Reaction Rate of Electron Injected Air on biomass Gasification

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Ionization background

Charged species in flames:

Used for diagnostics and control in engineering applications

Examples: plasma-enhanced combustion, ionization sensors, flame blowout sensing

Understanding charged species concentrations:

Aids in developing control methodologies and diagnostic sensors

Research focus:

Gas combustion ionization (previous studies)

Our case: Solid fuel combustion without air carrier electron

Electric field interaction with flames:

Improves thermochemical technologies (pyrolysis, combustion, gasification)

Need to clarify key physical phenomenon for stabilization improvement

Challenges in modelling electric field interaction:

Lack of complete models in the literature

Assumptions made in existing models (e.g., constant electric field intensity, ion transport equation only)

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Our Objectives:

1

Developing a fast and robust tool to conduct a detailed study of the equilibrium composition of combusting fuel/air mixtures

2

COMMENT-Code (Combustion Mathematics and Energy Transport)

3

This mathematical model try to effectively tightens the gap between large-scale commercialized beds and pilot-scale testing models.

COMMENT Code

Experimental investigation on the effect of electron injection into air for thermal decomposition of solid waste. Applied Energy, 2021.

Numerical investigation on the effect of electron injected air for thermal decomposition of solid waste. Applied Energy, 2020.

Forest Residues Gasification in a Plasma Gasifier. Energy, 2019.

Ionized Gasifier Theory

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Ionization Airflow and Negative Pressure

Ionization airflow in enclosed reactor, Negative pressure state and Addition of oxygen breaks up [O_2]

Plasma State and Oxidation:

Highly reactive oxygen atoms, Plasma state with powerful energy and Complete oxidation of organic matter

Electric Field Effect and Carbide Formation:

Electron acceleration in electric field, Infiltration into organic molecules and Rapid carbide formation

Enhanced Heat and Mass Transfer:

Electric field-induced body force, Boosted flow vorticity and Improved air-fuel mixture

Thorough Decomposition:

All organic matter decomposed, Plastics, paper, chemicals, rubber (except wheel hubs) and Free-pollution disposal

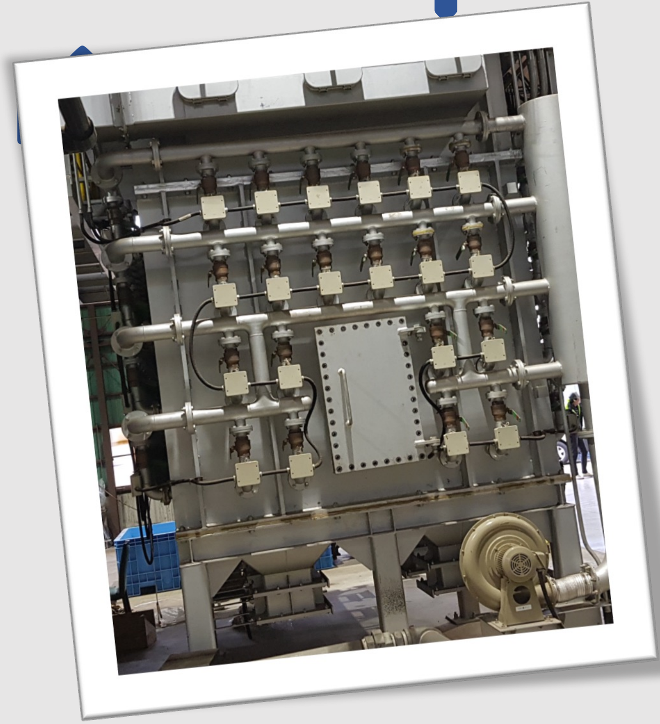
Negative Ion Generation:

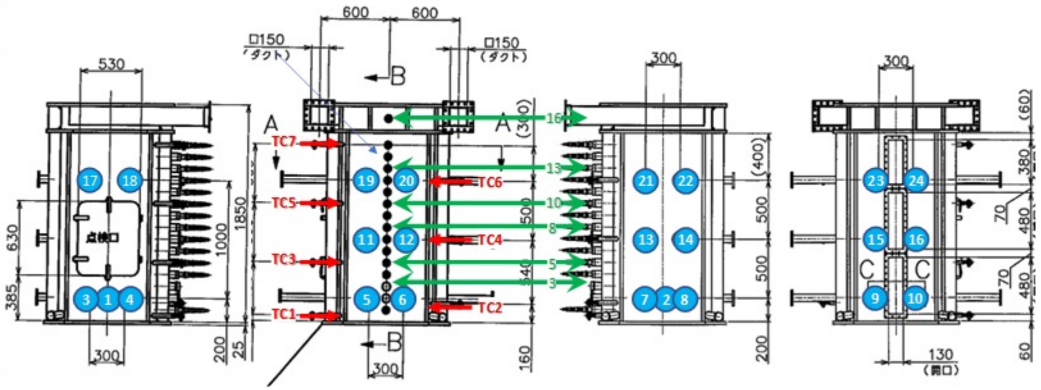
Negative ion emitter in airstream, No ground connection and Suppression of positive ions

Electron Emission Type

Piezoelectric transformer amplification, Rectification of AC voltage and Generation of negative ions

