BIOMASS ENERGY
and
BIOMASS CHARACTERISATION STUDIES

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PRESENT ENERGY SCENARIO

- **The world is unlikely to run out of energy in the near future.**
- **At present, 'energy poverty' hinders the economic and social development of many countries.**
- **There lies a vast gap between the energy supply and demand and likely to increase in future.**
- **Current patterns of energy production and use have destructive impacts on the environment.**

PRESENT ENERGY SCENARIO

Energy resource	Percentage of usage
OIL	34% (200 years)
COAL	24% (30 years)
NATURAL GAS	21% (100 years)
BIOMASS	11%
NUCLEAR	7%
HYDROGEN	2%
OTHERS	1%

WORLD WIDE SUGGESSTIONS:

The demand can be managed through

- greater conservation of energy
- optimum fuel mix
- public transport rather than private transports
- better urban planning to reduce energy needs
- shift to solar, wind, biomass energy sources
- emphasis on research and development
- use of energy efficient technologies

RENEWABLE ENERGY IN INDIA

- India is blessed with an abundance of sunlight, water and biomass
- India has the world’s largest program for renewable energy.
- 1982 -The Department of Non-conventional Energy Sources (DNES).
- 1992 -a full fledged Ministry of Non-conventional Energy Sources (MNRES).

ACTIVITIES OF MNRES

- promotion of renewable energy technologies
- create an environment conducive to promote renewable energy technologies
- create an environment conducive for their commercialization
- renewable energy resource assessment,
- research and development
- demonstration
- production of biogas units, solar thermal devices, solar photo voltaics, cook stoves, wind energy and small hydropower units.

BIOMASS ENERGY

- The world as a whole is now looking for alternate cleaner energy resources.
- Biomass is the traditional energy source with many positive attributes.
- An energy conversion technology with increased doses of Energy,Economics & Environment is presently needed.
- Biomass residues meet out these 3 E's, especially on Environment.
- Biomass remains even now as an important energy source contributing 11% of the world energy and 38% of energy in the developing countries.
- Biomass residues are socially acceptable, regenerative, eco-friendly, clean & green energy resource.

What is Biomass?

- Renewable energy that can be used as a solid, a liquid & a gaseous fuel.
- Organic matter produced by plants.
- Solar energy stored in plants.
- Harnessing of solar energy by photo synthesis.
- Photo chemical approach to get solar energy.
- Crops grown especially for their energy content in "energy farms".
- Agricultural residues.

Why Biomass?

- Can be easily generated.
- Generation helps in greening the globe.
- Low sulfur fuel, cleaner fuel.
- Reduces environmental hazards.
- Supplements Renewable sources of carbon & other chemicals.
- Can be converted to ethanol and methanol & used as a liquid fuel.
- When fermented anerobically gives gaseous fuel –biogas.
- Waste management is also carried out.
- The 5F uses of biomass are:

  Food, Fodder, Fuel, Fiber & Feed stock.

Objective of the Presentation

- Design & performance of biomass based energy conversion devices mainly depend on the properties of the biomass residues to be used as fuel.

- In future the biomass energy generation may require the compulsion of using them in the mixed form or one after another in the conversion devices.

- For the perfect designing of the burning device or the gasifier a systematic study on the characterization of the biomass residues in their native form & also in their mixed form is needed.

Objective of the Presentation

- The bio resources can be more effectively used in their charred form and will be suitable for ready adoption in the commonly used combustion devices.

- The behavior of biomass chars in the mixed form is a study which needs attention.

- Lot of primary data is available for the characteristics of bio residues in their native form but in their mixed form & charred form data is not available.

Preparatory Work

The characteristics of bio residues vary from species to species. Let us restrict with only three bio resources:

Rice Husk, Saw Dust & Groundnut Shell. (RH, SD & GS)

The analysis of bio residue mixtures RH: SD, SD: GS & GS: RH in proportions of 70:30, 50:50 and 30:70 with two end members 100:0 & 0:100 were carried out.

Collection of samples:

Rice husk-rice mills
Saw dust-timber industries
Groundnut shell-decorticating units

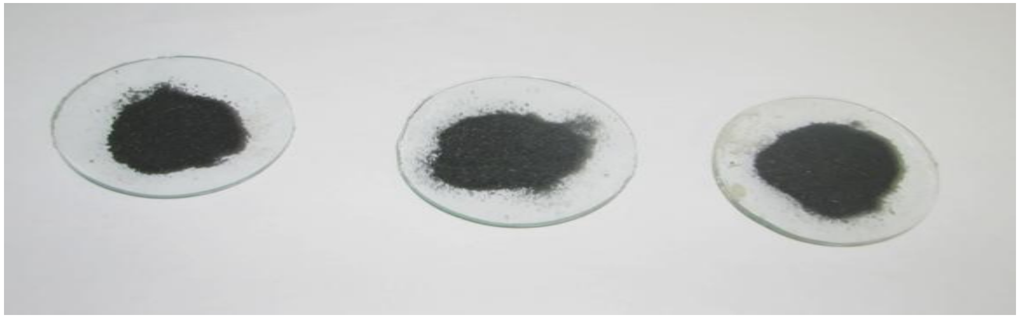
Preparation of Samples

- Cleaning by hand- removal of unwanted materials as stones dry leaves, small sticks etc.
- Sieving using simple manual sieves-to get approximately same size of the samples.
- Air drying for two days-collected in polythene bags.
- Grinding using Ultra centrifugal mill & Ball mill unit – approximately 200 microns output is obtained.
- Mixing of the fine samples in the desired ratios.
- Storing in separate air tight polythene bags.

Original Samples

Milled Samples

Charred Samples



List of instruments to be used

- **Electronic Balance** - accuracy 0.001g.
- **Muffle Furnace**-max range 1000ºC.
- **Centrifugal Mill & Ball Mill**- to grind the samples.
- **CHN Analyzer** -to determine C,H,N contents.
- **Bomb Calorimeter**-to determine the calorific values of the samples.
- **Flammability Apparatus**-to determine the flammability index.
- **TGA-Thermo Gravimetric Analyzer**- to carry out the thermal analysis of the samples.
- **SEM-Scanning Electron Microscope**- to look at the microscopic distribution.

Characterization Studies of Biomass Fuels

Combustion based properties from proximate and ultimate analysis.

