Entrained Flow Gasification of Municipal Solid Waste and Coal Mixture

Idowu Adeyemi, Haider Khan, and Isam Janajreh*

Mechanical Engineering Department, Khalifa University, Abu Dhabi, United Arab Emirates
Center for Membranes and Advanced Water Technology, Khalifa University of Science and Technology, Abu Dhabi, United Arab Emirates

21 JUNE 2023

Outline

- INTRODUCTION
- OBJECTIVE
- MATERIALS & METHOD
  - Material characterization
  - Low fidelity modeling
  - Kinetic study
  - High fidelity modeling
- RESULTS
  - Materials Characterization and Low Fidelity
  - Kinetic Study and High Fidelity
- CONCLUSION

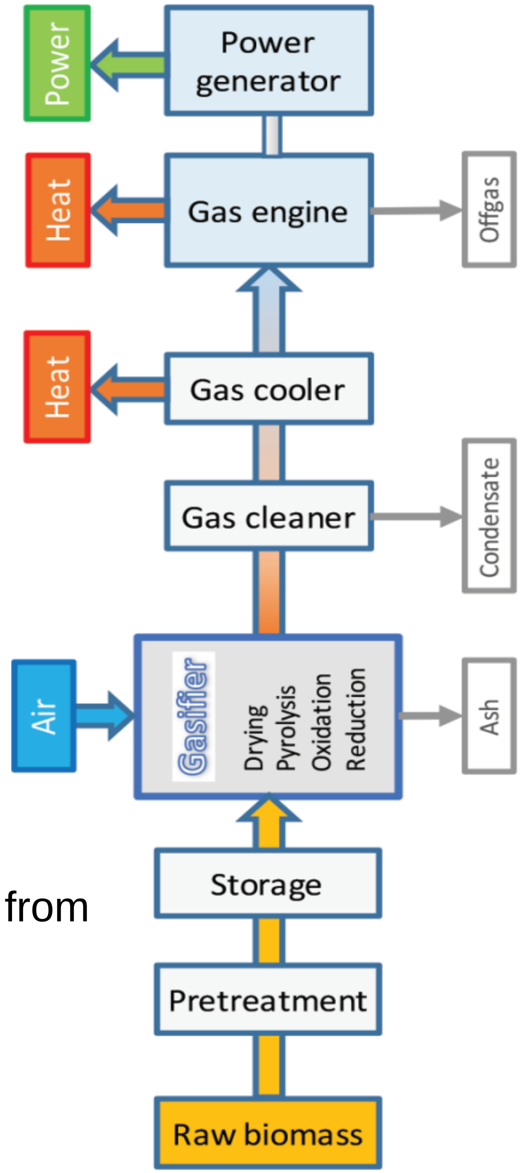
Introduction

1. *Waste to energy* is an emerging concept that raps on the abundant and steadily increasing municipal solid waste (MSW) due to urbanization and human development.

2. MSW generation is strongly correlated with human development averaging daily over 1kg in the underdeveloped economy to over 2kg in developed nations. MSW is huge (about 2Bt in 2021) and is increasing gradually, and it is projected that it reaches 2.2 and 4.2Bt by 2025 and 2050, respectively [1].

3. According to United Nations Environment Program (UNEP), solid waste contributes to about 5% of the global greenhouse gases (GHGs), especially carbon dioxide (CO_2) and methane (CH_4) [2].

4. Gasification is considered a mature and proven technology for a variety of feedstock including coal, biomass, auto-shredder residue, and fossil fuels. However, gasification of MSW or its segregated derivatives such as plastics is relatively recent, and is facing number of technical barriers [3].



Flow diagram of power generation from biomass gasification produced [4]

[1] Danish MSS, Senjyu T, Zaheb H, Sabory NR, Ibrahimi AM, Matayoshi H. A novel transdisciplinary paradigm for municipal solid waste to energy. J Clean Prod 2019;233:880e92. https://doi.org/10.1016/ j.jclepro.2019.05.402.
[2] UNEP. Solid waste management. 2019. https://www. unenvironment.org/explore-topics/resource-efficiency/ what-we-do/cities/solid-waste-management. [Accessed 24January 2021].
[3] Gershman, Brickner and Bratton, solid waste management consultants: Gasification of Non-Recycled Plastics From Municipal Solid Waste In the United States, The American Chemistry Council, GBB/12038-01 August 13, 2013, www.gbbinc.com
[4] Koido K, Iwasaki T. Biomass gasification: a review of its technology, gas cleaning applications, and total system lifecycle analysis. Lignin - Trends Appl., InTech; 2018.

Introduction

There is limited literature on MSW gasification compared to coal and their co-gasification.

1. *Alvarez et al. [1] studied plastic and biomass co-gasification, finding that adding plastic increased H_2 syngas fraction, with PP favoring H_2 production over PS* [1].

2. Armin et al. [2] simulated plasma co-gasification of MSW and coal, discovering that higher H_2 production occurred at low equivalence ratios or high steam ratios. Maximum H_2 production was achieved with high amounts of coal and low steam to waste ratio (SWR) or high amounts of MSW and high SWR.

3. Zaccariello et al. [3] analyzed fluidized bed gasification of plastic waste, woody biomass, and coal blends, observing a reduction in hydrogen content from plastic gasification but enhanced CO, H_2, and CO_2 production from woody biomass.

4. Ding et al. [4] analyzed co-gasification of MSW with bituminous coal in a CO_2 atmosphere, finding improved gasification with the addition of MSW due to the easier gasification of MSW char compared to coal char.

Sl number	Feedstock	Gasifier Type	CO mole fraction	H_2 mole fraction	Reference
1	Coal/Biomass	Fixed-Bed	0.28	0.46	[3]
2	Coal/Plastics	Fluidized-Bed	0.32	0.42	[4]
3	Coal/Wood	Fixed-Bed	0.29	0.45	[5]
4	Biomass/Coal	Fluidized-bed	0.34	0.4	[6]
5	Biomass/Waste Plastic	Entrained-flow	0.33	0.41	[7]
6	Waste Plastic/ Biomass	Entrained flow	0.31	0.42	[8]
7	Coal/ Municipal Solid waste	Fixed-Bed	0.28	0.46	[9]
8	Biomass/Municipal Solid Waste	Fluidized-Bed	0.33	0.41	[10]
9	Coal/Biomass/Waste Plastics	Entrained-Flow	0.32	0.42	[11]
10	Fixed-Bed	Coal/Waste Plastics	0.3	0.44	[12]
11	Fluidized-Bed	Coal/Miscanthus	0.35	0.39	[13]
12	Entrained-Flow	Coal/Municipal Solid Waste	0.28	0.46	[14]
13	Fixed-Bed	Biomass/Plastics	0.33	0.41	[15]
14	Fluidized-Bed	Coal/Paper Waste	0.32	0.42	[11]
15	Entrained-Flow	Coal/Wood	0.29	0.45	[16]
16	Fluidized-Bed	Coal/Rice Husk	0.35	0.39	[17]
17	Entrained-Flow	Biomass/Paper Waste	0.33	0.41	[18]
18	Fixed-Bed	Coal/Miscanthus	0.34	0.4	[19]
19	Fluidized- Bed	Biomass/Paper Waste	0.31	0.42	[20]
20	Entrained-Flow	Coal/Municipal Solid Waste	0.3	0.44	[21]
21	Fixed-Bed	Coal/Rice Husk	0.35	0.39	[22]
22	Fluidized-Bed	Biomass/Plastics	0.33	0.41	[23]
23	Entrained-Flow	Coal/Miscanthus	0.34	0.4	[24]
24	Fixed-Bed	Coal/Paper Waste	0.31	0.42	[25]

[1] Jon Alvarez, Shogo Kumagai, Chunfei Wu, Toshiaki Yoshioka, Javier Bilbao, Martin Olazar, Paul T. Williams, Hydrogen production from biomass and plastic mixtures by pyrolysis-gasification, International Journal of Hydrogen Energy, Volume 39, Issue 21, 15 July 2014, Pages 10883–10891
[2] Armin O, Mohammad R K, Babak S, Abel R, Eliseu M. Optimizing the operating conditions for hydrogen-rich syngas production in a plasma co-gasification process of municipal solid waste and coal using Aspen Plus, International Journal of Hydrogen Energy 47 (2022) 26891 e26900
[3] Zaccariello L, Mastellone ML. Fluidized-Bed Gasification of Plastic Waste, Wood, and Their Blends with Coal. Energies. 2015; 8(8):8052-8068.
[4] Ding G and He B Process Simulation of Co-Gasification of Raw Municipal Solid Waste and Bituminous Coal in CO2/O2 Atmosphere Appl. Sci. 2020, 10, 1921; doi:10.3390/app10061921
[5] Muhammad Aziz, Arif Darmawan, Firman Bagja Juangsa, Hydrogen production from biomasses and wastes: A technological review, International Journal of Hydrogen Energy,Volume 46, Issue 68, 2021, Pages 33756-33781,ISSN 0360-3199,
[6] Society of Chemical Engineers Japan (SCEJ), Japan Institute of Energy (JIE). Biomass Process Handbook. 1st ed. Tokyo: Ohmsha; 2012

Introduction

High fidelity modelling is mature tool to study a reactive complex flow. It requires accurate analysis of the kinetic data for both devolatalization/pyrolysis.