The Experimental Test





From bottom (cm)	TC1	TC2	TC3	TC4	TC5	TC6	TC7
	5	16	50	70	100	120	170

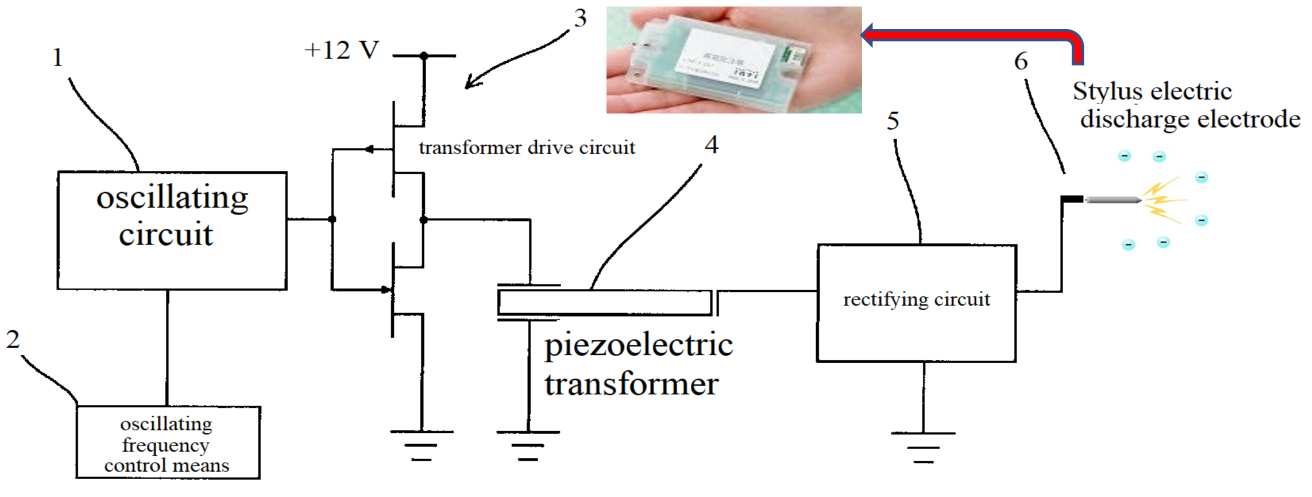
From bottom (cm)	3	5	8	10	13	16
	30	50	80	100	130	172.5

Air port · thermocouple · gas samplingport

Fig.1 Drawing of the up-draft fixed bed reactor showing the location of thermocouples and gas sampling ports

The study used a fixed bed reactor with electron injection or normal air supply. The reactor had a volume of $1 m^3$ and dimensions of 160cm x 80cm. Air was supplied through 20 ports, and electron concentration was 30,000 electrons/ml. Incomplete combustion occurred due to insufficient airflow

The Experimental Test rig



A Schematic circuitry diagram of the negative ion generator according to the present invention.

$1\ amp \equiv 6.23\times10^{23} electron/sec$ general case

$0.03\ amp \equiv 1.87\times10^{22} electron/sec$ present case

Reaction Mechanism

In hydrocarbon flames, ions and electrons are formed through chemi-ionization and subsequent ion chemistry.

Positive ions and neutral electrons appear naturally due to the complex chemical reactions occurring during combustion.

The movement of ions in the flame generates an electric body force, leading to the formation of an ionic wind.

The ionic wind causes bulk flow motion and modifies the overall flow field of the flame.

In the absence of external electric or magnetic fields, the ionic wind is a result of the distribution of charged species within the flame

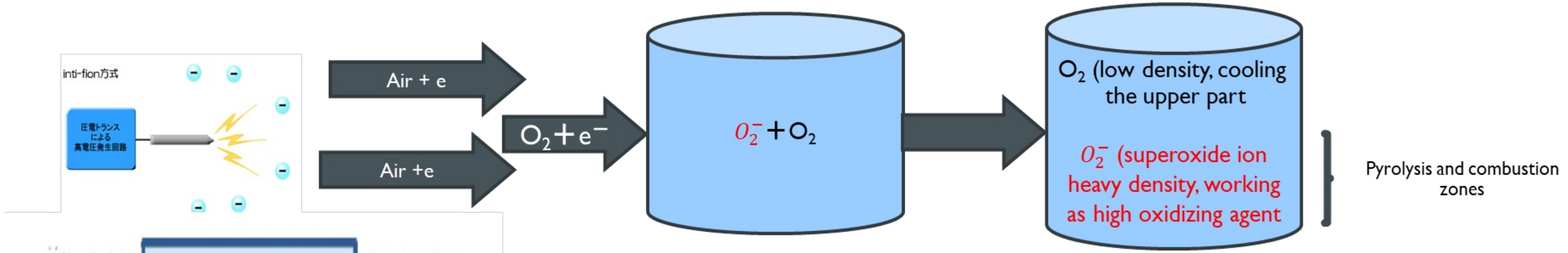
The direction of the ionic wind and resulting flow modification depend on factors such as the relative concentrations of positive and negative ions.

