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MALAYSIA

Application of Microwave (MW) technology in oil palm industry

Arshad Adam Salema, PhD, C.Eng. (India)

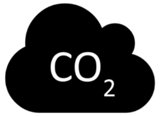
Mechanical Engineering

September 7, 2020

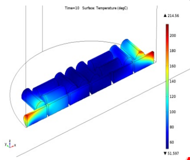
Malaysia

My research interest

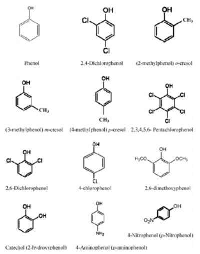
Biomass and bioenergy



Energy efficiency and management



Thermal process design and development



Value added products

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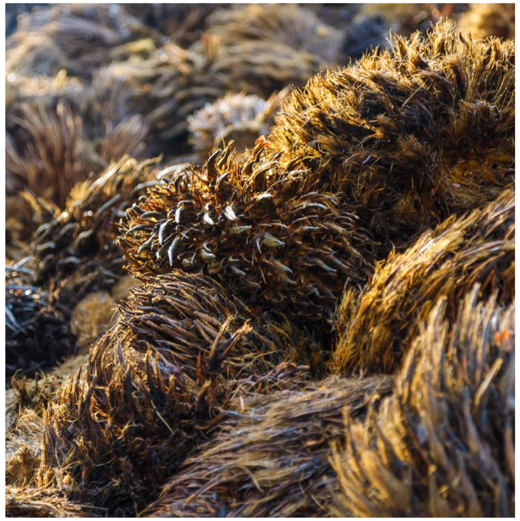
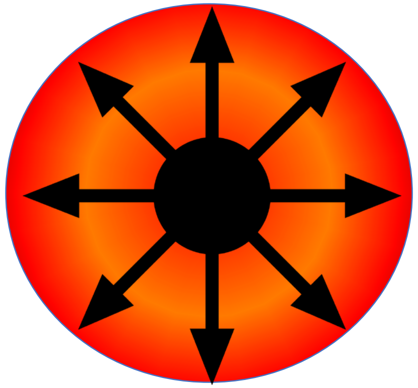
MW Sterilization

MW Biomass Processing

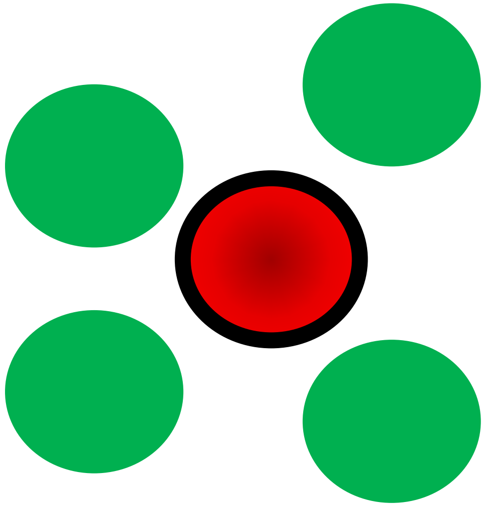


Why Microwaves?

Advantages of MWs



Volumetric heating



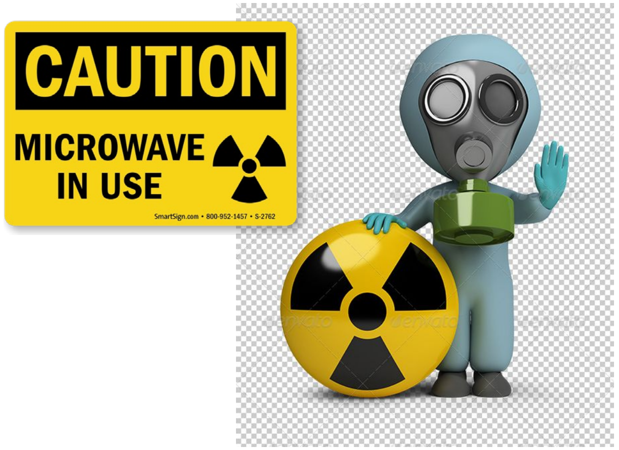
Selective heating

Energy saving

Rapid heating

What is not said about MWs?