- **Bulk density -**the storing aspects, the compactness of the fuel, voids.
- **Proximate analysis-**combustible & non-combustible constituents,
  - Moisture content
  - Volatile matter
  - Ash content
  - Fixed carbon.
- **Ultimate analysis**- to quantify the contents of the organic constituents **C,H,N,S,O.**
- **Air Fuel ratio**- gives the minimum air requirements for a complete combustion. Theoretical, Gravimetric, Dry Air Fuel ratio- $\mathbf{(A/F)_{TGD}}$.

- **Flammability Index-**the ease with which the fuel may be brought to a stable sustained combustion. It is the lowest temperature at which a visible steady flame appears.

- **Derived parameters-**from the proximate and ultimate analysis:
  - ❖VM/FC ratio
  - ❖C/H ratio
  - ❖[(C+H) /O] ratio
  - ❖C % present in the VM.

- **Correlation studies:**
  - ❖Ash Content Vs Calorific Value.
  - ❖Flammability Index Vs Calorific Value.
  - ❖Flammability Index Vs Proximate Analysis.

Bulk density

- A property that depends on the moisture content, shape & the size of the biomass.

- Data on bulk density is useful to decide the storing aspect of such bio resource mixtures for longer periods to generate energy on a sustainable basis.

- **RH=285 Kg/m^3 SD=210 Kg/m^3 GS=185 Kg/m^3.**

- Thus from point of storage, GS: SD system is ideal and from the combustion angle also it is good.

PROXIMATE ANALYSIS

Moisture Content

- Moisture present in the sample evaporates during burning.
- Presence of moisture reduces the burning capacity.
- High moisture lowers the calorific value of the fuel.
- Anyhow 10% of moisture is needed for the burning of the fuel.
- MC needed for maintaining a more uniform bed & loss of fly ash.
- Percentage of moisture**=** (loss of wt due to removal of moisture/ wt of sample taken) x 100.
- **RH=10.78 % SD=18.34 % GS=8.38%.**
- Literature value approximately = 10%. MC in coal= 8%.

Volatile Matter

- This property decides the calorific value & the smoke liberated.
- Bio fuels with high volatile matter are not desirable.
- High VM makes the biomass to get ignited at low temp.
- High volatile means the heating value is also low.
- Percentage of Volatile present= (loss of wt due to removal of volatile/wt of sample taken) x100.
- **RH=55.52 % SD=65.07 % GS=63.81%**
- Literature value =52% to 60%. Coal = 20 to 30% (Grover).
- In SD: GS system it is fairly steady at around 64%.

Ash Content

- Ash is non combustible matter.
- High ash means Calorific value of the sample is less.
- Ash causes inherent hindrance to the flow of air and heat thereby lowering the temperature of the burning device.
- High ash also obstructs air supply & causes early wear of furnace walls, burning apparatus & feeding mechanism.
- Removal, handling & storing of ash is a problem. Additional cost is involved in ash disposal.

Ash Content

- Lower is the ash better is the fuel. Mixing of biomass gives a better solution to choose biomass with low ash.
- **RH=17.36 % SD=3.42 % GS=5.41%.**
- Literature value = 3 to 20%. Coal = 5 to 40% (Grover).
- The SD:GS system generates minimum ash (5%).
- RH contributes more ash where ever it is present.
- But compared to coal the ash problem is less severe in any one of the bio residue mixed system studied.

Fixed Carbon

- FC represents the quality of carbon in the samples that can be burnt by the current of air drawn through the hot bed of a fuel.
- A biomass with high FC is desirable.
- Higher FC means higher Calorific value.
- Higher FC then VM will be smaller.
- FC is determined using the mass balance formula.
- Percentage of Fixed carbon= 100-(MC%+VM%+AC%).
- RH=16.34 % SD=15.30 % GS=22.40%.
- Literature value = 10% to 20%. Coal = 60 to 80% (Grover).
- Fixed Carbon with more than 20% is available in,

  RH: SD (50:50)-21%,

  SD: GS (0:100)-22.4%,

  GS: RH (30:70)-24.91%.

Table 3.2 Proximate Analysis

Fuel	Fuel Ratio	Moisture Content %	Volatile Matter %	Ash Content %	Fixed Carbon%
RH:SD	100:0	10.78	55.52	17.36	16.34
	70:30	13.05	52.67	16.36	17.72
	50:50	14.56	52.95	11.47	21.02
	30:70	16.07	58.75	6.41	18.77
	0:100	18.34	65.07	3.42	15.30
SD:GS	100:0	18.34	65.07	3.42	15.30
	70:30	15.35	64.82	3.00	15.46
	50:50	14.45	66.25	4.81	14.76
	30:70	11.14	65.99	5.00	17.89
	0:100	8.38	63.81	5.41	22.40
GS:RH	100:0	8.38	63.81	5.41	22.40
	70:30	8.70	63.15	7.51	21.00
	50:50	8.93	62.12	8.96	19.99
	30:70	8.46	55.50	11.23	24.91
	0:100	10.78	55.52	17.36	16.34

Ultimate Analysis

- The ultimate analysis gives the extent of Carbon, Hydrogen, Nitrogen, Sulfur and Oxygen present in the solid fuels.
- Greater Carbon content is an indication of the degree of quality of the fuel.
- Nitrogen is rather inert with very low calorific value and its presence is undesirable though not inescapable.
- Sulfur contributes the heating value of the fuel but during combustion process one gets SO_2&SO_3 which have harmful effects of corroding the combustion device as also causing atmospheric pollution.
- Presence of higher percentage of Oxygen is also not desirable as it may lower the calorific value.
- The Percentage of moisture content and ash when added with the percentage of C, H_2, N, S, and O_2 gives the total 100% contribution