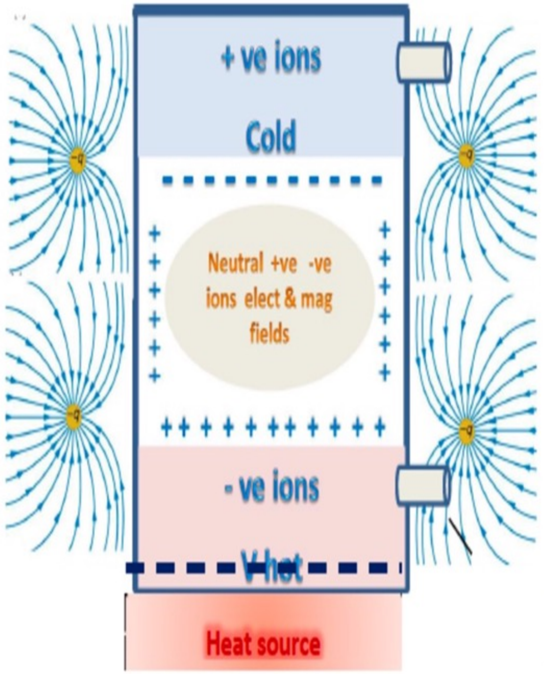
The skewing of the flame towards the cathode can be attributed to a net electric body force from positive ions outnumbering negative ions.

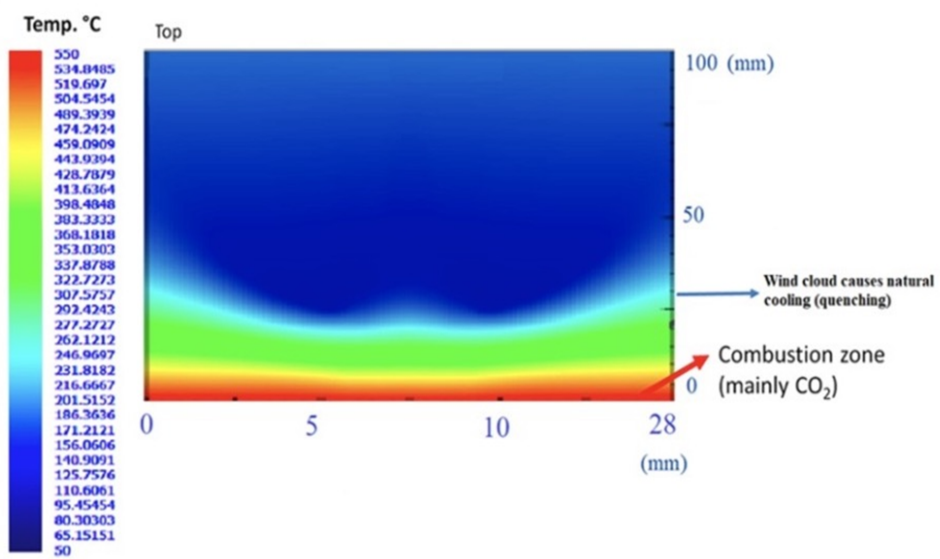
The ionic wind leads to a bi-directional flow and three-dimensional flow modification within the reactor.

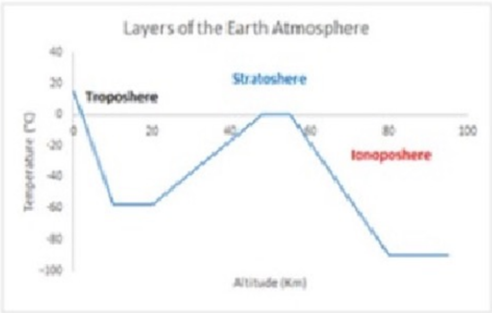
The behavior of the ionic wind is influenced by flame conditions, reactor geometry, and the presence of other gases or impurities.