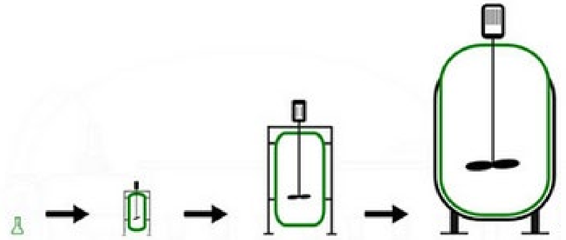
Limitation of MWs



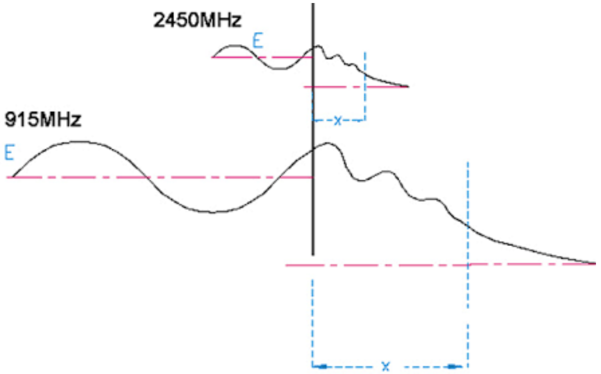
Safety

Few grams

Modified domestic oven



Scaling up

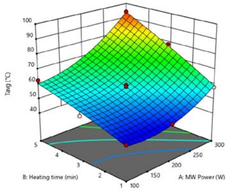


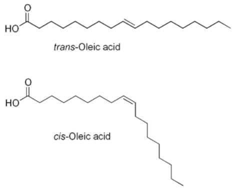
Penetration depth

MW Sterilization

MW sterilization

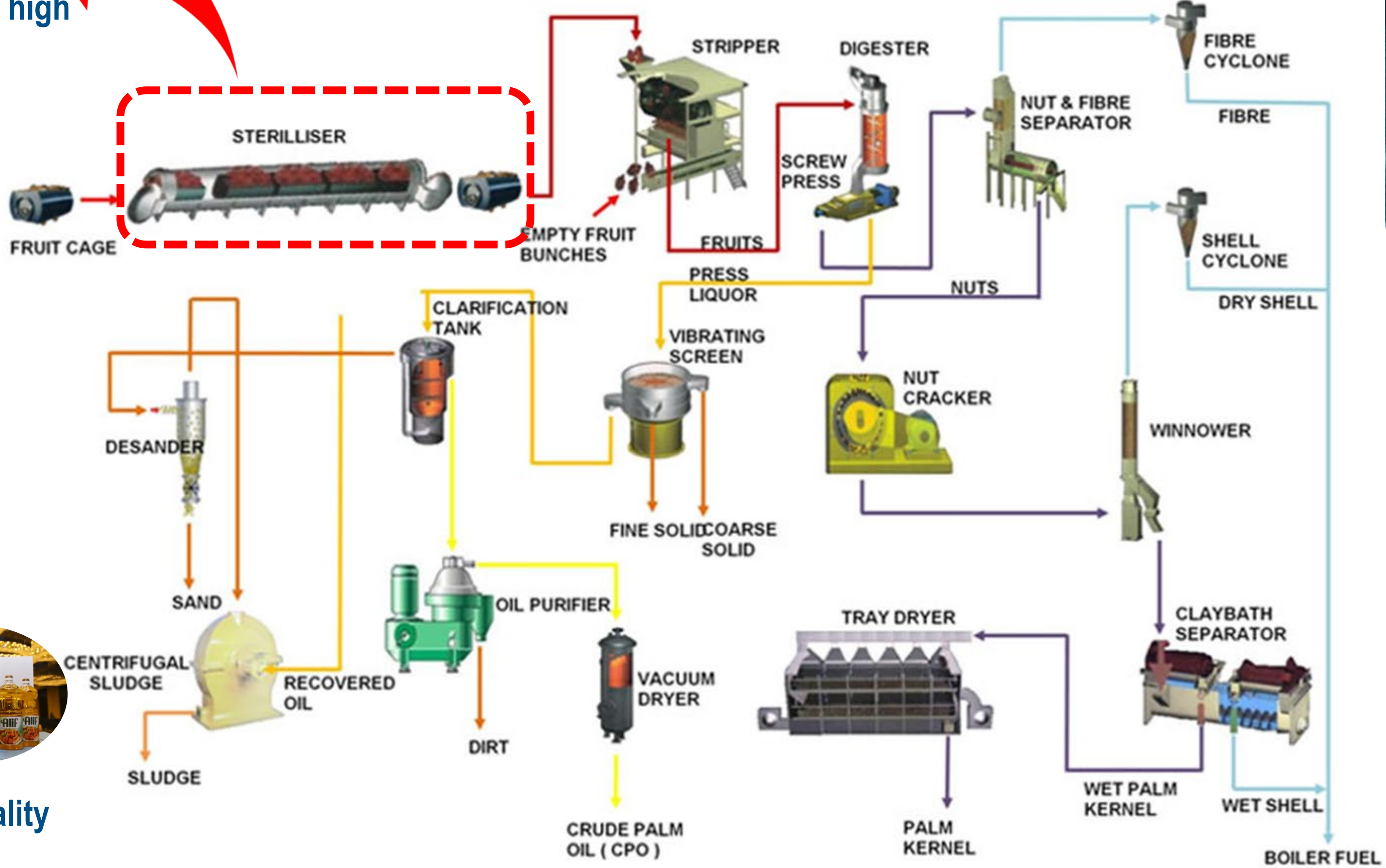
Palm oil mill industrial process





Sterilization process consumes high energy and longer time

