sample being Ignited

Sample with the Flame



Ultimate Product

Percentage Residue=31.3

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Sawdust with 20% Silica

Sample being Ignited



Ultimate Product Formed —

Percentage Residue= 18.3

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Sample with the Flame





Pulverised Rice Husk

Sample being Ignited







Ultimate Product Formed

Percentage Residue= 31.3

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Saw Dust

Sample being Ignited

Sample with the Flame



Ultimate Product Formed ———

Percentage Residue= 6.9

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Wood sphere catching the flame and briquette sphere being ignited

Percentage Residue =1.7

Wood sphere burning and the briquette starting to burn.

Percentage Residue = 21.0

Glowing wood sphere and the flame dying away in case of briquette.

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Ash formed from wood sphere



Percentage Residue= 1.69

Process Time : Ignition = 36 s (In Seconds)

Flame = 108 s

Glow = 604 s

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Ash formed from Rice husk briquette Sphere



Percentage Residue= 21.0

Process Time : Ignition = 68 s (In Seconds) Flame = 195 s

Glow = 1332 s

Relevance to Rice Husk gasifiers

- The conversion of rice husk char is slower than of wood char.
- It occurs only at very slow heating rates and at temperatures below 800°C.
- Rice husk char is structurally more complex than wood char. It has 40 to 50 % inert. The Silica (~95 % inert ash) is molecularly interspersed with carbon making carbon more inaccessible to conversion by O_2 and for sure, CO_2 and H_2O as these are less reactive with endothermicity.
- One can therefore expect that rice husk gasifiers using as-received rice husk to work virtually as pyrolisers with limited cracking at high temperatures.
- One can therefore expect more tarry gas.

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What happens inside the reactor?



- Also fluid mechanical effects tunneling of air through the bed of rice husk.
- This leads to varying quality of the gas over the operating period.

• Use of briquettes whose mechanical Integrity is good leads to uniform flow of air and gases through the porous bed.Conversion can be expected to be higher inferred from single particle studies. Performance of the reactor will be more robust and reliable.

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Experimental setup for the packed bed



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Typical temperature profile in the packed bed (model prediction)

Coordinate system is fixed to the solid phase; coordinate system moves with respect to the gasifier hardware at a velocity equal to the particle velocity



Procedure

Set the initial conditions same through out the bed, except below certain height assign higher temperature for ignition

Solve for the individual particle and then for the packed bed

Axial distance, local particle velocity, temperature and the species fraction are obtained

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Temperature and reactant profile in the bed near the reaction zone for different air mass flux

Profile chosen when the rate of propagation of the reaction front through the bed is constant



Peak temperature increases as the air mass flux increases
 Thickness of the propagation front increases with air flux; consistent with the qualitative observation during the present experiments and earlier references[5]
 At low air flux CO concentration is low and increases with air flux

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Propagation rate vs mass flux in a packed bed char reactor with peak bed temperature and CO concentration



With increase in mass flux the front velocity initially increases and then reduces
 With increase in mass flux the CO concentration in the exit gas increases

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Producer gas Combustion features for engine applications

Plot of the flame speed vs air-to-fuel ratio



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Flame speed vs equivalence ratio for the CO-air mixture



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Plot of Flame speed vs % H₂ for H₂-air mixture



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The heat release rates v/s $\tau = (T-T_u)(T_{ad} - T_u)$ for the producer gas, H₂-CO₂-N₂-air(ϕ =1.2) and CO-CO₂-N₂-(H₂O)-air (ϕ =1.2)



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Heat release rates vs Temperature





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Plot of temperature vs time for an adiabatic reactor (CO –air)



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Heat release rates vs Temparature for $\phi = 1.0, 1.459, 1.7$ and 2.02 for H₂- air



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Power Gasifiers

M/s Senapathy Whiteley Pvt Ltd, Ramanagaram, Bangalore Rural district.



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Gasifier Stoves







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In this presentation, we have seen:

- Background on biofuels and their importance
- Single particle combustion and inferences for gasification
- Flame propagation in particle beds
- Producer gas Combustion features for engine applications
- Power Gasifiers and Gasifier Stoves

