EB2W UNiLAB

- National University of Singapore, Singapore
- University of Tokyo, Japan
- Ghent University, Belgium
- Shanghai Jiao Tong University, China
- Korea University, South Korea
- Sejong University, South Korea
- National Taiwan University, Taiwan
- The University of British Columbia, Canada
- University of Glasgow, UK

Missions of EB2W UNiLAB

EB2W is a virtual lab regarding the gasification-based conversion of energy and biochar from biomass/solid waste via linking the experts of gasification, renewable energy, waste management, and biochar. The program focuses on the technical research of conventional/solar gasification, the advanced cooling driven by waste heat from gasification-based CCHP system, and biochar, which covers wide scopes of chemical engineering, mechanical engineering, and environmental engineering. The proposed research program aims to build an inter-disciplinary collaboration, which promotes fundamental research and application design, using expertise from eight regions (South Korea, Japan, China, Taiwan, Hong Kong, Singapore, Canada, UK and Belgium).
Model-based downdraft biomass gasifier operation and design for synthetic gas production

Wei-Cheng Yan, Ye Shen, Siming You, Soong Huat Sim, Zheng-Hong Luo, Yen Wah Tong, Chi-Hwa Wang *

In this study, three-phase flow model together with a thermal-equilibrium model was developed to study the operation of downdraft biomass gasifiers. Gasification experiments were conducted to obtain pyrolysis kinetics and validate the models. A good agreement was found between experiment data and model predictions, in terms of syngas composition and temperature, respectively. Kinetics based on experimental study improves the accuracy of simulation. The thermal-equilibrium model was applied to study the effects of air to biomass ratio on gas composition, LHV (lower heating value), and temperature. The 3D multiphase flow model was applied to investigate the spatial distributions of various parameters (i.e. pressure, gas velocity, temperature, and gas composition) inside the gasifier that are critical to the design of gasifier.

A rough division of four gasification zones was determined based on temperature profile. It was also found that the cold gas efficiency was around 63% based on CFD (computational fluid dynamic) simulation. The temperature distributions could be used to guide the application of heat resistant materials inside the gasifier. In addition, the simulation results indicated that blockage of the gasifier has a high chance to occur at the top of reduction bell when using feedstock of high metal contents. Effects of reduction bell dimension and operation conditions on the temperature distribution and syngas production were also investigated by the 3D CFD model, which sheds light on the improvement of the design and operation of reactor. The syngas production could be enhanced by varying the size of reduction bell.

The physical model and the grid of gasifier for CFD simulation.

Temperature and syngas composition distributions inside the gasifier.

Char distribution inside the gasifier.

Scheme diagram of cone and quartering method for biomass sampling.
Characterization of bioenergy biochar and its utilization for metal/metalloid immobilization in contaminated soil

XiaoYang, Avanthi D. Igalavithana, Sang-Eun Oh, Hyungseok Nam, Ming Zhang, Chi-Hwa Wang, Eilhann E. Kwon, Daniel C.W.Tsang, Yong Sik Ok

This study is a comparison of the effect of biochar produced by bioenergy systems, via the pyrolysis and gasification processes, on the immobilization of metals/metalloids in soil. Because the processes for these two techniques vary, the feedstocks undergo different heating regimens and, as a result, their respective char products exhibit different physicochemical properties. Therefore, this study focuses on (1) the characterization of derivative biochar from the bioenergy system to understand their features and (2) an exploration of various biochar impacts on the mobility of As and Pb in contaminated soil. The results showed bioenergy biochars (BBCs) performed well in mitigating Pb extractability (1 M ammonium acetate) with a Pb immobilization >80%, but unfavorably mobilized the bioavailable As, likely because of electrostatic repulsion and ion exchange competition. The BBC surface functional group would chemically bond with the As and remain stable against the pH change. An increment in aromatic carbon would effectively enhance cation-π interaction for Pb immobilization. Nevertheless, an amendment with richer condensed structure and higher inorganic minerals (Ca$,^2+$, K$,^+$, Mg$,^2+$, and Na$,^+$) can lead to better performance in retaining Pb.

The immobilization of Pb and As contaminants from soil onto BBCs was also comprehensively investigated. The properties of BBC are closely related to their immobilization rate of Pb and As in soil. For Pb, the high pH and more highly condensed carbon as well as the high inorganic minerals (exchangeable cations) facilitate Pb immobilization. For As, the abundant surface functionality and less negatively changed carbon surface is helpful in retaining As. A large surface area of biochar amendment might play a role in retaining contaminants, but it is not required.