1. *Lee et al* have used CFD to numerically model the circulating fluidized bed gasifier for the plastic waste in an Eulerian-Granular approach [1]. Their attempt were more focus on the circulating of the particle while no gasification/reaction were considered. They however study the change of the fluidized velocity and the particle size circulation.

2. *Gao et al* studied thermal degradation at inert gas conditions for HDPE sample using the two methods. Dynamic heating was conducted at five heating rates, 4, 6, 8, 10 and 20 ^{o}C /min, whereas the isothermal was carried at three different temperatures, 440, 450, and 460 ^{o}C. The reported activation energy for dynamic and isothermal are respectively 194.8 KJ/mole and 201.5 KJ/mole [2] .

3. *Manu et al* investigated the thermal degradation of rice husk at temperatures ranging from 650 $^{\circ}$ C to 750 $^{\circ}$ C and steam to biomass ratio of 0.5–2. They reported that increasing the steam-to-biomass ratio (SBR) from 0.5 to 2 linearly reduces CO and increases H_2 to 45%. Both lower heating value (LHV) and thermal efficiency show positive trends with higher SBR. Introducing CO_2 increases CO in the syngas and decreases H_2. [3].

4. As a result, combining numerous feedstocks is an option that can improve the efficiency of the gasification process. The majority of co-gasification research mentions the usage of coal and biomass. [4,5].

[1] Ji Eun Lee, Hang Seok Choi, Yong Chil Seo, Study of hydrodynamic characteristics in a circulating fluidized bed gasifier for plastic waste by computational fluid dynamics modeling and simulation, Journal of Material Cycles and Waste Management, October 2014, Volume 16, Issue 4, pp 665–676
[2] Gao, Z., I. Amasaki, and M. Nakada, A thermogravimetric study on thermal degradation of polyethylene. Journal of Analytical and Applied Pyrolysis,. 67,1, (2003), 1-9.
[3] J. Manu, Vasudeva Madav, Numerical modeling of rice husk gasification in fluidized bed gasifier for sustainable biofuel production ,Case Studies in Thermal Engineering, Volume 39, 2022, 102429, ISSN 2214-157X
[4] G. Ding, B. He, Process simulation of Co-gasification of raw municipal solid waste and bituminous coal in CO2/O2 atmosphere, Appl. Sci. 10 (2020) 1921.
.[5]] A. Boharapi, G. Kale, O. Mahadwad, Co-Gasification of coal and biomass -thermodynamic and experimental study, Int. J. Renew. Energy Technol. 4 (2015) 346–352.

Objectives

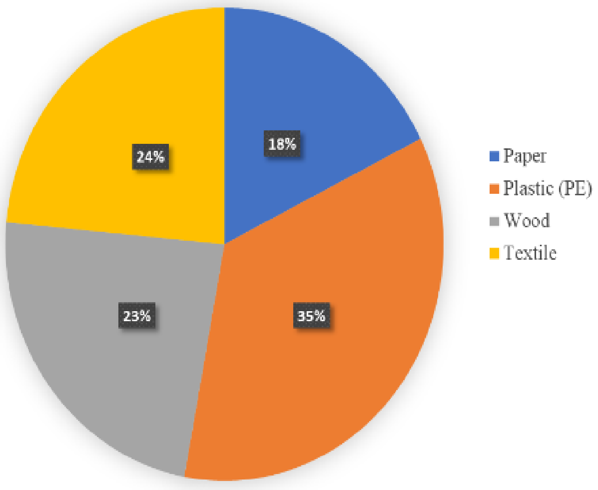
-It should be emphasize that despite the progress made to date on both experimental and modeling studies of MSW gasification, a wide range of research and development program is lacking on this subject. Current implementations are extended set of reactions covering the devolatilization, combustion, water and gas shifts beside the sensible heating.

-Gasification of MSW blends is an emerging technology as this source will continue to grow that requires strong need for detailed gasification investigations covering the different plastic types and their mixtures.

- This work addresses this need by:

  - ✓ Assessing the proximate and ultimate analyses of the coal and MSW blend
  - ✓ Carry out Thermodynamic Equilibrium Approach (TEA): Determine species & metrics at different coal/MSW ratios
  - ✓ Conduct TGA/DSC analysis to infer the devolatilization kinetics of reaction.
  - ✓ Carry out high fidelity inside an entrained flow gasifier simulated in a drop tube reactor environment.

Materials and Method: Material characterization



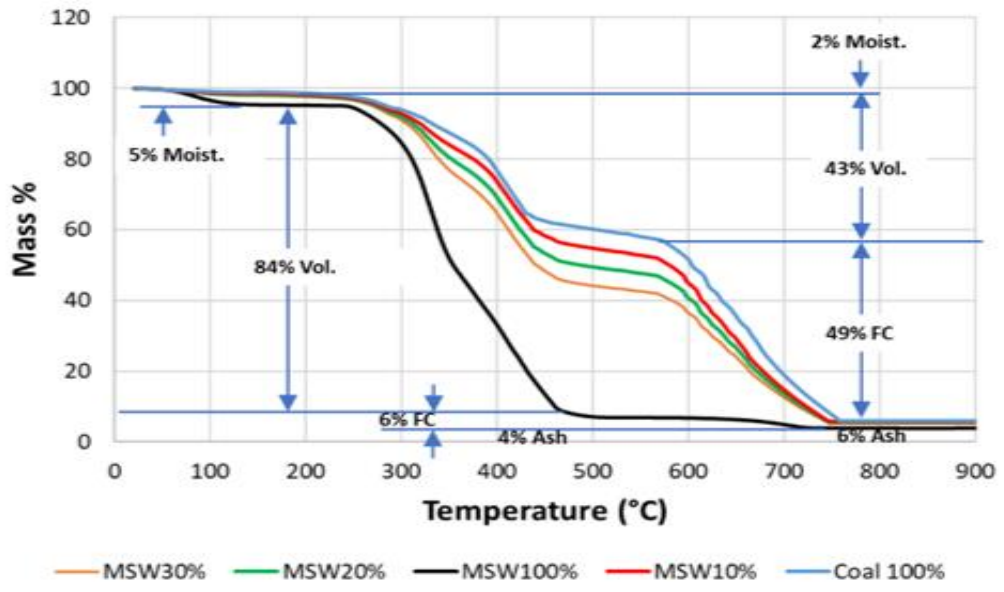
1. Reduce the MSW into the 4 main components: paper, wood, LDPE, and textile [1] and individually crush and sieve in Retsch-zm200 mills, then subject the to proper weight mixing using high precision scale (±µg: Metteler Toledo USA).
2. Carry out Thermo-Gravimetric and elemental analyses on coal as baseline and MSW and Kentucky coal mixtures: 30% MSW and 70% Kentucky coal, 20% MSW and 80% Kentucky coal, and 10% MSW and 90% Kentucky coal using TGA proximate & ultimate/elemental analyses using STDQ600 and FLASH 200, respectively as well as bomb calorimeter.
3. Setup Equilibrium based stochiometric gasification model and carry out temp sweep analysis.
4. Evaluate chemical kinetics of the devolatilization from the TGA using various model: Arrhenius and Redfern
5. Setup up high fidelity reactive flow model using optimal conditions in 3 and kinetics of 4.