Table 3.3. Ultimate Analysis of mixed biomass fuels

Fuel	Fuel Ratio	% C	% H	% N	% S	%O_2	% MC	% Ash
RH:SD	100:0	32.46	4.18	0.66	0.06	34.3	10.78	17.36
	70:30	34.77	4.40	0.59	0.10	33.78	13.05	16.36
	50:50	36.32	4.54	0.54	0.13	33.43	14.56	11.47
	30:70	37.86	4.68	0.49	0.15	33.08	16.07	6.41
	0:100	40.17	4.90	0.42	0.19	32.56	18.34	3.42
SD:GS	100:0	40.17	4.90	0.42	0.19	32.56	18.34	3.42
	70:30	41.30	4.95	0.68	0.17	33.54	15.35	3.00
	50:50	42.05	4.99	0.85	0.16	34.19	14.45	4.81
	30:70	42.80	5.03	1.02	0.14	34.84	11.14	5.00
	0:100	43.92	5.08	1.28	0.12	35.81	8.38	5.41
GS:RH	100:0	43.92	5.08	1.28	0.12	35.81	8.38	5.41
	70:30	40.48	4.81	1.09	0.10	35.36	8.70	7.51
	50:50	38.19	3.79	0.97	0.09	33.06	8.93	8.96
	30:70	35.90	4.45	0.85	0.08	34.75	8.46	11.23
	0:100	32.46	4.18	0.66	0.06	34.30	10.78	17.36

Air Fuel Ratio

- This gives the minimum air requirements for a complete combustion.
- The most important exothermic chemical reaction in the production of energy is the combustion of the fuels.
- This reaction is an oxidation reaction in which the three combustible elements found in most of the solid fuels Carbon, Hydrogen and Sulfur are respectively converted in to CO_2, H_2O & SO_2.
- The theoretical, gravimetric (mass), dry (no water vapor), air-fuel ratio, **$(A/F)_{TGD}$** is determined from the as-burned ultimate fuel analysis.

Air Fuel Ratio

- This ratio is evaluated by performing an oxygen mass balance on the combustible reactants.

- $(A/F)_{TGD}$ = (Kg Oxygen needed from the air per Kg fuel)/0.232.

- Simplified equation,

  $(A/F)_{TGD} = (2.66\,\mathbf{C}+7.94\,\mathbf{H_2}+0.998\,\mathbf{S} - \mathbf{O_2}) / 0.232$

  0.232 = Mass fraction of Oxygen in the air.

- For our samples A/F ratio = 3.67 to 5.23.
- Coal A/F ratio = 8 to12.
- SD:GS system offers the highest A/F ratio(5).

Table 3.4. Ultimate analysis Vs A/F of mixed bio mass fuels

Fuel	Fuel ratio	% C	% H	% S	% O_2	Air fuel ratio $(A/F)_{TGD}$
RH:SD	100:0	32.46	4.18	0.06	34.30	3.67
	70:30	34.77	4.4	0.10	33.78	4.04
	50:50	36.32	4.54	0.13	33.43	4.28
	30:70	37.86	4.68	0.15	33.08	4.52
	0:100	40.17	4.90	0.19	32.56	4.88
SD:GS	100:0	40.17	4.90	0.19	32.56	4.88
	70:30	41.30	4.95	0.17	33.54	4.99
	50:50	42.05	4.99	0.16	34.19	5.06
	30:70	42.80	5.03	0.14	34.84	5.13
	0:100	43.92	5.08	0.12	35.81	5.23
GS:RH	100:0	43.92	5.08	0.12	35.81	5.23
	70:30	40.48	4.81	0.10	35.36	4.76
	50:50	38.19	3.79	0.09	33.06	4.25
	30:70	35.90	4.45	0.08	34.75	4.14
	0:100	32.46	4.18	0.06	34.30	3.67

Calorific Value

- Dominant factor in choosing a particular biomass or its mixture for a particular combustion device.
- Bio resources by way of their high VM and less FC content and medium calorific value are more useful for quicker heating at low and medium temperatures.
- The use of bio residue mixtures is recommended for specially designed boilers.
- The calorific value of the fuel is based on the combined heats of combustion of C, H_2, N_2 and S in the organic matter.

Calorific Value

- The value determined in the laboratory using Bomb Calorimeter is the GCV (Gross calorific value) or
  HCV (Higher heating value).
- But when the fuel is burning the moisture present in the fuel gets evaporated. Hence corrections are made to the gross or high heating value to get Net or Low calorific value (NCV).
  NCV= GCV-5.72(Hx9)
- Calorific value of woody biomass 19.3MJ/Kg (Kiyoshi Dowaki et al,2004).
- Calorific value of coal 16-34 MJ/Kg (Anuradha Ganesh, 2006).
- Calorific value of our samples lie between 13.69 to 18 MJ/Kg.

Table 3.5 Calorific Value of mixed bio mass fuels

Fuel	Fuels Ratio	Calorific Value of Mixtures			
		GCV		NCV	
		Kcal/kg	MJ/kg	Kcal/kg	MJ/kg
RH:SD	100:0	3270	13.69	3055	12.78
	70:30	3454	14.46	3228	13.51
	50:50	3810	15.95	3576	14.97
	30:70	4080	17.08	3849	16.11
	0:100	4322	18.10	4070	16.04
SD:GS	100:0	4322	18.10	4070	17.04
	70:30	4286	17.95	4031	16.88
	50:50	4200	17.59	3943	16.51
	30:70	4158	17.41	3900	16.33
	0:100	4190	17.54	3928	16.44
GS:RH	100:0	4190	17.54	3928	16.44
	70:30	3886	16.27	3638	15.23
	50:50	3710	15.53	3515	14.72
	30:70	3614	15.13	3385	14.17
	0:100	3270	13.69	3055	12.28

Derived Parameters

- The derived parameters are,
    - VM/FC,
    - C/H ratio,
    - [(C+H)/O] ratio,
    - C % present in the VM.
- (VM/FC) ratio helps to decide whether one should use conversation route of pyrolysis or direct combustion it also helps in ranking the bio residue with coal.

Flammability Index

- The term flammability means the ease with which the fuel may be brought to a visible sustained combustion.
- It is the lowest temperature at which a visible sustained flame appears.
- This index for various bio resource mixtures lies between 338 °C to 336 °C in closer argument with earlier studies reported for biomass fuels in the range of 350 °C to 400°C (Lawrence Thesis, 1999).
- For coal it is the range of 450 °C to 550°C (Fuels of opportunity).

Thermal Analysis of Mixed Biomass Fuels

- In this analysis the thermal changes taking place in the fuel as a function of time are studied.
- From the initiation of heating
    - the changes in temperatures as a function of time
    - the changes in mass of the fuel while heating

  are noticed.
- This study reveals when steady state would be attained
    - for release of moisture,
    - for the start and completion of the devolatization
- This continuous, dynamic and microscopic data on the burning profile gives relevant information about the complete combustion properties.