Novel reactor

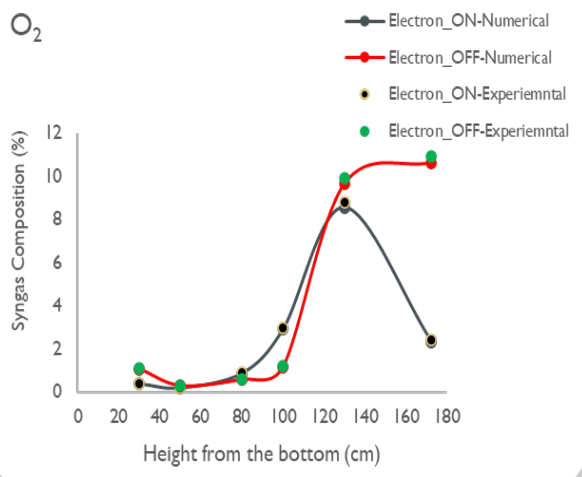


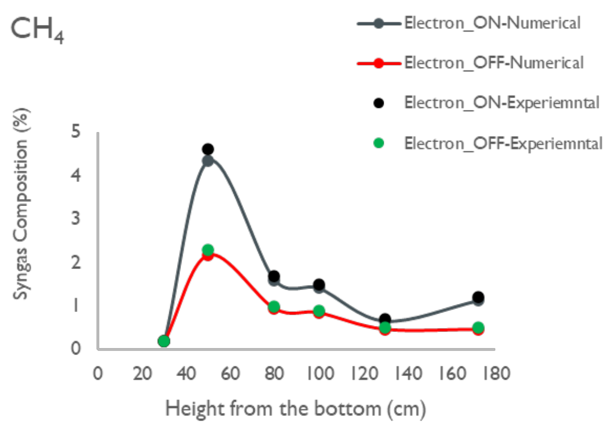


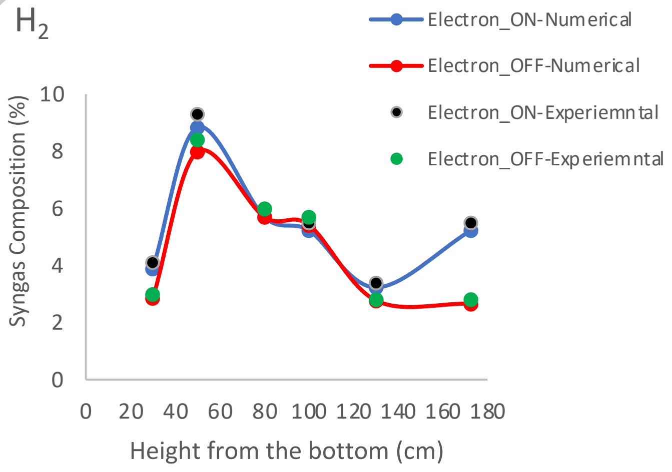


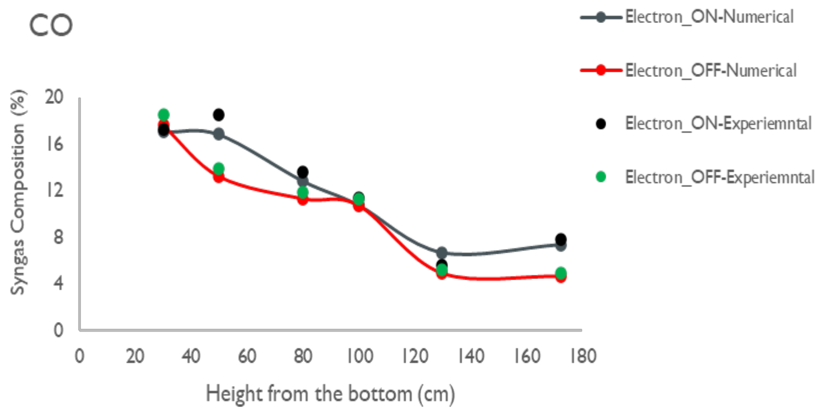


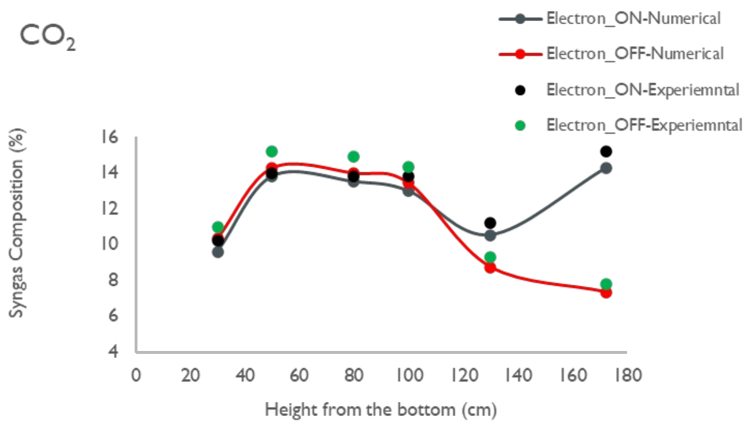
Results and discussions



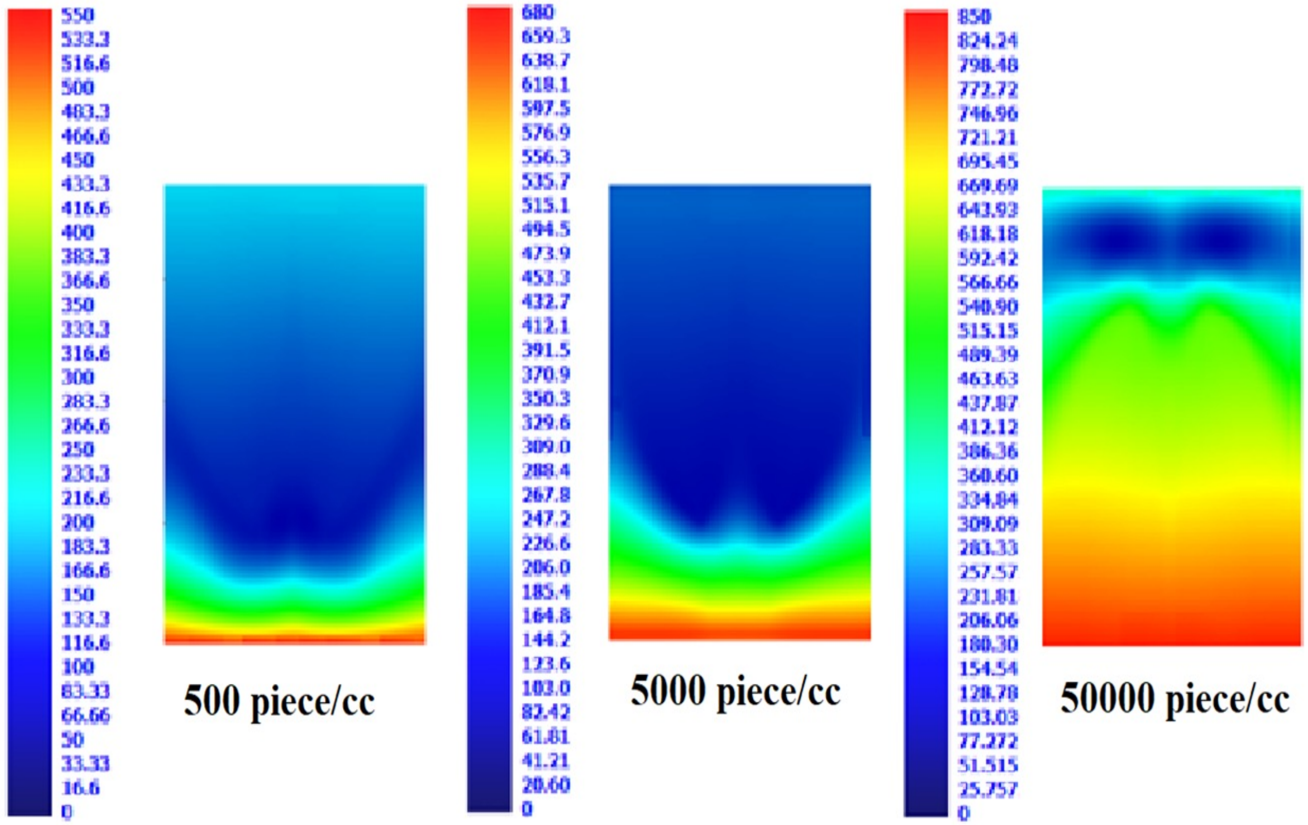








The RESULTS



ion recombination (discharge)

The hypothesis of the effect of ionized air.

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Finally, the following are deduced:

Electrons from each of anion generators collide with air and pyrolysis gas molecules in the air phase of pyrolysis zone, with generating secondary electrons.
→ions and radicals are generated.
→Faster combustion of gas
→Generated heat from combustion of gas transfers to combustion zone which has carbonized organic matters after pyrolysis.
→Faster combustion of char
→Total reduction rate becomes high compared with the case without anion generator.

The final word

Successful Simulations:

The experimental data obtained from Tokyo Institute of Technology, the proposed reactor was successfully simulated by the developed model

Processes:

The model considered all major chemical and physical processes involved during incineration. Significant agreement with the experimental measures were confirmed.

Conclusion

- The effect of electric field on the thermal decomposition of biomass improves the temperature homogenization, promotes the release of the main pyrolysis products (CO and CH_4) and increases the heat energy consumption. The mechanism of thermal decomposition of biomass caused by DC electric field is considered to be the overlap of "ion-wind" effect caused by field, which enhances the homogenization and stabilization of temperature and the field-induced interfacial polarization of biomass caused by field.

- The numerical results show that the effect of the electric field on the combustion is the reason why the field intensity enhances the ion wind movement, which by default enhancement the heat and mass transfer of biomass particles in the field and promotes the heating of biomass. Enhancing the formation of biomass thermal decomposition and volatile flow (CO, H_2).