Microwave sterilization



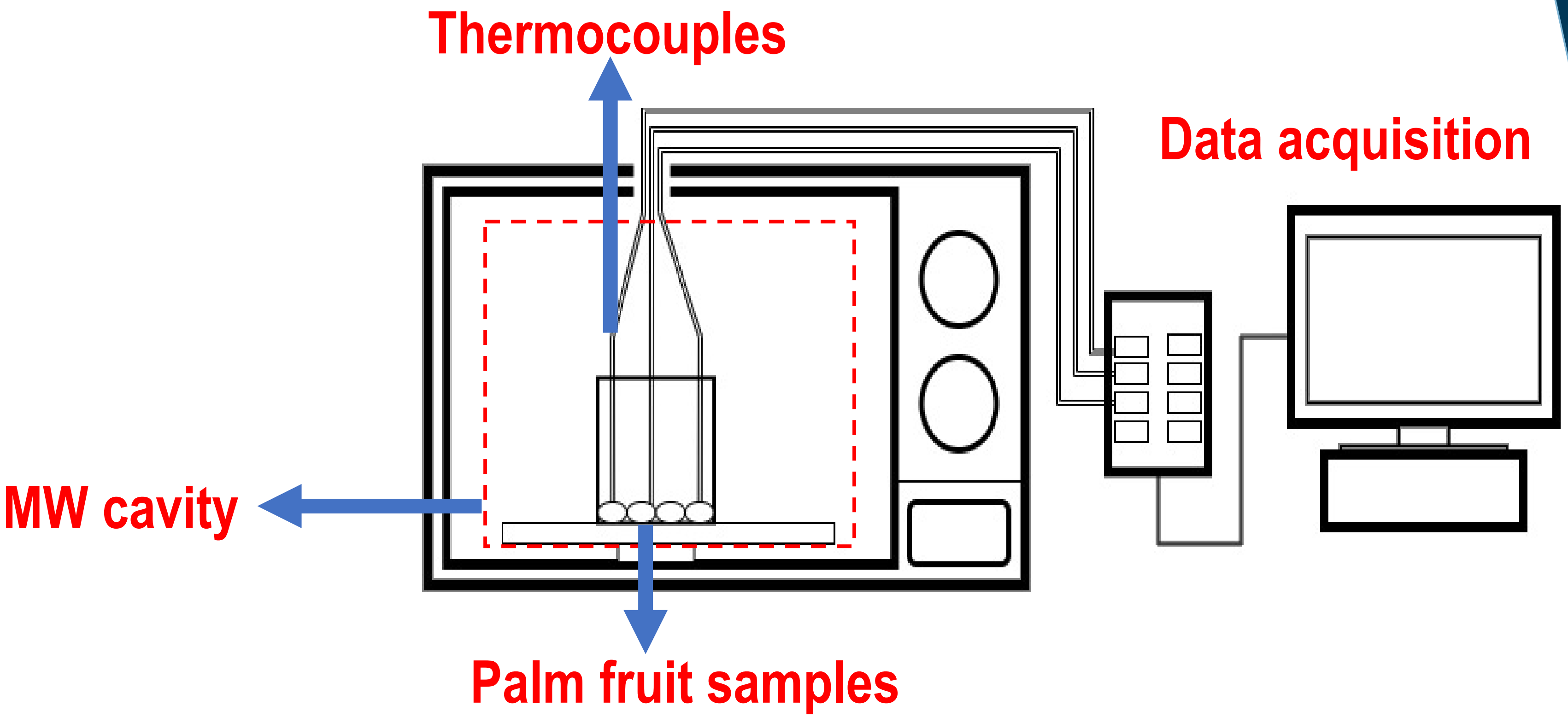
Economical analysis

Energy consumption

Save cost Save energy Quality

MW sterilization R&D at Lab scale

Increase the productivity by stacking the fruits



R&D design

Response Surface Methodology (RSM) software

Central Composite Design

Each numeric factor is set to 5 levels: plus and minus alpha (axial points), plus and minus 1 (factorial points) and the center point. If categoric factors are added, the central composite design will be duplicated for every combination of the categorical factor levels.

Numeric factors: 2 (2 to 50) ◉ Horizontal ◉ Enter factor ranges in terms of ±1 levels

Categoric factors: 0 (0 to 10) ○ Vertical ○ Enter factor ranges in terms of alphas

	Name	Units	Low	High	-alpha	+alpha
A [Numeric]	MW power	W	100	300	58.5786	341.421
B [Numeric]	Heating time	min	1	5	0.171573	5.82843