The immobilization of Pb and As contaminants from soil onto BBCs was also comprehensively investigated. The properties of BBC are closely related to their immobilization rate of Pb and As in soil. For Pb, the high pH and more highly condensed carbon as well as the high inorganic minerals (exchangeable cations) facilitate Pb immobilization. For As, the abundant surface functionality and less negatively changed carbon surface is helpful in retaining As. A large surface area of biochar amendment might play a role in retaining contaminants, but it is not required.

SEM images of BBCs from algae at 500 °C (a), sorghum at 500 °C (b) and 600 °C (c), and dairy manure at 600 °C (d).

Geochemical fractions of Pb and As analysis by sequential extraction. A-500, S-500, S-600 and DM-600 represent the BBC produced from algae at 500 °C, sorghum at 500 and 600 °C, and dairy manure at 600 °C.

Evaluation of sewage sludge incineration ash as a potential land reclamation material

Wenlin Yvonne Lin, Wei Cheng Ng, Belinda Shu Ee Wong, Serena Lay-Ming Teo, Gayathiri d/o Sivananthan, Gyeong Hun Baeg, Yong Sik Ok, Chi-Hwa Wang

This study evaluated the potential of utilising sewage sludge incineration ash as a land reclamation material. Toxicity assessment of the leachate of the ash was carried out for both terrestrial and marine organisms. Both the fruit fly Drosophila melanogaster and barnacle Amphibalanus amphitrite showed that both bottom and fly ash leached at liquid-to-solid (L/S) ratio 5 did not substantially affect viabilities. The leachate carried out at L/S 10 was compared to the European Waste Acceptance Criteria and the sewage sludge ashes could be classified as non-hazardous waste. The geotechnical properties of the sewage sludge ash were studied and compared to sand, a conventional land reclamation material, for further evaluation of its potential as a land reclamation material. It was found from direct shear test that both bottom and fly ashes displayed similar and comparable shear strength to that of typical compacted sandy soil based on the range of internal friction angle obtained. However, the consolidation profile of bottom ash was significantly different from sand, while that of fly ash was more similar to sand. Our study showed that the sewage sludge ash has the potential to be used as a land reclamation material.

In terms of the toxicity assessment, when the leachate was tested using Drosophila melanogaster, the results showed that the leachate did not affect the viability of the fruit flies. For the leachate generated using seawater, no overt toxicity was detected on Amphibalanus amphitrite. More detailed studies may be conducted to determine if the mild toxicity detected in the SSFA has any longer term impacts. However, no toxicity was detected in the seawater leachate of SSBA. From geotechnical testing, both SSBA and SSFA displayed similar and comparable shear strength to that of typical compacted sandy soil. On the other hand, SSBA may not be suitable to be used as fill material on its own due to its poor consolidation property but SSFA and its mixture with 25% SSBA had more similarity in the consolidation properties than that of sand.
A comparative life cycle assessment on four waste-to-energy scenarios for food waste generated in eateries

Huanhuan Tong, Ye Shen, Jingxin Zhang, Chi-Hwa Wang, Tian Shu Ge, Yen Wah Tong

A life cycle assessment (LCA) was conducted to determine the best solution for dealing with the food waste (FW) generated in Singapore eateries. Since the representativeness of the life cycle inventory (LCI) data determined the overall quality of the LCA, this study made a significant endeavor to capture the local specificities, such as waste composition, water supply and treatment plant operation. Characterization data showed that eatery FW from Singapore contained 16% non-biodegradable impurities (such as plastic and metal) and a higher methane generation potential was found in FW from the dining table than in FW from the kitchen. Based on the FW chemical element composition, mass balances were established for the four examined scenarios, including incineration (Inci), anaerobic digestion (AD) followed by composting (ADcom), AD followed by incineration (ADinci) and AD followed by gasification (ADgas). Because of the environmental benefits from compost production in addition to electricity generation, ADcom outperformed other scenarios in all impact categories except Eutro (eutrophication), GW (global warming) and POC (photochemical ozone creation). The best score of GW was observed in ADgas, mainly ascribed to the highest electricity output and the carbon sequestration of biochar. The disadvantages of the AD scenarios in Eutro and POC were associated with NOx and CO emissions from the biogas engine. Finally, the sensitivity analysis demonstrated that better environmental profiles could be achieved if improvements can be made by minimizing water usage, mitigating gas engine pollution, and diverting as much FW as possible from incineration plants to AD plants. However, based on the local context, source separation was not an urgent issue for improving the sustainability of eatery FW management.