The final word

Now We Can . . . .

Predict the flow of patterns and composition profile of gas product and the distributions of Chemi-ionization kinetics in the gasifier.

Now We Can . . . .

Recognize the complex gas-solid flow behaviors and chemical reactions in the process of gasification in the presence of free electron with the air.

MSW into Energy (HTT)

The widespread availability of MSW has been widely recognized, as has its potential to supply much larger amounts of useful energy with fewer environmental impacts than fossil fuels. MSW can be converted into commercial products via either biological or thermochemical processes.

Many thermochemical processes can be used to convert MSW into energy (incineration, pyrolysis, gasification, biochemistry, activation processes, etc.).

Approach and Contribution

- **Hydrothermal Treatment (HTT):**
  - Uses water and heat to convert MSW into usable products
  - Operating conditions are practical and buildable

- **Developed HTT:**
  - Lower temperature and pressure regions
  - Feasible and cost-effective

- **Advantages over other methods:**
  - Waste dichlorination
  - Suitable as a substitute for solid fuel

- **Economic Incentives:**
  - MSW disposal fees ($25 to $100 per ton)
  - Offsets extra processing costs

- **Sustainability Considerations:**
  - Energy and resource inputs
  - Environmental impacts of combustion

Note: HTT offers a promising solution to convert MSW into coal-like solid fuel, with potential economic benefits and reduced reliance on fossil fuels. However, sustainability aspects should be carefully evaluated.

Background

Coal genesis, the transformation from plant waste to black coal, is governed by many processes of polymerization, degradation and re-condensation. The study of coal genesis has a long history. Experiments imitating coalification by subjecting a material to heating with water under pressure were reported first by Bergius' in 1913. He called it hydrothermal carbonization, obtained a black product and defined the type of reaction to be valid only up to a certain degree of coalification.

What does hydrothermal treatment mean?