Type: Full Blocks: 1

Points

Non-center points: 8

Center points: 5

Central Composite Design

Responses: 5 (1 to 999) ◉ Horizontal ○ Vertical

Name	Units
T1	
T2	
T3	
T4	
MC	

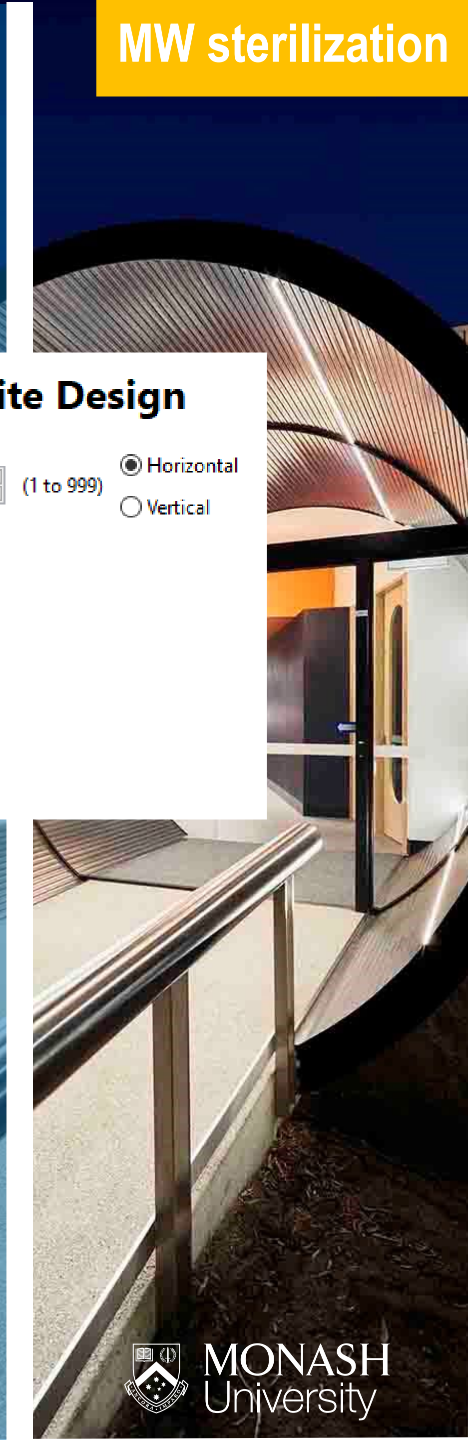
Navigation Pane

- Design (Actual)
  - Information
    - Notes
    - Summary
    - Graph Columns
    - Evaluation
  - Analysis
    - R1:T1 (Empty)
    - R2:T2 (Empty)
    - R3:T3 (Empty)
    - R4:T4 (Empty)
    - R5:MC (Empty)
  - Optimization
    - Numerical
    - Graphical
  - Post Analysis
    - Point Prediction
    - Confirmation
    - Coefficients Table

Design Properties

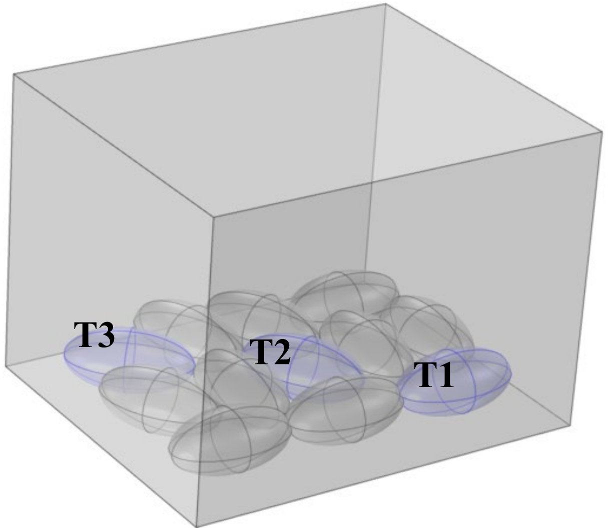
Run 1	
Comment	
Row Status	Normal

Std	Run	Factor 1 A:MW power W	Factor 2 B:Heating time min	Response 1 T1	Response 2 T2	Response 3 T3	Response 4 T4	Response 5 MC
2	1	300	1					
11	2	200	3					
12	3	200	3					
4	4	300	5					
13	5	200	3					
1	6	100	1					
5	7	58.5786	3					
3	8	100	5					
7	9	200	0.171573					
8	10	200	5.82843					
10	11	200	3					
9	12	200	3					
6	13	341.421	3					