Environmental impacts of each scenario with process contributions (per functional unit).
Simultaneous syngas and biochar production during heavy metal separation from Cd/Zn hyperaccumulator (Sedum alfredii) by gasification

Xiaoqiang Cui, Ye Shen, Qianying Yang, Sibudjing Kawi, Zhenli He, Xiao Yang, Chi-Hwa Wang

Phytoremediation is increasingly recognized as a cost-effective approach for remediation of heavy metal (HM) contaminated soils, whereas the derived HM-enriched hyperaccumulators must be properly harvested and disposed. In this study, gasification of Sedum alfredii was performed at a temperature series (300–900 °C) with different gasifying agents (N2, CO2 and air), then the transfer behaviors of zinc (Zn), cadmium (Cd), and lead (Pb) and the characteristics of the derived biochar and syngas were investigated.

The high gasification temperatures and reducing atmosphere (N2) effectively enhanced the volatilization of Zn, Cd, and Pb, and the results from toxicity characteristic leaching process indicate that gasification greatly enhanced the stability and reduced the availability of HMs in S. alfredii. The CO2-derived biochars had moderate pH and greater stability, while the N2-derived biochars showed better energy density. The evolution of functional groups and crystalline phases in biochars were both influenced by the temperature, and the role of atmosphere was increasingly obvious at temperatures above 600 °C. As expected, biochars derived under N2 and CO2 both showed considerable sorption capacity for Pb (134.2–198.8 mg g⁻¹) and Cd (38.1–186.8 mg g⁻¹). CO2 atmosphere greatly enhanced the production of CO at higher temperatures (>700 °C), while N2 atmosphere favored the yield of H2 and CH4. These results imply that gasification could be a promising technique to achieve the separation of HMs from hyperaccumulator as well as the production of energy and multifunctional material, and this process is greatly affected by the gasification temperature and atmosphere.
Integrated downdraft gasification with power generation system and gasification bottom ash reutilization for clean waste-to-energy and resource recovery system

T. Maneerung, X. Li, C. Li, Y. Dai, C. H. Wang

In this work, the small-scale downdraft gasification system was integrated with a set of internal combustion engine power generation and successfully used for converting biomass waste into energy in the forms of electricity and heat. The performance of integrated system was investigated by using redwood pellets with a lower heating value of 17 MJ/kg as a feedstock.

Schematic of the gasification-based CHP system.

Exergy flows of the gasification-based CHP system (unit: MJ/h): (a) P = 4 kW, (b) P = 6 kW, (c) P = 8 kW, and (d) P = 10 kW.

Apart from syngas, gasification system also generates significant amount of bottom ash that can be harmful to the environment and public health if it is not treated properly. Therefore, this work also focused on the reutilization of bottom ash in order to reduce the environment and health concerns associated with its disposal, making the overall process more environmentally friendly. From elemental analysis, bottom ash produced from redwood pellets gasification contains significant amount of silica, making it become a highly potential source for synthesizing silica-containing compounds. In this work, alkali hydrothermal reaction has been successfully used to convert this bottom ash into zeolite (or aluminosilicate compound) which can be potentially used as an adsorbent material.

SEM images of bottom ash obtained from gasification of redwood pellets.

The effect of electric power load P on syngas composition and LHV

Zeolites prepared from alkali hydrothermal reaction of bottom ash activated carbons.

Jingxin Zhang, Xiang Kan, Ye Shen, Kai-Chee Loh, Chi-Hwa Wang, Yanjun Dai, Yen Wah Tong

A hybrid biological and thermal waste-to-energy system in lab-scale level of application was developed to combine a 1000L anaerobic digester and a 10 KW gasifier for solid organic wastes treatment and energy generation. Energy performance of the single system (anaerobic digestion (AD) and gasification) and the integrated AD – gasification system treating blended food waste (FW) and medium-sized woods chips (WCs) by cutting or chipping were studied.

The results showed that the methane yield of AD of FW was 0.52 L CH4/g VSt/d with a volatile solid reduction rate of 85%. Producer gas with over 34% of CH4, H2, and CO was generated from gasification of WCs with biochar as a by-product. A small amount of the methane-rich gas generated from AD were mixed with a large amount of producer gas generated from gasification in a gas storage tank, improving the heating value of the producer gas. The waste heat generated from the gasification of WCs was used for the heat preservation of AD, increasing the overall energy efficiency of the integrated AD-gasification system. When the treatment capacity ratio of AD to gasification is below 0.4, the integrated AD - gasification system can operate with a self-supply heat recovery system.