- Hydrothermal treatment (HT) converts solid waste using high temperature, pressure, and water.
- It changes waste properties, increasing energy density similar to high-quality brown coal.
- HT is suitable for wet waste like spent grain.
- Spent grain offers advantages in particle size, chemical properties, and mechanical compatibility.
- It enables high load capacity and homogeneous waste distribution.

objectives

1. To present an applied technology for converting MSW to a material like coal, to gain clean energy.
2. To present a developed mathematical model for such process
3. The mathematical model of the bed in the present work will be used to model the processing rate and combustion process.
4. **COMMENT-Code** investigates the species concentration, and temperature profile for gas and solid phases, with less sophistication, and with substantial savings in computational requirements.
5. This mathematical model try to effectively tightens the gap between large-scale commercialized beds and pilot-scale testing models.

Experimental Test Rig

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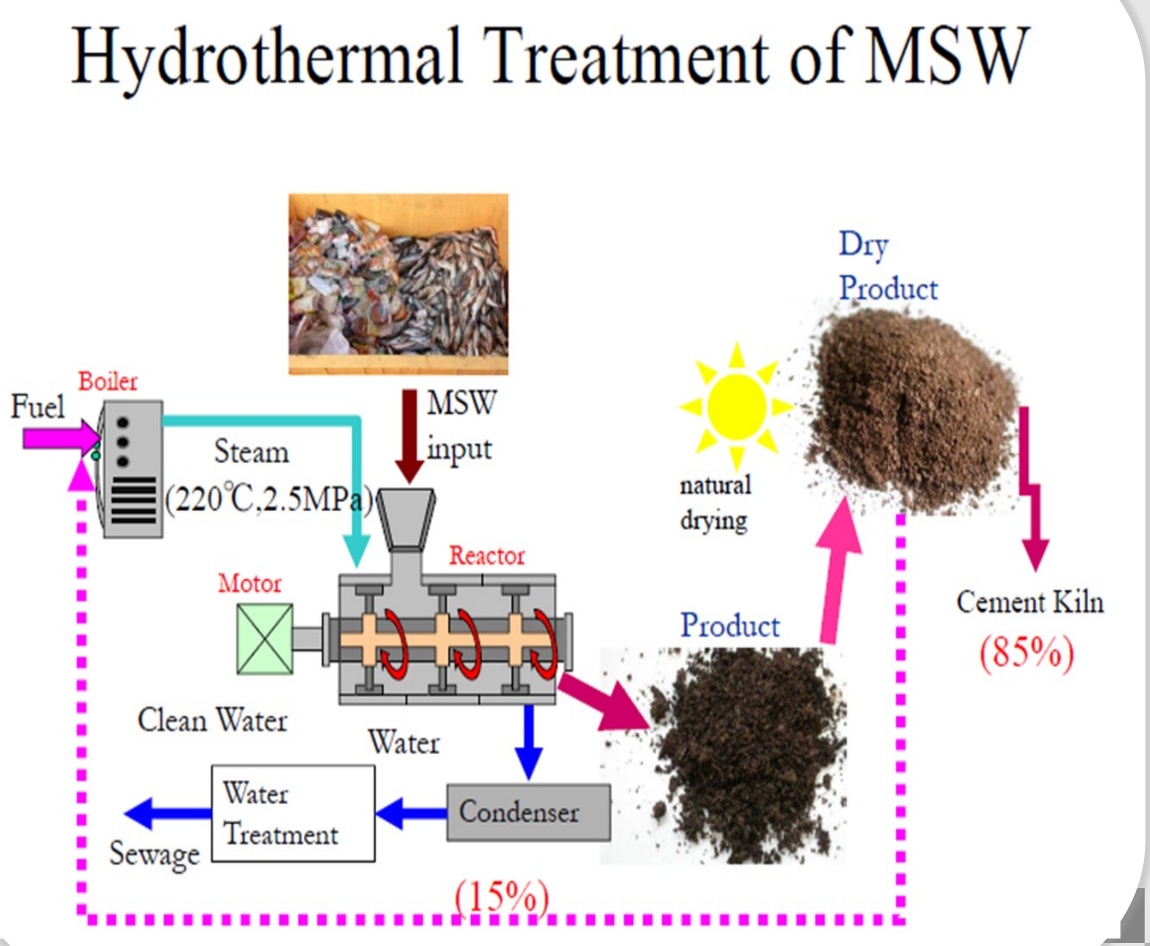
EXPERIMENTAL STUDIES WERE CONDUCTED TO VALIDATE THE PRESENT MODEL:

- This reactor test facility has been built at School of Environment and Society, Tokyo Institute of Technology, Japan.

- The MSW was first loaded into the reactor container.
- The container will be sealed and steam will be introduced into the reactor.
- As the temperature rises, the pressure in the system increases.
- During the reaction and discharge stages, water vapor will be generated from the system and passed through the downstream condenser.
- Mainly carbon dioxide, are suitable for discharge into the atmosphere.