Burning Profiles

- The thermal analysis is done with TGA, Thermo Gravimetric Analyzer.
- Samples with initial mass varying from 2 to 10 grams were used.
- Heating rate of 10°C/min is used for the samples.
- The particle sizes of the samples used were of approximately 200 microns.
- Heating is done at atmospheric conditions (oxidative atmosphere).
- The TGA/DTG curves are plotted between
  Temperatures in ºC & Weight in mg,
  Temperatures in ºC & Rate of weight loss in mg/min.

Burning Profiles

From the burning profiles of the mixed biomass residues we can do:

- **Moisture release Analysis**
- **Volatile Matter release analysis**
- **Fixed Carbon release analysis**
- **Weight loss analysis**
- **Thermal degradation analysis.**

The results we obtain from the burning profiles have excellent coincidence with the results we obtain out of proximate and ultimate Analysis of the samples.

Burning Profiles

From these analyses we can get the following information:

- **MC_{RT} - Moisture Content Release temperature.**
- **VM_{IT}-Volatile Matter Initiation Temperature.**
- **VM_{PT}- Volatile Matter Peak Temperature.**
- **VM_{CT}- Volatile Matter Cease Temperature.**
- **FC_{PT-}Fixed Carbon Peak Temperature.**
- **FC_{BT}-Fixed Carbon Burn out Temperature.**
- **Temperature range of thermal degradation.**
- **Rate of thermal degradation.**
- **Percentage of thermal degradation.**
- **Activation Energy of mixed bio residues.**

Figure 4.1 RH: SD 100:0 TGA/DTA Curve

Sample Name: S1-RH:SD-100:0
Sample Weight: 2.844 mg

Pan: Alumina, O_2 Atm
10 Deg C – rise in T

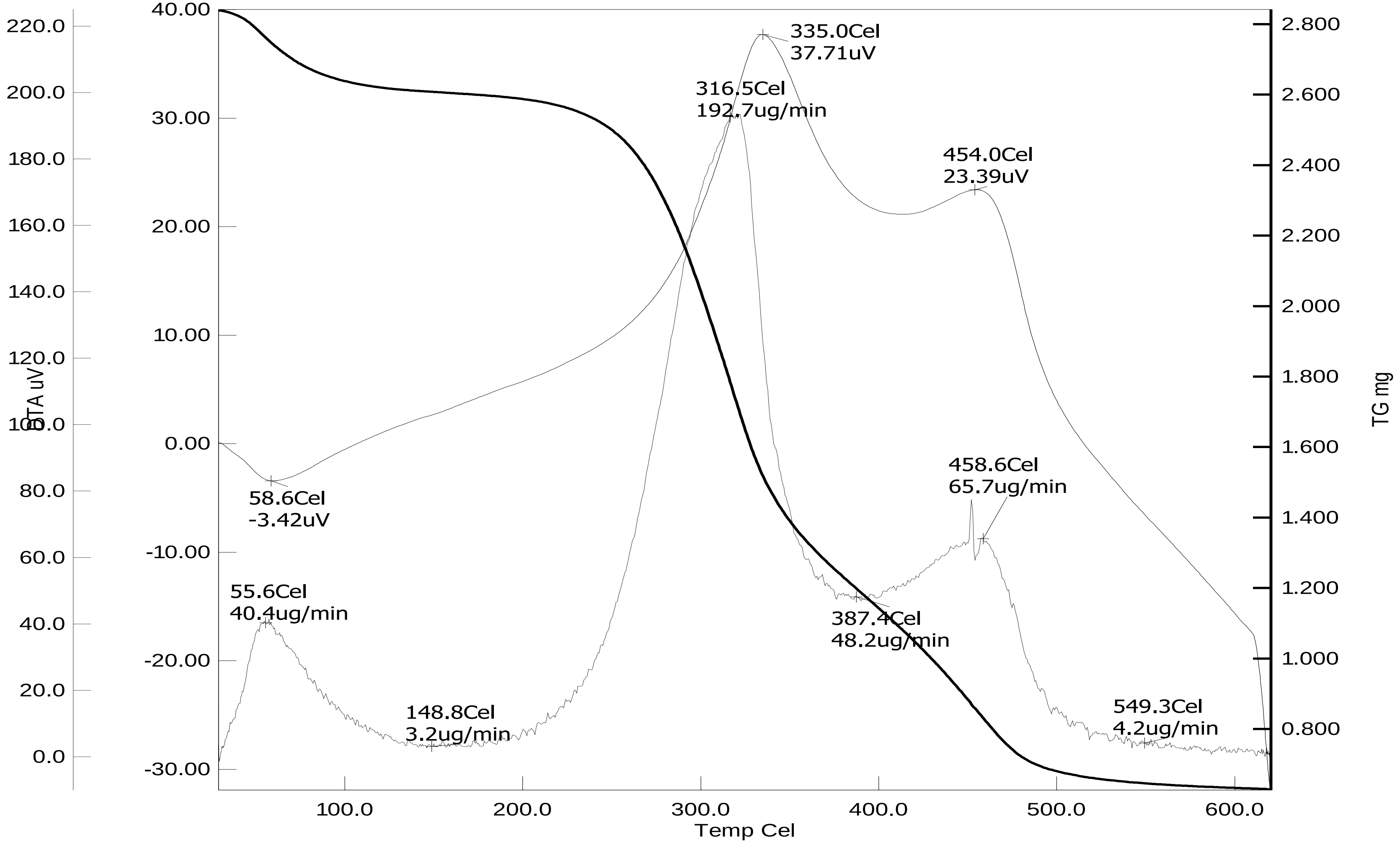


Table 4.1 Burning Profile

Fuel	Sample Name	Fuel Ratio	MC_{RT} °C	VM_{IT} °C	VM_{PT} °C	VM_{CT} °C	FC_{PT} °C	FC_{BT} °C
RH:SD	S1	100:0	56	149	316	387	459	549
	S2	70:30	53	181	324	378	-	478
	S3	50:50	66	200	325	425	425	600
	S4	30:70	55	198	324	379	434	521
	S5	0:100	60	209	315	363	436	520
SD:GS	S5	100:0	60	209	315	363	435	520
	S6	70:30	69	200	331	368	441	500
	S7	50:50	40	200	333	366	430	500
	S8	30:70	64	219	317	373	461	510
	S9	0:100	70	200	333	344	440	500
GS:RH	S9	100:0	70	200	333	344	440	500
	S10	70:30	61	194	338	340	461	520
	S11	50:50	68	233	330	366	458	600
	S12	30:70	61	200	330	344	459	525
	S1	0:100	56	149	317	387	459	549