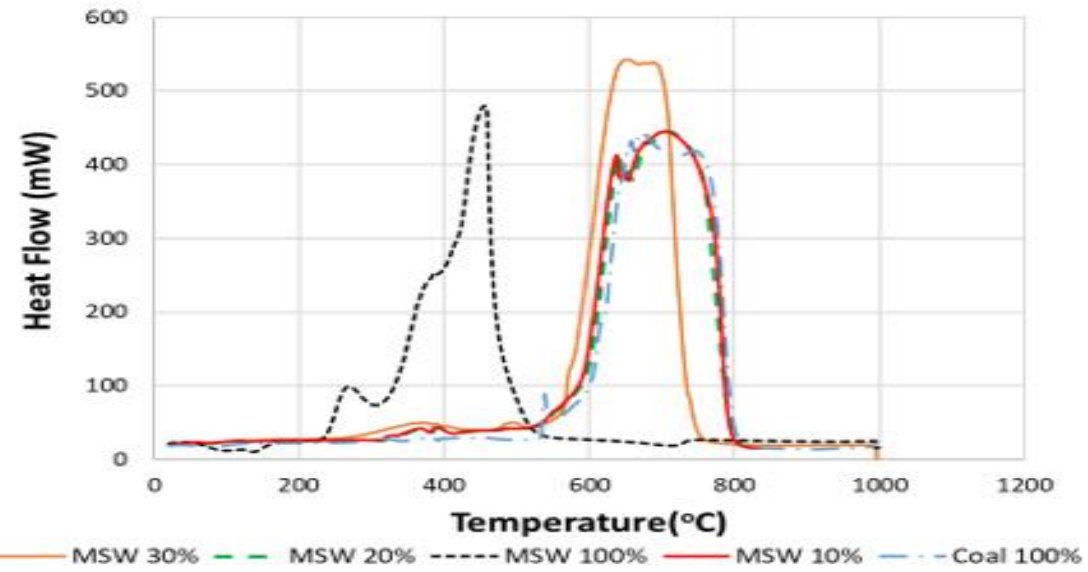
$$\underline{CH_xN_yO_zS_p} + \underline{m\,O_2} + \underline{nH_2O} \Leftrightarrow \underline{x_1CO + x_2H_2 + x_3CH_4} + \underline{x_4H_2O + x_5\,CO_2} + x_6C(s) + x_7\,O_2 + pSO_2 + \frac{y}{2}N_2$$

Equation:	Description	Mathematical/Stoichiometric Formula
1	Element Carbon Balance	$\sum_{i=rect}^{n\ of\ species} C_i = \sum_{i=prod}^{n\ of\ species} C_i$
2	Element Hydrogen Balance	$\sum_{i=rect}^{n\ of\ species} H_i = \sum_{i=prod}^{n\ of\ species} H_i$
3	Element Oxygen Balance	$\sum_{i=rect}^{n\ of\ species} O_i = \sum_{i=prod}^{n\ of\ species} O_i$
4	Heat balance	$\sum_{i=rect}^{n\ of\ species} nh_i = \sum_{i=prod}^{n\ of\ species} nh_i + Q$
6	Equilibrium: Methanation	$C + 2H_2 \Leftrightarrow CH_4\ - 75MJ/Kmol$
7	Equilibrium: CO shift	$CO + H_2O \Leftrightarrow CO_2 + H_2\ - 41MJ/Kmol$
8	Equilibrium: Steam Reforming	$CH_4 + H_2O \Leftrightarrow CO + 3\,H_2\ + 206MJ/Kmol$
9	Product mole sum	$\sum_{i=prod}^{n\ of\ species} X_i = 1$

Results: TGA

- Sample: 25 mg and HR=20 ºC/m TGA and STA plot for the 100% Coal/MSW and mixtures of 30%, 20% and 10% MSW with Kentucky coal





Proximate Analysis of Coal and MSW

	Kentucky coal	Paper	Plastic (PE)	Wood	Textile	MSW
Moisture	0.027	-	-	-	-	
VM	0.396	0.7614	0.9944	0.7587	0.8269	0.858
FC	0.511	0.1166	0.0008	0.1729	0.1375	0.094
Ash	0.066	0.122	0.0048	0.0684	0.0356	0.048

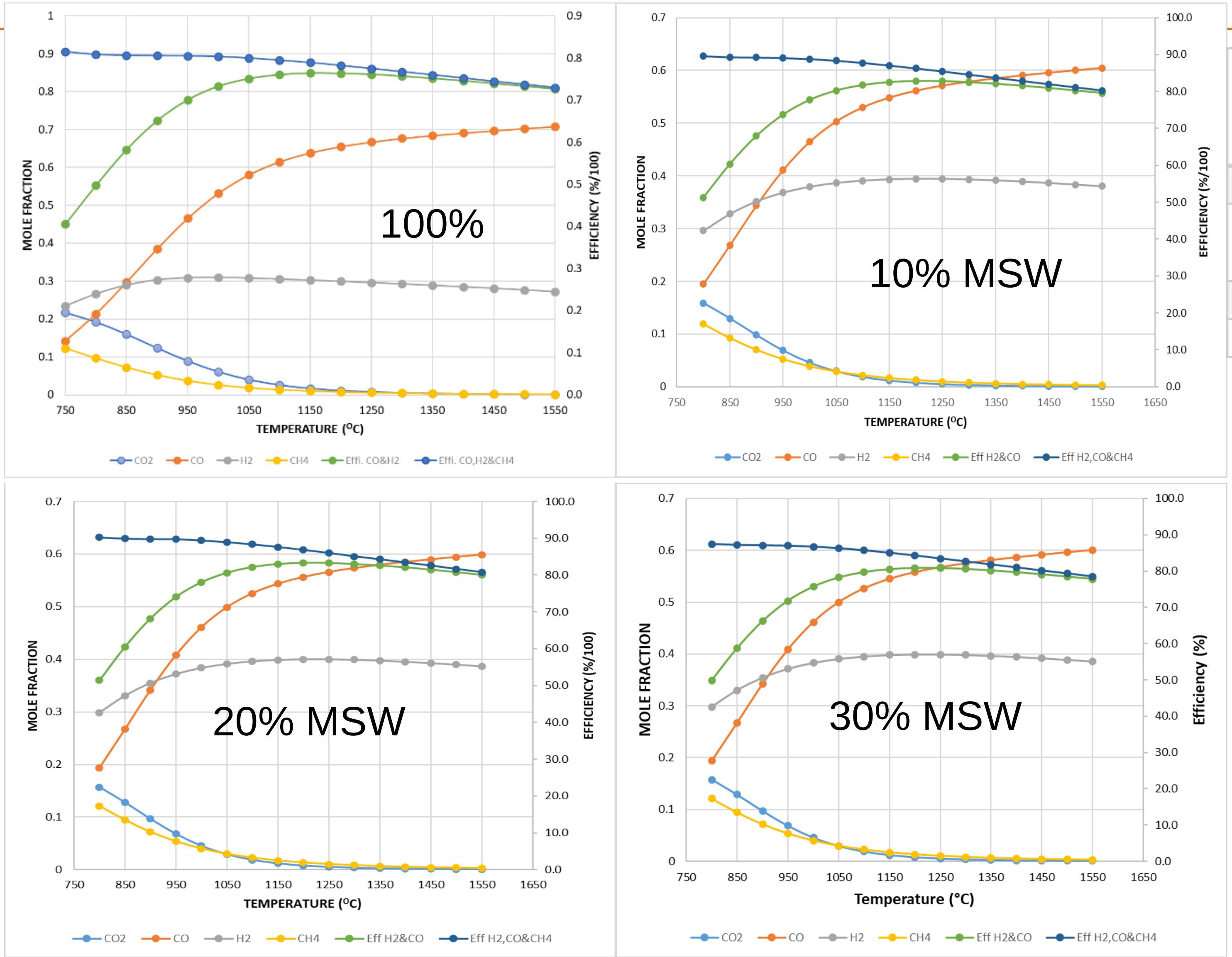
Ultimate Analysis of Coal and MSW

	Kentucky coal Formula $CH_{0.822}N_{0.026}S_{0.005}O_{0.081}$	Paper	Plastic (PE)	Wood	Textile	MSW Formula $CH_{1.611}N_{0.012}S_{0.001}O_{0.322}$
C	0.819	0.4562	0.8622	0.5135	0.5408	0.633
O	0.089	0.0601	0.1297	0.0639	0.0584	0.272
H	0.056	0.4778	0.0073	0.405	0.3809	0.085
N	0.025	0.0034	0.0008	0.0159	0.017	0.009
S	0.011	0.0022	0.0005	0.0018	0.0022	0.002
HHV (MJ/kg)	32.00	17.608	44.427	19.771	23.260	28.848

[1] Green, A. and S. Sadrameli, Analytical representations of experimental polyethylene pyrolysis yields. Journal of Analytical and Applied Pyrolysis, 2004. 72(2): p. 329-335.