MSW Treatment Physical Appearance

- So, now we have set of parameters affected the hydrothermal process that we must focus on it to enhance the output product and to reach the optimized operating conditions, such as:

  1- Pressure
  2- Temperature
  3- Steam
  4- Flow rate
  5- Continuous process instead of batch process

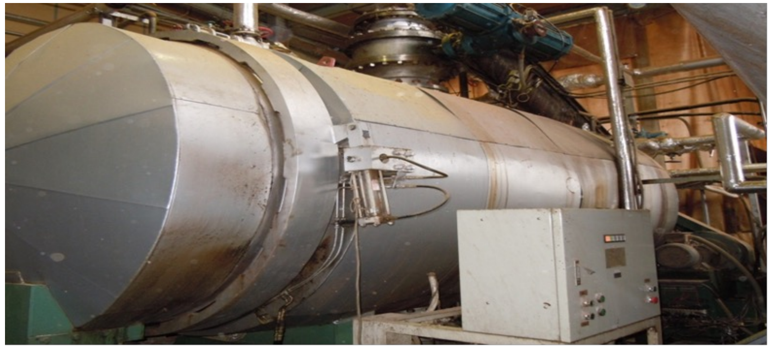
As for example

Raw MSW

2 MPa

2.4 MPa

Photos



Food Wastes (10m^3)
Japan

Sewage Sludge (7.8 m^3)
China

25t/day MSW Plant (Jakarta)

The Mathematical Model

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A hydrothermal treatment model for Municipal Solid Waste (MSW) is studied using the COMMENT code. This code, written in C#, has been successfully used for modeling various processes and reactors. By conducting parametric studies, researchers can optimize the design and operating conditions of the process while generating a large amount of data. This mathematical modeling approach is widely recognized as a valuable tool in gasification research

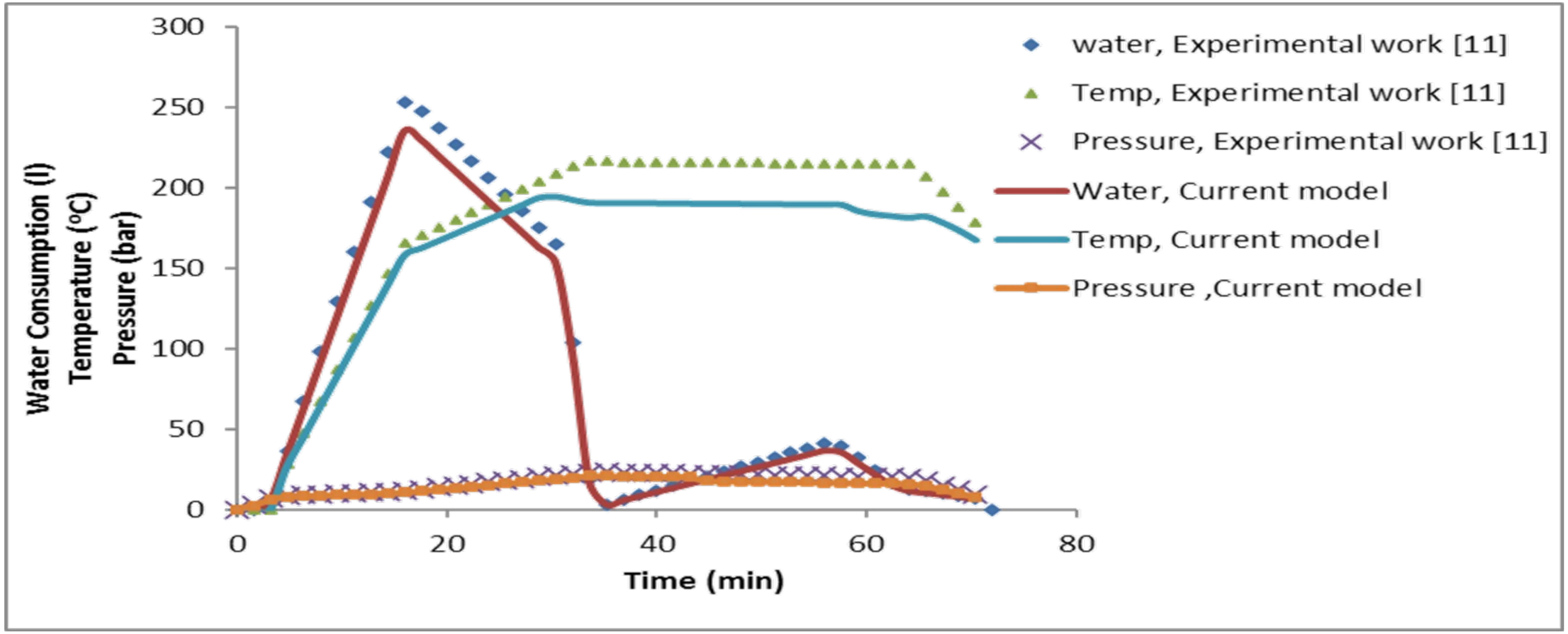
- **Step 1** — Coalification model
- **Step 2** — Arrhenius-type overall kinetic equations
- **Step 3** — Energy and mass balance

Integration between Energy and CFD

- CFD reduces costs and time-to-market for new products.
- Expertise in air quality, fuel combustion, wind resource management, and more.
- Accurately predicts fluid flow and aids design evaluations.
- Models complex thermal and fluid flow in systems like incinerators and gasifiers.
- Driving force in industries and growing in R&D, manufacturing, and more.
- Theoretical model development for better waste combustion understanding.
- COMMENT-Code: Mathematical model for simulating combustion in packed beds.