Table 4.2 Weight Loss Profiles

Fuel	Sample Name	Fuel Ratio	Initial weight $(w_1) \times 10^{-3}$ g	Final weight $(w_2) \times 10^{-3}$ g	Weight loss $(w_1 - w_2) \times 10^{-3}$ g
RH:SD	S1	100:0	2.84	0.70	2.14
	S2	70:30	6.44	3.44	3.00
	S3	50:50	7.62	0.96	6.66
	S4	30:70	8.00	1.14	6.86
	S5	0:100	7.00	1.06	5.94
SD:GS	S5	100:0	7.00	1.06	5.94
	S6	70:30	10.0	0.96	9.04
	S7	50:50	8.30	0.20	8.30
	S8	30:70	10.0	1.60	8.40
	S9	0:100	7.24	0.20	7.04
GS:RH	S9	100:0	7.24	0.20	7.04
	S10	70:30	10.0	2.40	7.60
	S11	50:50	7.77	0.20	7.57
	S12	30:70	11.44	2.80	8.64
	S1	0:100	2.84	0.70	2.14

Table 4.3 Comparison of Theoretical and Experimental Weight Loss

Fuel	Sample Name	Fuel Ratio	Theoretical Weight Loss %	Experimental Weight Loss %
RH:SD	S1	100:0	48	75
	S2	70:30	52	47
	S3	50:50	65	87
	S4	30:70	75	86
	S5	0:100	82	85
SD:GS	S5	100:0	82	85
	S6	70:30	84	90
	S7	50:50	75	97
	S8	30:70	78	84
	S9	0:100	81	97
GS:RH	S9	100:0	81	97
	S10	70:30	74	76
	S11	50:50	69	75
	S12	30:70	69	76
	S1	0:100	48	75

Table 4.4 Thermal Degradation Profiles

Fuel	Sample Name	Fuel Ratio	Temperature Range of Thermal Degradation °C	Rate of Thermal Degradation mg/min	Percentage of Thermal Degradation
RH:SD	S1	100:0	317-387	7.09	41.86
	S2	70:30	324-378	5.31	55.96
	S3	50:50	325-425	6.69	24.32
	S4	30:70	324-379	5.43	35.14
	S5	0:100	319-363	4.38	43.75
SD:GS	S5	100:0	319-363	4.38	43.75
	S6	70:30	317-368	5.04	26.84
	S7	50:50	333-366	2.20	12.05
	S8	30:70	317-373	5.59	50.00
	S9	0:100	331-344	1.25	15.97
GS:RH	S9	100:0	331-344	1.25	15.97
	S10	70:30	338-340	0.22	27.02
	S11	50:50	333-366	2.20	23.87
	S12	30:70	330-344	1.45	31.85
	S1	0:100	317-387	7.09	41.86

Table 4.5 Comparison of Reactivity Data

Fuel	Sample Name	Fuel Ratio	First Peak		Second Peak	
			DTG mg/min	DTA μV	DTG mg/min	DTA μV
RH:SD	S1	100:0	1.927	37.71	0.657	23.39
	S2	70:30	1.064	89.50	-	-
	S3	50:50	1.400	167.98	0.330	110.64
	S4	30:70	1.653	130.00	0.469	99.00
	S5	0:100	0.827	125.00	1.373	305.00
SD:GS	S5	100:0	0.827	125.00	1.373	305.00
	S6	70:30	2.652	173.30	1.681	332.30
	S7	50:50	4.200	408.34	1.380	345.87
	S8	30:70	1.627	112.90	1.620	286.40
	S9	0:100	2.449	286.32	-	-
GS:RH	S9	100:0	2.449	286.32	-	-
	S10	70:30	4.733	338.10	0.475	99.40
	S11	50:50	1.670	194.63	0.260	83.99
	S12	30:70	3.865	216.40	0.479	78.00
	S1	0:100	1.927	37.71	0.657	23.39

Activation Energy

- The activation energy is the energy required to initiate the chemical reactions during the combustion of a fuel.

- The reactivity of the biomass samples depend on the activation energy.

- This analysis throws light on devolatisation process of the mixed biomass fuel.

$K = Ae^{\frac{-E}{RT}}$

- In the kinetic analysis activation energy calculation is very important as it gives an idea about the burning efficiency of fuel.

- The Arrhenius equation is used to determine the activation energy of the mixed biomass samples.

Arrhenius Equation

The reaction rate of a specimen according to the law of Arrhenius is expressed by the following equation:

$$K = Ae^{\frac{-E}{RT}}$$

Where,

- K = rate constant
- A = frequency factor/Pre-exponential factor
- R = gas constant (8.314 KJ/mol Kg °K)
- T = absolute temperature °K.
- E = Activation Energy

From TGA/DTA curves for various mixed biomass fuels the values of K are calculated for various temperatures and then in turn the activation energy values are determined.

Table 4.6 Activation Energy

Fuel	Sample Name	Fuel Ratio	Activation Energy KJ/mol Kg °K
RH:SD	S1	100:0	36.99
	S2	70:30	28.63
	S3	50:50	31.05
	S4	30:70	30.45
	S5	0:100	31.28
SD:GS	S5	100:0	31.28
	S6	70:30	27.90
	S7	50:50	27.89
	S8	30:70	31.13
	S9	0:100	28.41
GS:RH	S9	100:0	28.41
	S10	70:30	30.98
	S11	50:50	31.62
	S12	30:70	31.03
	S1	0:100	36.99

Characterization Studies of chars

- Combustion characteristics of chars of solid fuels help us to know the overall combustion efficiency of the fuels .
- The char of the biomass sample is nothing but the residue resulting from the devolatization.
- The char combustion is a slow process and it is the rate determining step of the overall fuel conversion.
- For our study the mixing is done first and then the mixture is charred.

Preparation of Char

- The char of the three host materials and their mixtures were prepared following the ASTM standards.
- The biomass sample was kept in the volatile matter crucible. The crucible was closed with the lid so as to avoid burning of carbon deposit.
- The crucible covered with the lid was then kept in the furnace maintained at a temperature of 900±25°C.
- After heating for seven minutes the crucible was taken out and without removing the lid it was allowed to cool.
- The left over in the crucible is the product of pyrolysis under specific conditions. This residue is called as ASTM char.
- The same procedure is repeated for each mixed biomass sample, till sufficient quantity of char was collected.