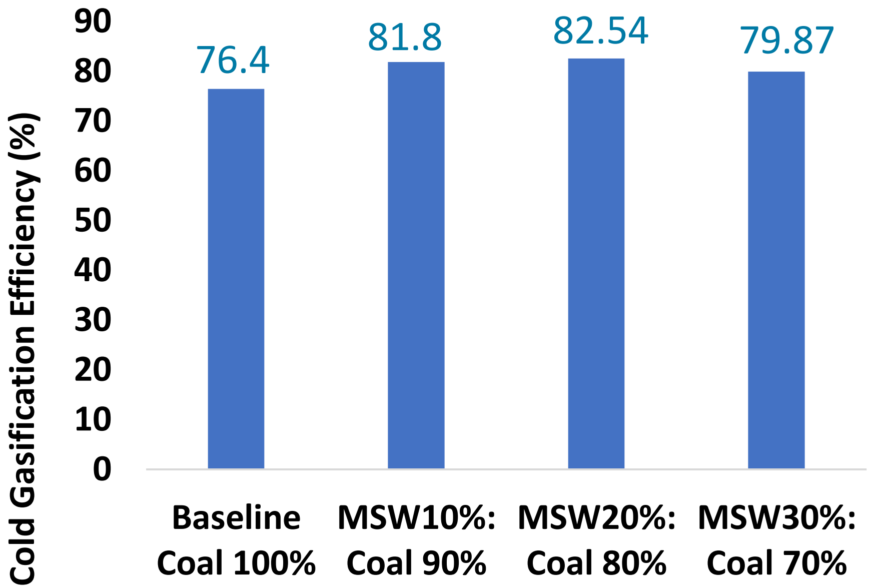
Results: Equilibrium modeling

The cold gasification efficiency for the mixture of MSW were estimated based on the expression given by Skodras et al. [1].



Specie/BEP	Baseline Coal 100%	MSW10%: Coal 90%	MSW20%: Coal 80%	MSW30%: Coal 70%
BEP (%)	76.4	81.8	82.54	79.87
PEP Temp (C°)	1150	1200	1250	1200
CO	0.63	0.55	0.57	0.54
H2	0.30	0.385	0.39	0.371

$$CGE(\%) = \frac{\dot{m}_{out}\,(y_{H_2} HHV_{H_2} + y_{CO} HHV_{CO} + y_{CH_4} HHV_{CH_4})}{\dot{m}_{in,fuel}\, HHV_{fuel}}$$



Results: Kinetic study

- Devolatalization reaction may proceed under the constrain of conservation of mass and energy:

$$Feedstock_{\ mixture} + heat \ \rightarrow Moisture + C_1 Volatile + C_2 Fixed_{carbon} + Ash$$

- From TGA/DTG experimental data devolatilization reaction is modeled as:

$$\frac{dX}{dt} = Ae^{-E/RT}(1-X)^n \quad or \quad \frac{dX}{(1-X)^n} = \beta Ae^{-E/RT} dT$$

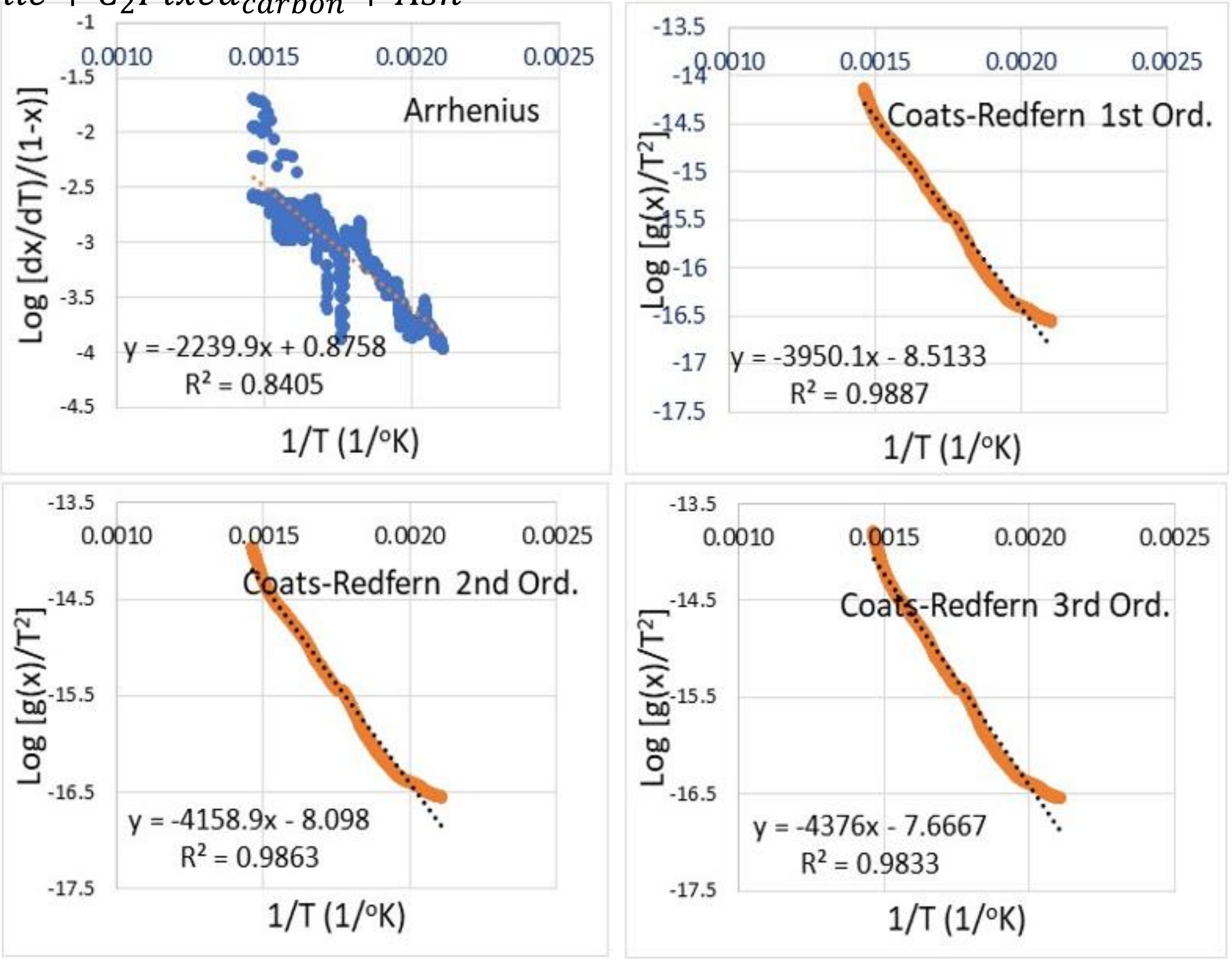
Arrhenius method: Direct extraction of E from the slope of the linear fit of log [dw/dt/w] versus 1/T via eq:

$$\log[dw/dt/w] = \log A - E/2.303RT$$

Coats and Redferm: E is determined from the slope of ln [g(x)/T^2]versus 1/T plot as:

$$ln\left(\frac{g(x)}{T^2}\right) = ln\left(\frac{AR}{\beta E}\right) - \frac{E}{RT}$$

Representation of Arrhenius model and 1st , 2nd and the 3rd order Coats-Redfern model data for 70% coal/MSW mixtures:



Results: Kinetic study (Cont'd)

The evaluated kinetic data for the LDPE, PP and PS based on Arrhenius, and Coats-Redfern, 1st , 2nd and the 3rd order models.