Validation of the present model

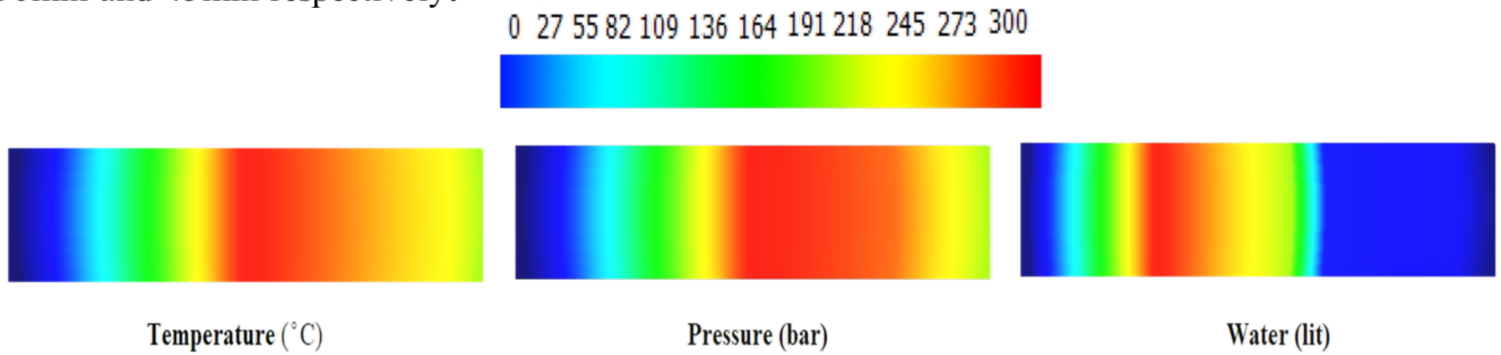
The comparison between the numerical model and the existing experimental results for hydrothermal process characteristics with short holding time (30min) for reactor of 3 m^3 volume, T=215°C, P= 2MPa, mass of MSW= 707kg.



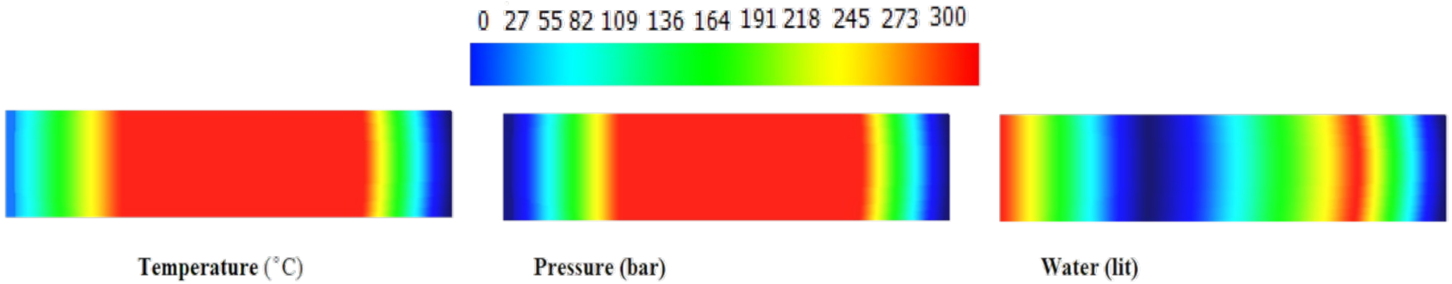
[11] Prawisudha P, Namioka T, Yoshikawa K. Coal alternative fuel production from municipal solid wastes employing hydrothermal treatment. Applied Energy. 2012 Feb 1;90(1):298-304.

Results

- Display the calculated temperature, pressure and water contours of the basic case inside the reactor of 10m³ in volume for two different holding period, 30min and 45min respectively.



Numerical contours for temperature (°C), pressure (MPa) and water (lit) within the HTT reactor for 30min holding period with pressure 2.5 MPa, 1500kg steam and 3770 kg MSW.



Numerical contours for temperature (°C), pressure (MPa) and water (lit) within the HTT reactor for 45min holding period with pressure 2.5 MPa, 1400kg steam and 3035 kg MSW.

The Final Word

Successful Simulations:

The experimental data obtained from the HTT test rig was successfully simulated by the developed model

Processes:

The model considered the major processes involved during hydrothermal process. Good agreement with the experimental measures were confirmed.

Conclusion

Hydrothermal Treatment of MSW: Mathematical Model

Model based on mass and energy balance equations
Predicts temperature, pressure, and water distribution
Accurate temperature distribution compared to experiments
Provides additional information and avoids costly equipment construction
Aids in designing and scaling-up systems efficiently.

Acknowledgment

- Many thanks to Professor Kunio Yoshikawa at Tokyo Institute of Technology (TIT) for his continuous support, supervision and the fruitful discussion.
- Special thanks are directed towards Dr. Kobori for technical supervision in this work during the experimental and theoretical work.
- We also would like to express our gratitude to all the collaborators from the Tokyo Institute of Technology

Thank You

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