Burning Profiles of Chars

From the burning profiles of the mixed biomass chars we can do

- Moisture release Analysis
- Fixed carbon release analysis
- Weight loss analysis
- Thermal degradation analysis.

Other studies made with chars of mixed biomass residues are

- Calorific value
- Flammability Index
- Estimated char quantity.

Results from the TGA curves of chars

- MC_{RT} - Moisture content Release temperature.
- FC_{PT}-Fixed Carbon Peak Temperature.
- FC_{BT}-Fixed Carbon Burn out Temperature.
- w_1-w_2 - weight loss of mixed bio residues.
- Temperature range of thermal degradation.
- Rate of thermal degradation.
- Percentage of thermal degradation.
- Activation Energy of mixed bio residue chars.

Figure 5.1 RH: SD/Char 100:0 TGA/DTA Curve

Sample Name: S1C-RH: SD-100:0
Sample Weight: 8.61 mg

Pan: Alumina, O_2 Atm
10 ºC – rise in T

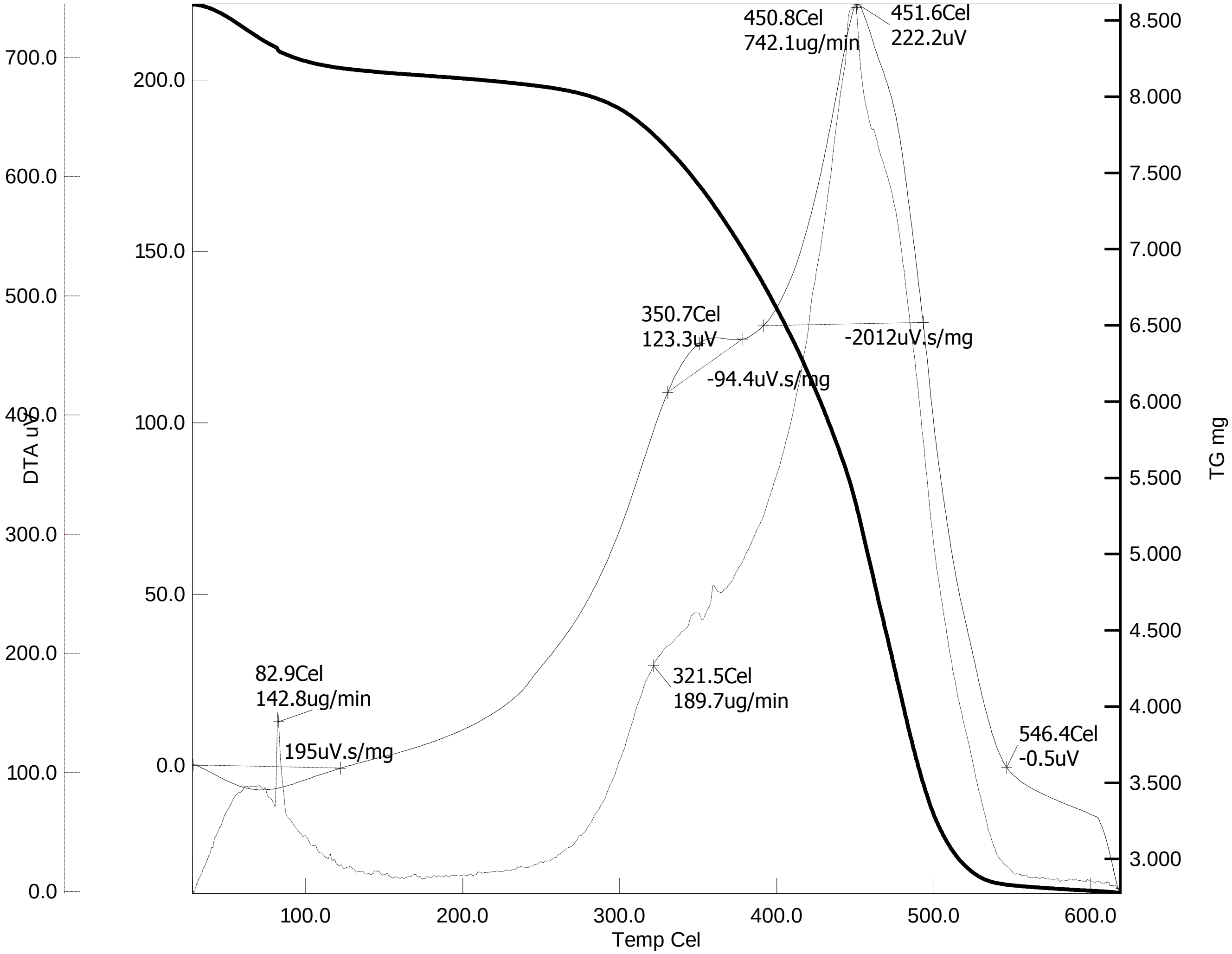


Table 5.1 Fixed Carbon Release Profiles

Fuel	Sample Name	Fuel Ratio	MC_{RT} °C	FC_{IT} °C	FC_{PT} °C	FC_{BT} °C
RH:SD	S1C	100:0	83	233	451	600
	S2C	70:30	101	266	462	600
	S3C	50:50	60	310	427	540
	S4C	30:70	53	244	445	566
	S5C	0:100	63	233	440	593
SD:GS	S5C	100:0	63	233	440	593
	S6C	70:30	70	350	431	583
	S7C	50:50	72	276	382	500
	S8C	30:70	54	309	506	534
	S9C	0:100	49	288	423	529
GS:RH	S9C	100:0	49	288	423	529
	S10C	70:30	61	259	461	600
	S11C	50:50	75	300	402	533
	S12C	30:70	60	328	471	600
	S1C	0:100	83	233	451	600