Coal 100%	Slope	Intercept	R2	E (KJ/mol)	A (1/sec) *
Arrhenius	-2239.900	0.876	0.841	42.888	1.252E-01
Coats-Redfern 1st	-3950.100	-8.511	0.989	75.633	5.139E-11
Coats-Redfern 2nd	-4158.900	-8.098	0.986	79.631	1.330E-10
Coats-Redfern 34d	-4376.000	-7.667	0.983	83.788	3.590E-10
MSW 100%	**Slope**	**Intercept**	**R2**	**E (KJ/mol)**	**A (1/sec) ***
Arrhenius	-2088.200	1.255	0.224	39.983	3.000E-01
Coats-Redfern 1st	-5736.800	-4.322	0.975	109.843	7.937E-07
Coats-Redfern 2nd	-7080.300	-1.787	0.976	135.568	2.724E-04
Coats-Redfern 3rd	-8643.500	1.154	0.968	165.498	2.376E-01
MSW 30%	**Slope**	**Intercept**	**R2**	**E (KJ/mol)**	**A (1/sec) ***
Arrhenius	-2376.500	1.309	0.794	45.503	3.395E-01
Coats-Redfern 1st	-4713.400	-6.770	0.988	90.248	2.830E-09
Coats-Redfern 2nd	-5207.100	-5.828	0.989	99.701	2.479E-08
Coats-Redfern 3rd	-5738.500	-4.816	0.989	109.876	2.549E-07
MSW 20%	**Slope**	**Intercept**	**R2**	**E (KJ/mol)**	**A (1/sec) ***
Arrhenius	-2243.500	1.021	0.797	42.957	1.750E-01
Coats-Redfern 1st	-4530.900	-7.225	0.991	86.754	9.928E-10
Coats-Redfern 2nd	-4939.900	-6.443	0.992	94.585	6.012E-09
Coats-Redfern 3rd	-5375.700	-5.611	0.991	102.929	4.081E-08
MSW 10%	**Slope**	**Intercept**	**R2**	**E (KJ/mol)**	**A (1/sec) ***
Arrhenius	-2115.900	0.732	0.787	40.513	8.986E-02
Coats-Redfern 1st	-4319.200	-7.748	0.995	82.700	2.976E-10
Coats-Redfern 2nd	-4650.600	-7.113	0.995	89.046	1.285E-09
Coats-Redfern 3rd	-5000.400	-6.444	0.993	95.743	5.996E-09

Results: Reactive flow

Conservation of mass:

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_x)}{\partial t} + \frac{\partial(\rho v_r)}{\partial t} + \frac{\rho v_r}{r} = S_m$$

Conservation of momentum:

$$\frac{\partial(\rho v_x)}{\partial t} + \frac{1}{r}\frac{\partial}{\partial x}(r\rho v_x v_x) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r v_x) = -\frac{\partial p}{\partial x} + \frac{1}{r}\frac{\partial}{\partial x}\left[r\mu\left(2\frac{\partial v_x}{\partial x} - \frac{2}{3}(\nabla\cdot\vec{v})\right)\right] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(\frac{\partial v_x}{\partial r} + \frac{\partial v_r}{\partial x}\right)\right] + F_x$$

$$\frac{\partial(\rho v_r)}{\partial t} + \frac{1}{r}\frac{\partial}{\partial x}(r\rho v_x v_r) + \frac{1}{r}\frac{\partial}{\partial r}(r\rho v_r v_r) = -\frac{\partial p}{\partial x} + \frac{1}{r}\frac{\partial}{\partial x}[r\mu(\frac{\partial v_x}{\partial r} + \frac{\partial v_r}{\partial x})] + \frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(2\frac{\partial v_r}{\partial r} - \frac{2}{3}(\nabla\cdot\vec{v})\right)\right] - 2\mu\frac{v_r}{r^2} + \frac{2}{3}\frac{\mu}{r}(\nabla\cdot\vec{v}) + \rho\frac{{v_z}^2}{r} + F_r$$

Conservation of energy:

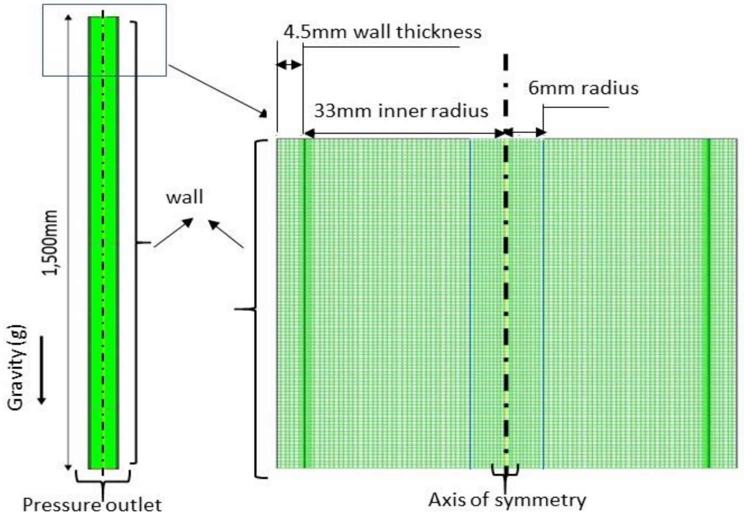
$$\frac{\partial(\rho E)}{\partial t} + \nabla\cdot\left(\vec{v}(\rho E + p)\right) = \nabla\cdot\left(k_{eff}\nabla T - \textstyle\sum_j h_j\vec{J}_j + (\bar{\bar{\tau}}_{eff}\cdot\vec{v})\right) + S_h$$

Where $E = h - \frac{p}{\rho} + \frac{v^2}{2}$

And $h = \sum_j Y_j h_j$

Conservation of species:

$$\frac{\partial(\rho Y_i)}{\partial t} + \nabla\cdot(\rho\vec{v}Y_i) = -\nabla\cdot\vec{J}_i + R_i + S_i$$



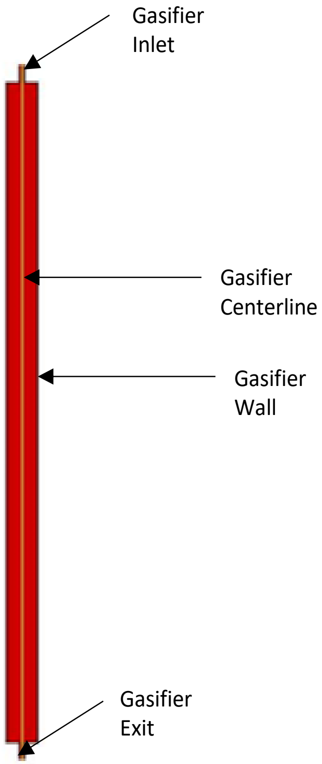
Kinetic Data for the Homogeneous and Heterogeneous Reactions [1]:

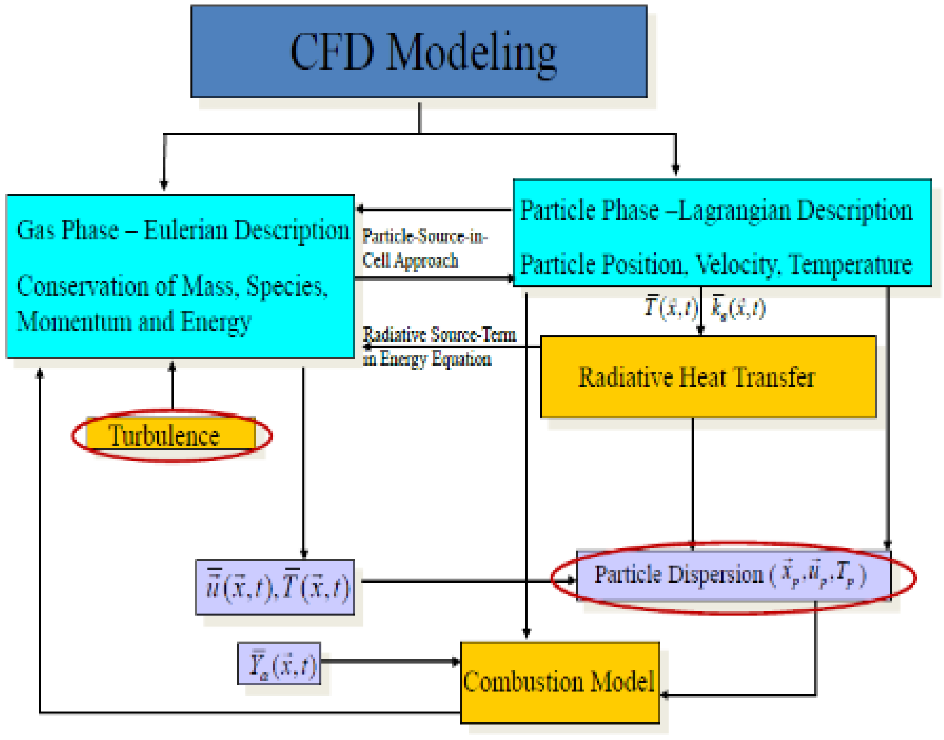
	Reaction	Activation Energy, E_a ($\frac{J}{mol}$)	Pre-Exponential Factor, A (sec^{-1})	N (Temperature exponent)
R1	$C_nH_m + \left(\frac{n}{2}\right)O_2 \rightarrow nCO + \frac{m}{2}H_2$	1.25×10^{8}	4.4×10^{11}	0
R2	$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$	1.67×10^{8}	6.8×10^{15}	-1
R3	$CO + \frac{1}{2}O_2 \rightarrow CO_2$	1.67×10^{8}	2.24×10^{12}	0
R4	$CO + H_2O \rightarrow CO_2 + H_2$	8.37×10^{7}	2.75×10^{9}	0
R5	$C + \frac{1}{2}O_2 \rightarrow CO$	9.23×10^{7}	2.3	1
R6	$C + CO_2 \rightarrow 2CO$	1.62×10^{8}	4.4	1
R7	$C + H_2O \rightarrow CO + H_2$	1.47×10^{8}	1.33	1

[1] Watanabe, H. and M. Otaka, Numerical simulation of coal gasification in entrained flow coal gasifier. Fuel, 2006. 85(12-13): p. 1935-1943.

Results: Reactive flow (cont'd)

Boundary Condition	Value (Coal)
Length of Gasifier	1540 mm
Outer Diameter of Gasifier	75 mm
Inner Diameter of Gasifier	66 mm
Mass Flow Inlet	1.3320 g/s
Outer Wall Temperature	1,100C



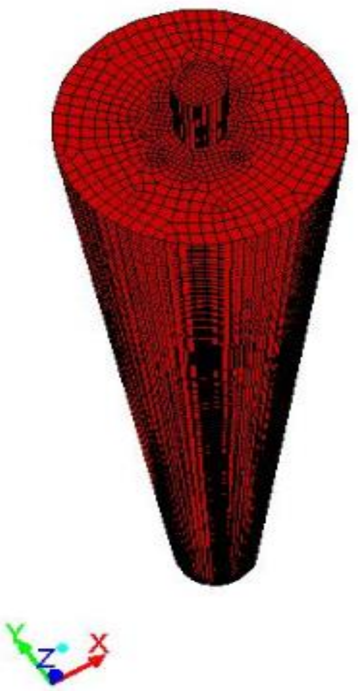


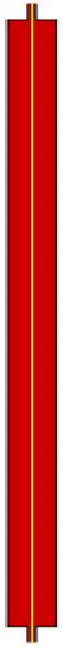
Geometry configuration and gasifier boundary conditions

Numerical solution approach for gasification [1]

[1] Adeyemi, I., Janajreh, I., Arink, T., & Ghenai, C. (2017). Gasification behavior of coal and woody biomass: Validation and parametrical study. Applied Energy, 185, 1007-1018.

Results: Reactive flow (cont'd)
Mesh Sensitivity Studies, Scale Effect and Model Validation