(A) Concept map of the hybrid biological and thermal waste-to-energy system. (B) Energy flow of the waste-to-energy system. (C) Sankey diagram of the waste-to-energy system.

Schematic diagram of the 10 kW fixed bed down-draft gasifier.

(A) Comparison of overall energy efficiency among single-stage AD, single-stage gasification and the integrated waste-to-energy system under different capacity ratio of AD to gasification; (B) Concept map of heat energy recovery at the heat energy balance point. (C) Sankey diagram of the waste-to-energy system at the heat energy balance point.

An investigation on utilization of biogas and syngas produced from biomass waste in premixed spark ignition engine

Xiang Kan, Dezhi Zhou, Wenming Yang, Xiaoqiang Zhai, Chi-Hwa Wang

Syngas and biogas are two typical biofuels generated from biomass wastes through gasification and anaerobic digestion processes, which are considered to be the future fuels for IC engines.

In this work, the utilization of biogas and syngas produced from horticultural waste in a premixed spark ignition engine was investigated. An experimentally validated KIVA4-based CFD simulation integrated with CHEMKIN was performed to evaluate engine performance fuelled by syngas and biogas under both single and blended-fuel modes. Effects of ignition timing, hydrogen content in syngas and methane content in biogas on both energetic and environmental performance have been studied. The indicated thermal efficiency (ITE) of syngas fueled engine at wide open throttle (WOT) condition under maximum brake torque (MBT) operation was found to be higher than that of biogas fueled engine, meanwhile, with much lower NOx emission. In addition, a comparison of the engine performance between the single and blended-fuel modes under different syngas mixing ratios was conducted in terms of ITE and NOx emission. The results suggest that the utilization of syngas and biogas under blended-fuel mode can not only maintain the MBT energetic performance under single-fuel mode, but also show its potential in reducing NOx emission and lessening the tendency of knock onset.

Effects of hydrogen content and ignition timing on indicated thermal efficiency and NOx emission for syngas fueled engine; (a) indicated thermal efficiency, (b) NOx emission.

Comparison of NO (mass fraction) and temperature distribution at 20 CAD ATDC between single and blended-fuel mode.

Comparison of NOx emission and indicated thermal efficiency between single and blended-fuel mode under various syngas ratios ('S' denotes single-fuel mode; 'B-I' denotes blended-fuel mode case I; 'B-II' denotes blended-fuel mode case II).

MBT operation for syngas fueled engine at WOT condition is found at ignition timing of 26 CAD BTDC with ITE of 39.0%, higher than that of biogas fueled engine, 37.5%. Under MBT operation, the NOx emission of the syngas fueled engine, 3.3 g/kWh, is much lower than that of biogas fueled engine, 7.2 g/kWh.

For syngas fueled engine, increase in hydrogen content raises the ITE at smaller ignition advance, however, it decreases ITE when ignition advance is relatively larger. Impact of hydrogen content on NOx emission is comparatively insignificant, whereas advance in ignition timing will increase the NOx emission.

For biogas fueled engine, increase in methane content will lead to an enhancement in both ITE and NOx emission. Ignition advance is also found to have a positive effect on the increase of the NOx emission due to the more complete combustion of methane content.

The utilization of syngas and biogas under blended-fuel mode can maintain the MBT energetic performance under single-fuel mode and shows its advantage in largely reducing the NOx emission and lessening the tendency of knock onset.
EB2W Technique Translation and Collaboration with Industries

Technologies

Characterization of solid waste
- Woodchips
- Sludge
- Horse & Chicken manure

Valuable materials from Biochar

Gasification

Combined cooling, heat and power

Test Bedding
- 1kg woodchips can produce about 2 m³ of syngas
- Feeding rate of biomass is about 10 kg/h for 10 kWe and 30 kg/h for 20 kWe.

R&D Translation

1 MWe
- Collaborated with

20 kWe
- Technical specifications of Gasifier:
  - Gasifier type: 1800 - 1100 °C
  - Gas flow rate: 3.750 m³/h
  - Moisture content: up to 30%
  - Biomass feed: On-line batch

10 kWe
- Technical specifications of Gasifier:
  - Gasifier type: 1800 - 1100 °C
  - Gas flow rate: 3.750 m³/h
  - Moisture content: up to 30%
  - Biomass feed: On-line batch

Temperature ranges:
- Pyrolysis: 550 to 800 °C
- Combustion: 900 to 1150 °C
- Reduction: 650 to 900 °C