Table 5.4 Thermal Degradation Profiles

Fuel	Sample Name	Fuel Ratio	Temperature Range of Thermal Degradation ° C	Rate of Thermal Degradation mg/min	Percentage of thermal Degradation
RH:SD	S1C	100:0	451-546	6.37	41.72
	S2C	70:30	462-517	5.49	92.02
	S3C	50:50	441-529	10.25	30.00
	S4C	30:70	445-550	10.46	20.56
	S5C	0:100	440-566	12.64	13.79
SD:GS	S5C	100:0	440-566	12.64	13.79
	S6C	70:30	431-530	9.86	93.49
	S7C	50:50	382-403	2.18	82.32
	S8C	30:70	511-553	4.19	13.44
	S9C	0:100	423-434	1.22	71.24
GS:RH	S9C	100:0	423-434	1.22	71.24
	S10C	70:30	461-562	10.10	85.90
	S11C	50:50	402-534	3.76	90.25
	S12C	30:70	471-523	5.27	62.91
	S1C	0:100	451-546	6.37	41.72

Table 5.6 Activation Energy

Fuel	Sample Name	Fuel Ratio	Activation Energy KJ/ mol Kg °K
RH:SD	S1C	100:0	36.69
	S2C	70:30	35.59
	S3C	50:50	42.23
	S4C	30:70	39.13
	S5C	0:100	40.32
SD:GS	S5C	100:0	40.32
	S6C	70:30	43.02
	S7C	50:50	33.86
	S8C	30:70	35.64
	S9C	0:100	35.64
GS:RH	S9C	100:0	35.64
	S10C	70:30	40.70
	S11C	50:50	37.55
	S12C	30:70	38.32
	S1C	0:100	36.69

Table5.7. Ratio of fuels Vs Calorific value

Fuel	Sample Name	Fuels Ratio	Calorific Value of Chars GCV	
			K cal/kg	MJ/kg
RH:SD	S1C	100:0	3966	16.61
	S2C	70:30	3965	16.60
	S3C	50:50	3977	16.65
	S4C	30:70	4266	17.86
	S5C	0:100	4239	17.75
GS:SD	S5C	100:0	4239	17.75
	S6C	70:30	4242	17.76
	S7C	50:50	4290	17.96
	S8C	30:70	4944	17.70
	S9C	0:100	4722	19.77
GS:RH	S9C	100:0	4722	19.77
	S10C	70:30	4593	19.23
	S11C	50:50	4481	18.76
	S12C	30:70	4605	19.28
	S1C	0:100	3966	16.61

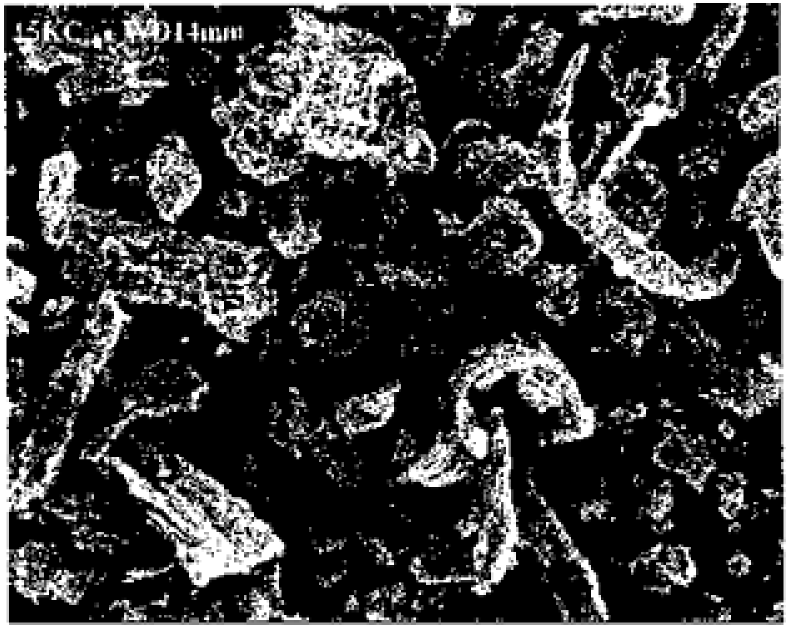
Table 5.9 Char Quantity

Fuel	Sample Name	Fuel Ratio	Char Quantity %
RH:SD	S1C	100:0	15.37
	S2C	70:30	20.22
	S3C	50:50	10.81
	S4C	30:70	12.12
	S5C	0:100	21.73
SD:GS	S5C	100:0	21.73
	S6C	70:30	10.00
	S7C	50:50	12.05
	S8C	30:70	10.00
	S9C	0:100	12.50
GS:RH	S9C	100:0	12.50
	S10C	70:30	14.80
	S11C	50:50	8.38
	S12C	30:70	6.29
	S1C	0:100	15.37

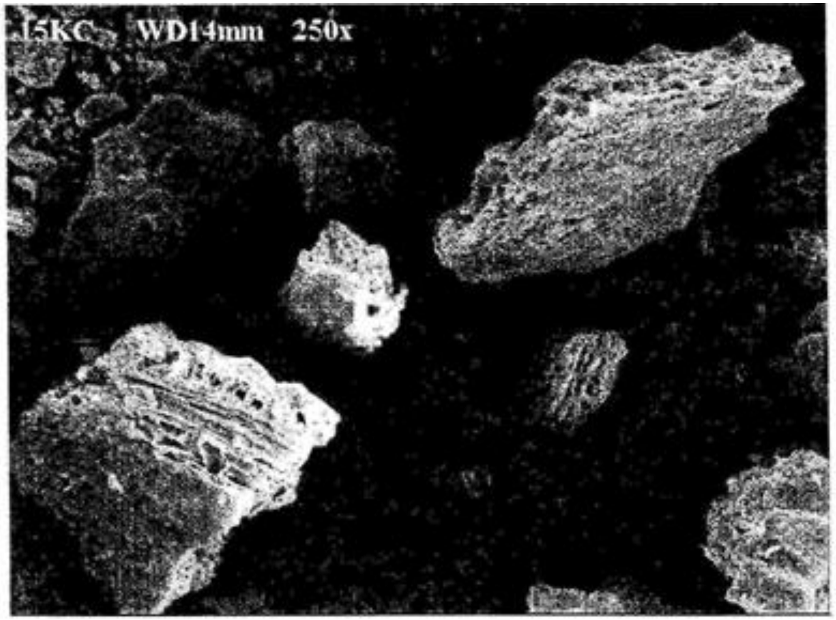
Microscopic analysis

- To look at the microscopic distribution of biomass residues in their mixed configuration & charred form SEM pictures were taken.
- To ascertain the effect of mixing and charring on homogeneity and compactness this is done.
- Deeper analysis is needed for quantifying the voids formation during mixing.
- Our study is limited to observing compactness in mixing
- From the microscopic analysis done for many samples we present our studies with 3 samples namely rice husk, saw dust and RH:SD 50:50 their respective chars.