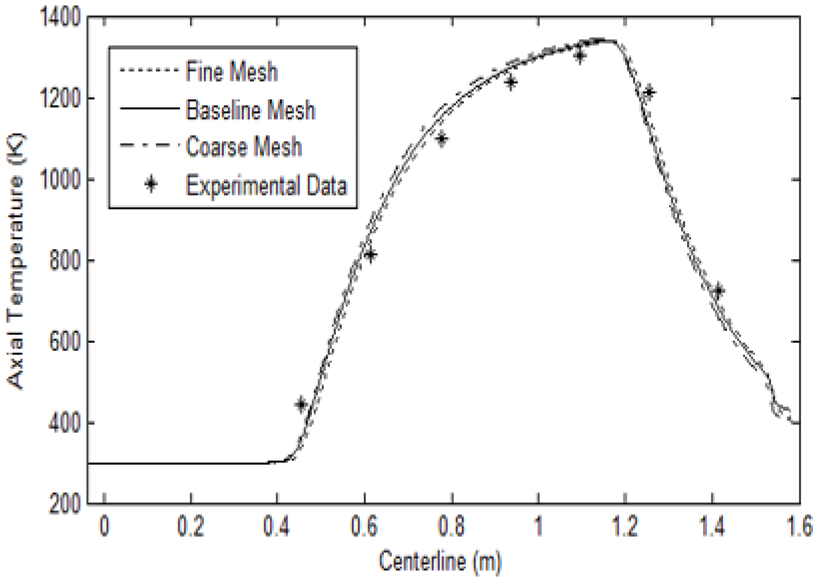


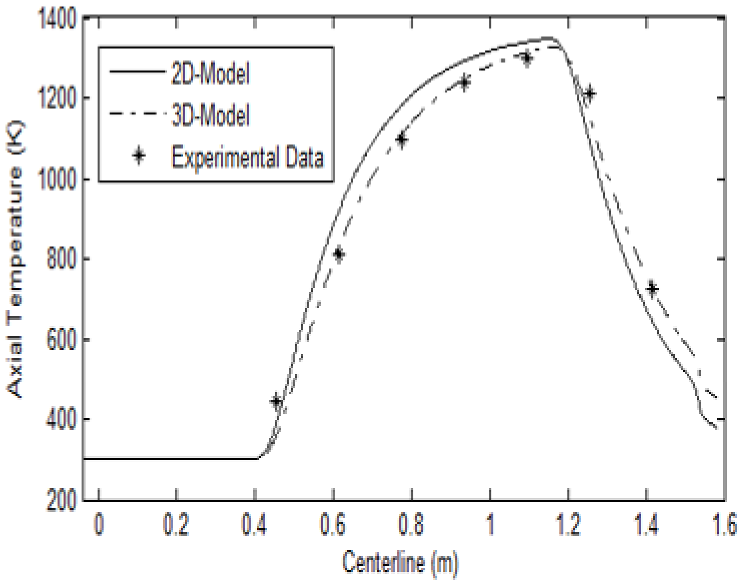


The 2D and 3D mesh structure

Details of the 2D meshes used for sensitivity analysis

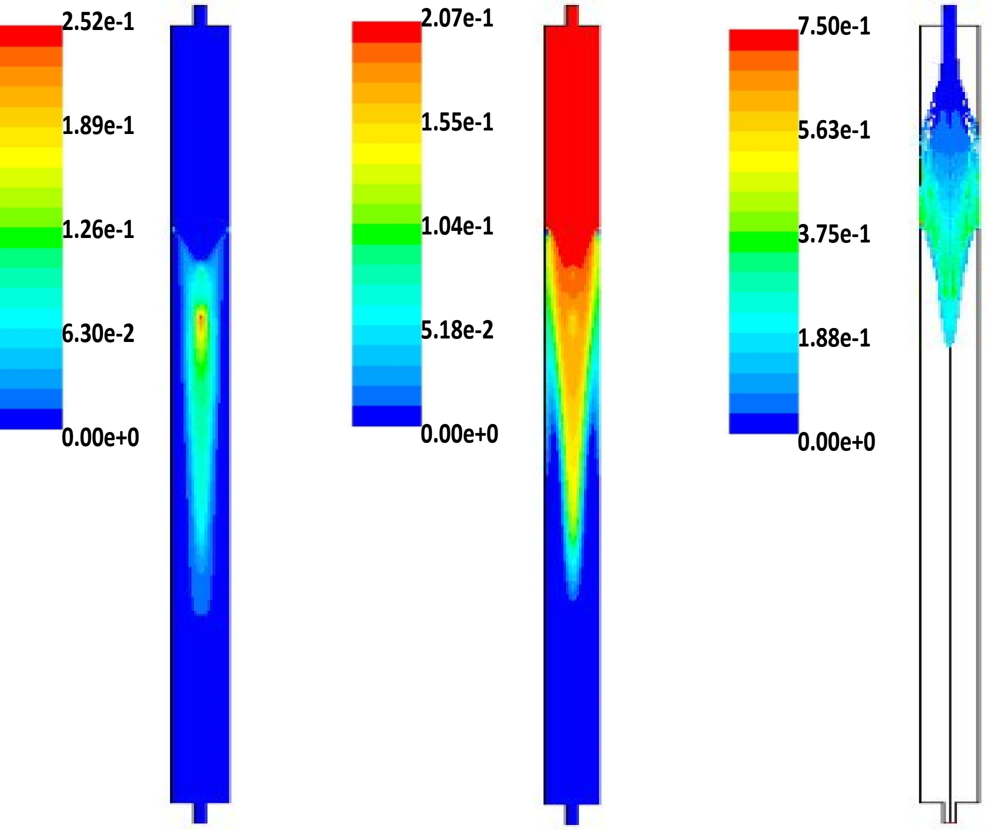
Mesh Type	Number of Cells	Number of Faces	Number of Nodes
Coarse	13,210	25,593	14,038
Baseline	68,680	135,686	70,355
Fine	142,525	282,294	145,282





Results: Reactive flow (cont’d)
Main species and temperature

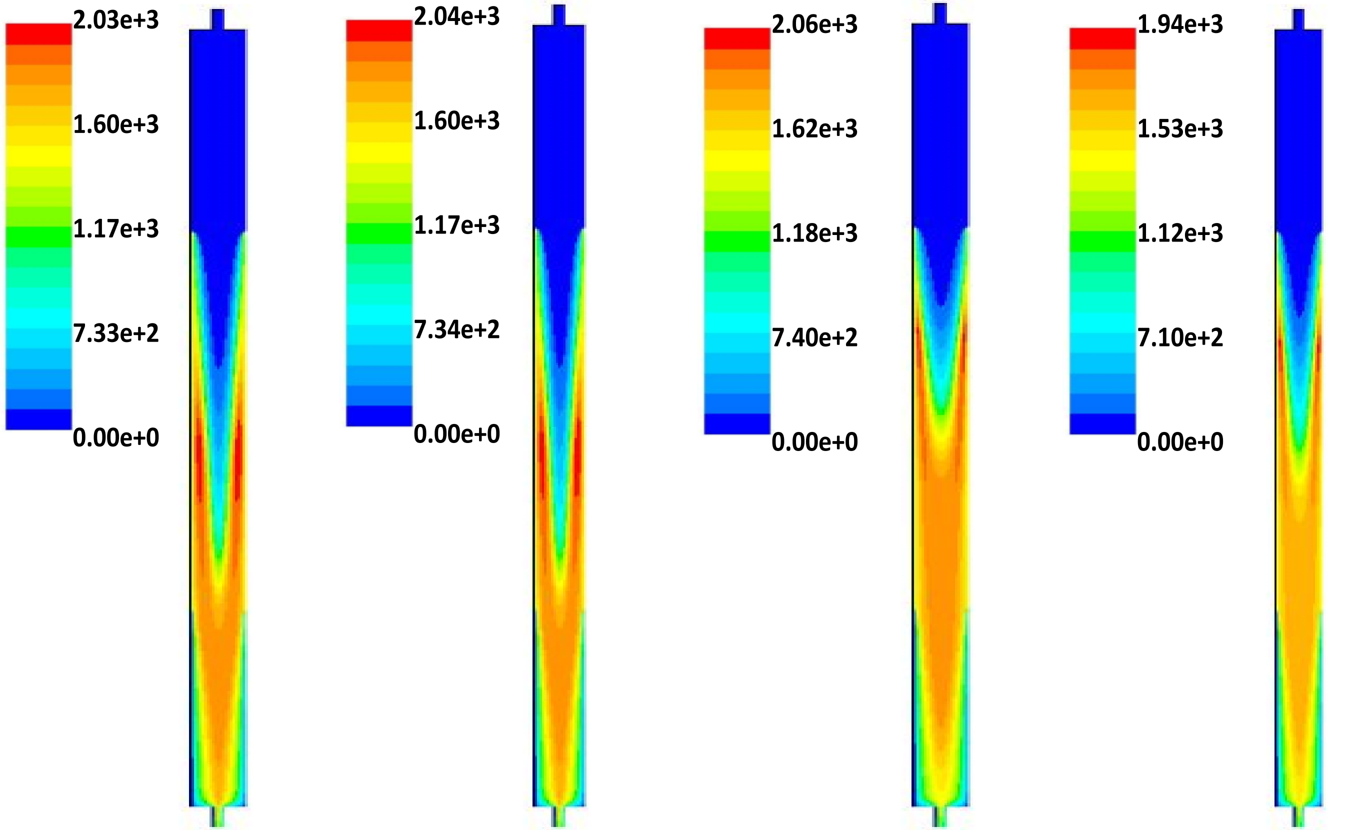
The Vol & O2 mole fractions contour and particle tracking