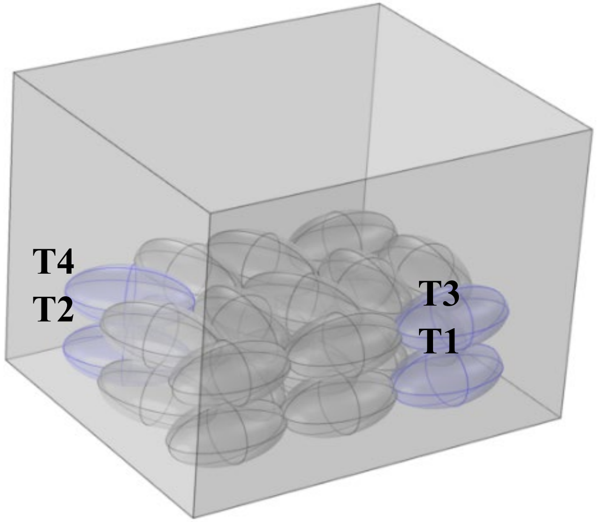


Computational simulation of lab scale

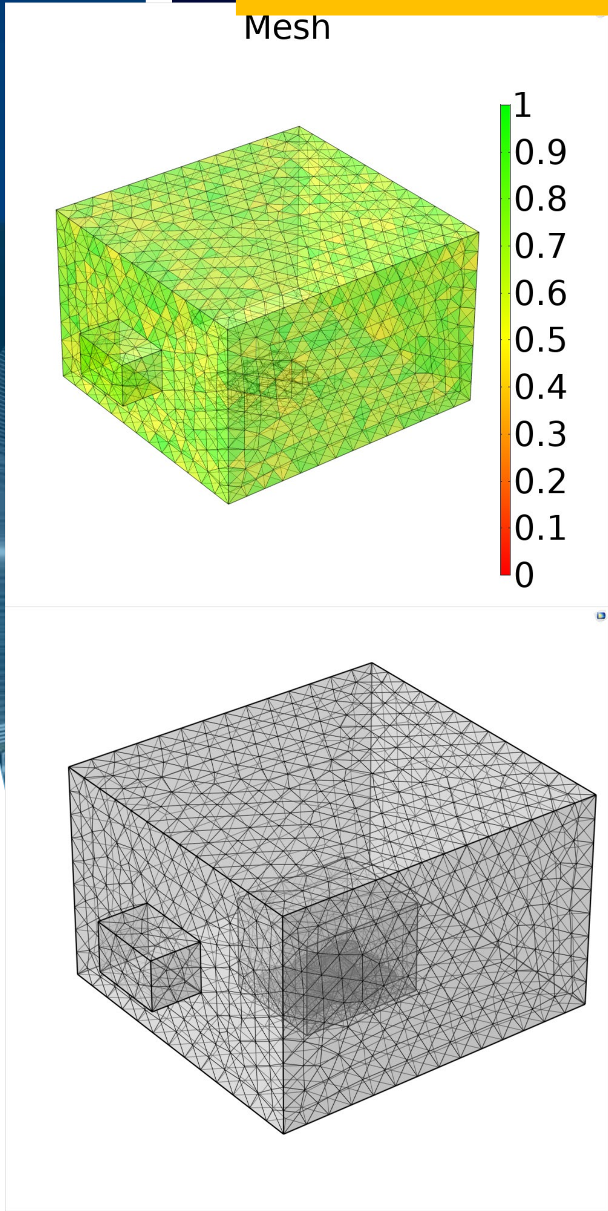
COMSOL Multiphysics



Single layer

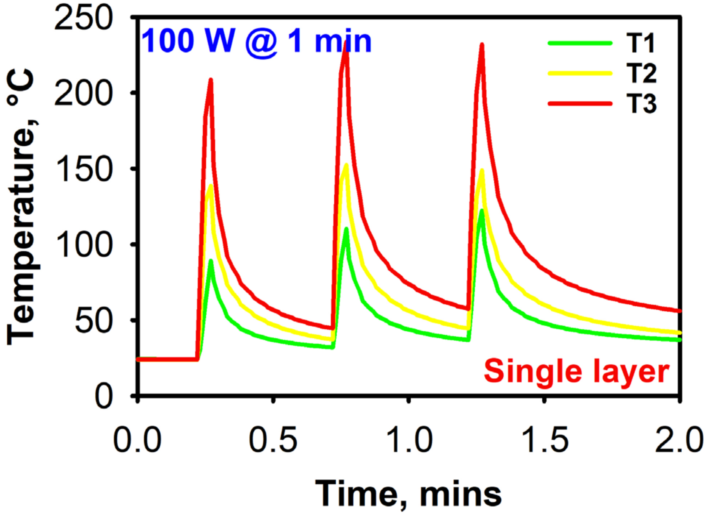