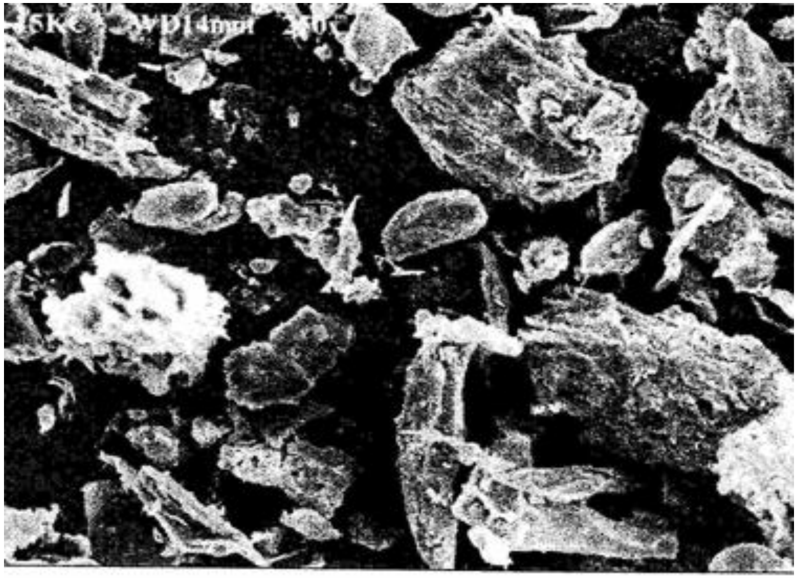
Rice Husk



Rice Husk Char

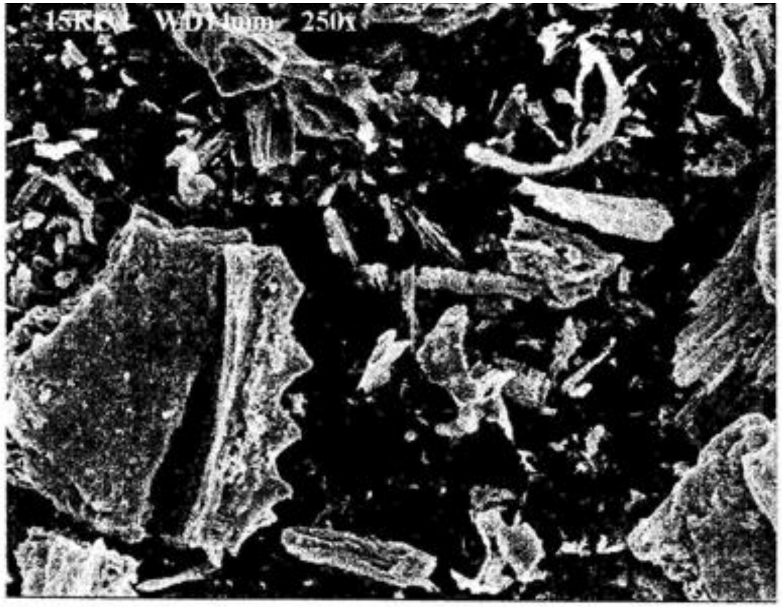


Saw Dust

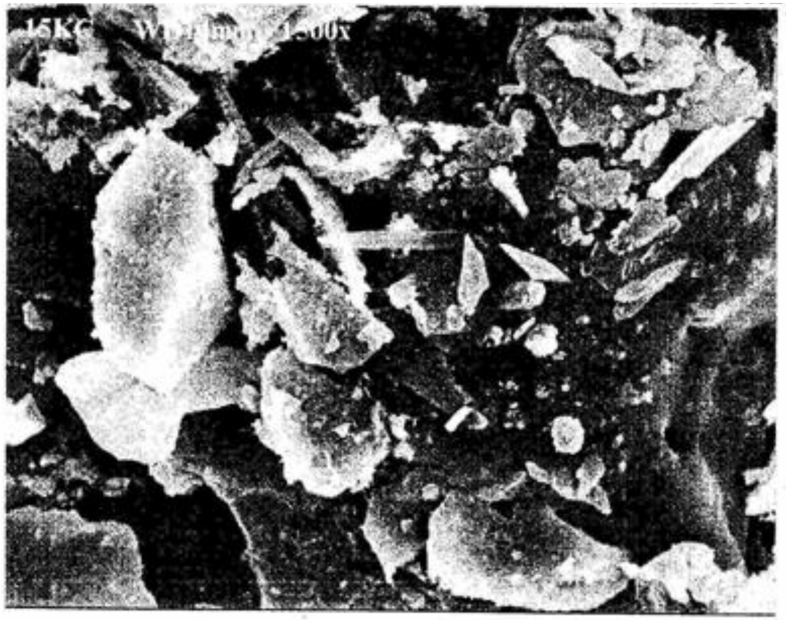


Saw Dust Char

RH : SD 50:50



RH : SD 50:50 Char



Conclusion of Microscopic analysis

- The photographs clearly show the presence of voids both in the host materials and also in their mixed configurations.
- The mixing process in the samples studied we do not get a clear picture on the contribution of voids (either showing increasing or decreasing tendency).
- However in the charred form one clearly sees the depth of compactness and the considerable reduction in the voids.
- Thus apart from the cleaner aspect of the fuel in the charred forms one also gets the benefit of better homogenization and compactness in the biomass residue chars.
- A detailed study in its own right on the influence of voids is probably required to throw more light on this aspect.

CONCLUSION

- The characterizations and analysis indicate that biomass residue mixtures are quite suitable as fuel resource particularly for the intermediate temperature range, especially in delivering industrial process heat.
- A few combinations are also suitable for high temperature applications such as electricity generation through the steam cycles.
- The present result quantifies the percentage of char coal yield from various bio residue mixtures.

CONCLUSION

- If suitably exploited, bio residue mixtures can be used more optimally for process heat and power generation either by themselves or by appropriate co-firing efforts with fossil fuels like coal and lignite.
- Using bio residue mixtures in the co-generation process is another option to be tried for reducing the energy gap between supply and demand.

CONCLUSION

- **Briquetting** the bio residue mixtures **as such** or **briquetting their chars** would be more desirable from energy delivery angle and environment angle.

THANK YOU