(a) Volatile Mole Fraction

(b) Oxygen Mole Fraction

(c) Particle Tracking



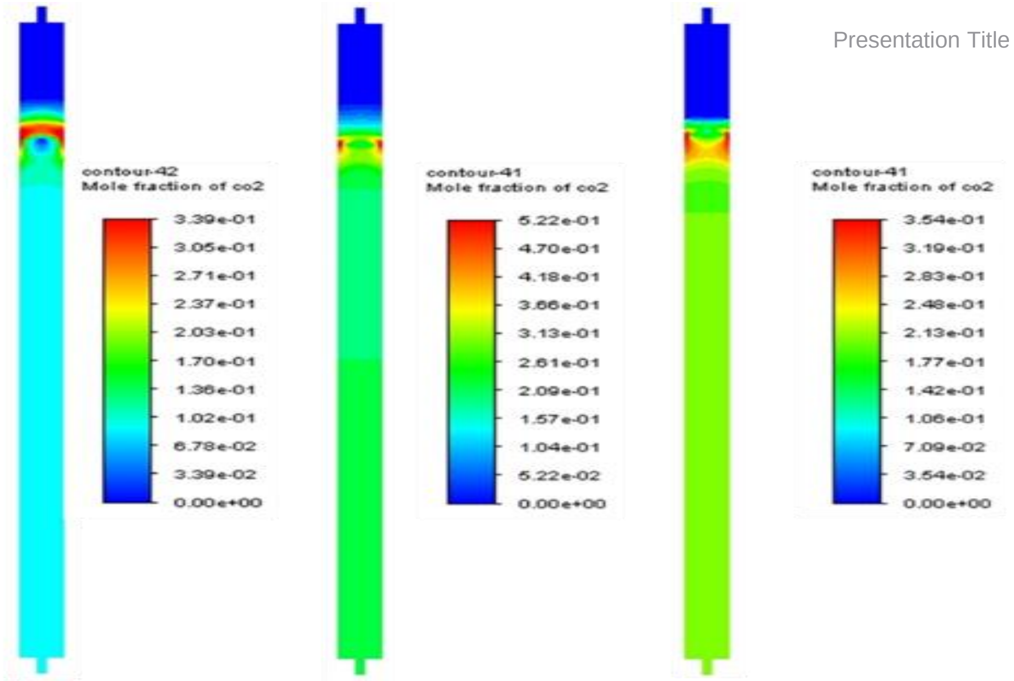
100% Coal | 10%MSW | 20%MSW | 30%MSW

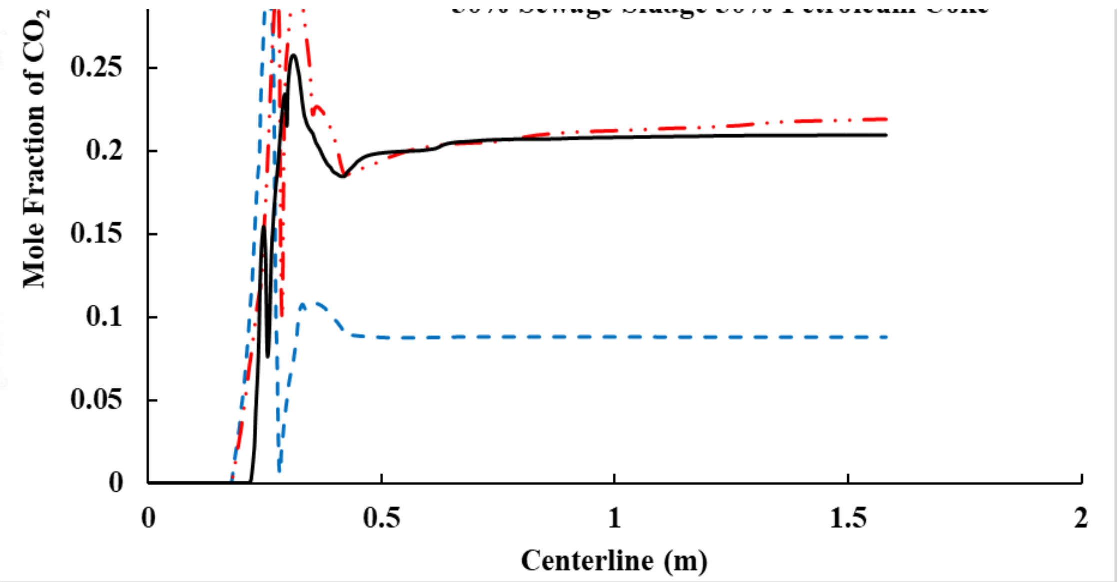
The isothermal Temperature contours for the coal and the three mixtures (in K)

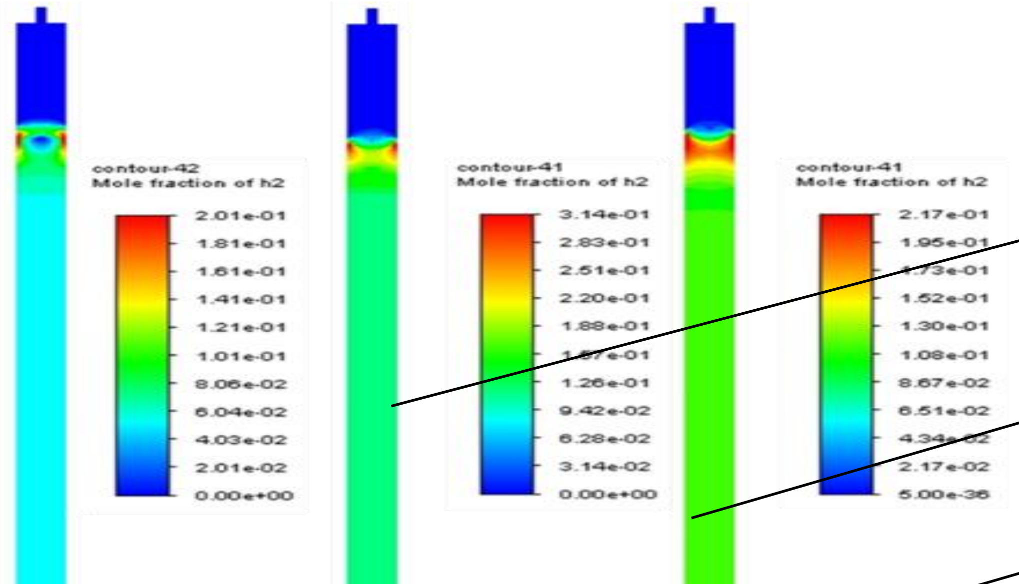
Conclusion

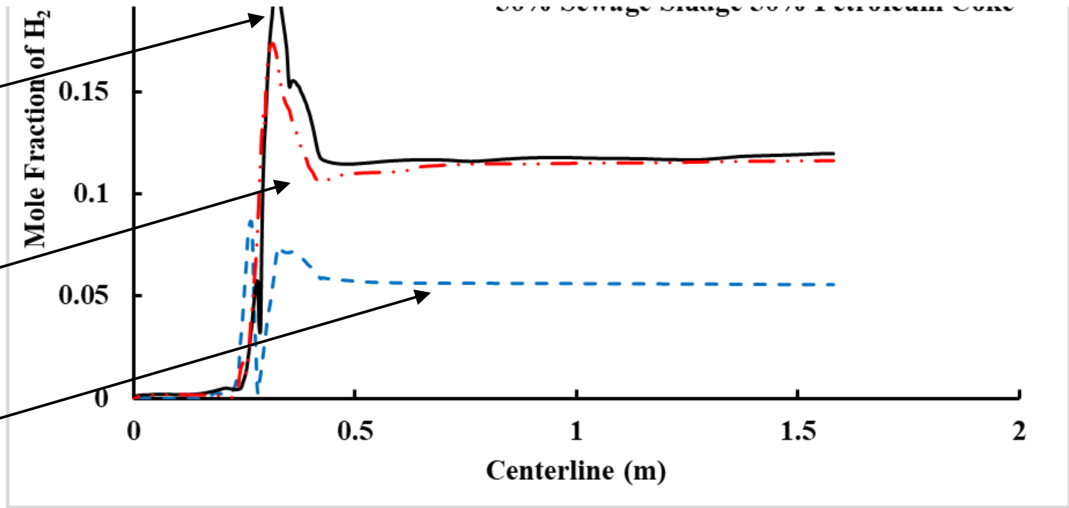
1. Co-gasification of coal has been considered as mitigation environmental strategy for the increasing landfilling of municipal and industrial waste (M&ISW).
2. The different proportion and composition of M&ISW, however, can compromise the gasification metrics and may possess processing challenges.
3. Here, two level of modeling are pursued to assess the gasification of coal and MSW mixture, the plug flow equilibrium-based model (EM) and the continuous high-fidelity reactive flow model (RFM).
4. Result shows maximum attained efficiency is 82.54% at 1250 ^{o}C the conditions when the 20% MSW and 80% coal mixture completely converted and resulted in syngas molar fractions X_{CO}= 0.57 and X_{H2}= 0.39.
5. Owing to higher volatile of the considered MSW composition these values surpassed the single coal gasification values which respectively 76.4%, 1150 ^{o}C, X_{CO}= 0.63 and X_{H2}= 0.30.
6. Using these conditions high-fidelity reactive flow model is developed that accounts for the reactor geometry and the devolatilization kinetics and deploys extended set of reactions covering the devolatilization, combustion, water and gas shifts, and outwards beside sensible heating.
7. Kinetics of devolatilization first is evaluated using the TGA thermographs for the mixtures as well as the coal. The model reveals that the gasification reaction is not instantaneous as suggested by lower fidelity models, but rather takes a certain length of residence time.
8. Asymptotic and steady species formation was seen around halfway downstream of the drop tube reactor, and the temperature curve shows a growing trend toward the center. Lower syngas output results in reduced performance at lower temperatures (<<1000 ^{o}C), and higher temperatures (1550 ^{o}C) were unfavorable because more heat is needed to get the gasifier wall up to the desired temperature.
9. Overall, both models demonstrate the feasibility of co-gasification of Coal and MSW and hence deployment of this process not only produce another energy source, but also help in reducing landfilling and their growing footprint

Thank You









10%MSW 20%MSW 30%MSW