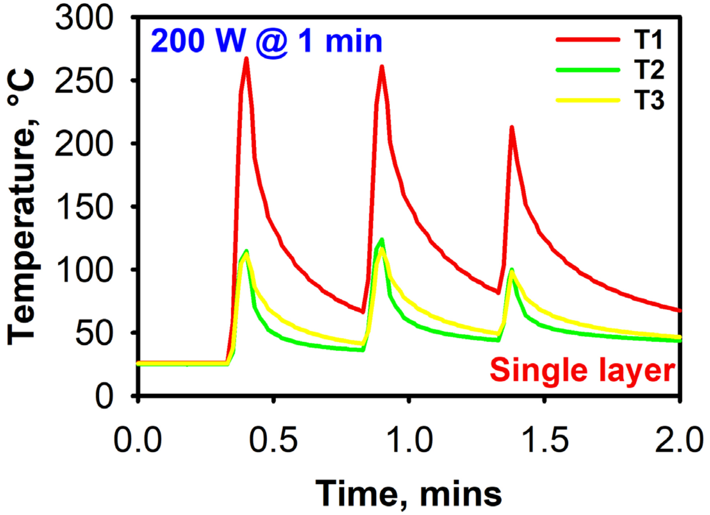
Stacked layer

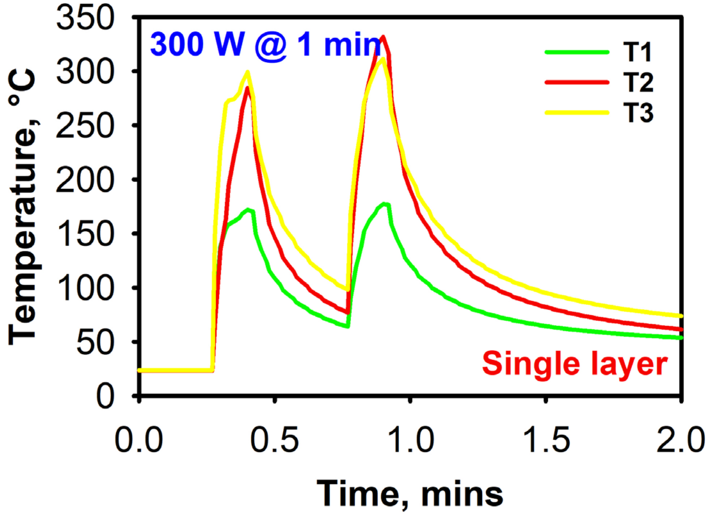


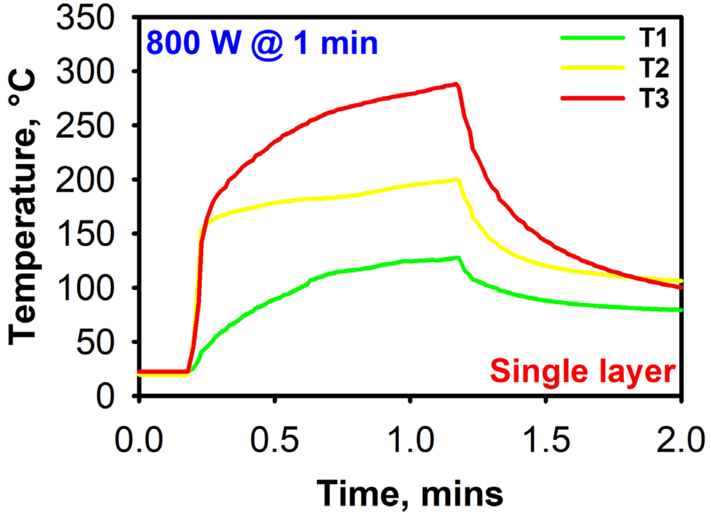
Results from Lab scale

Temperature profile



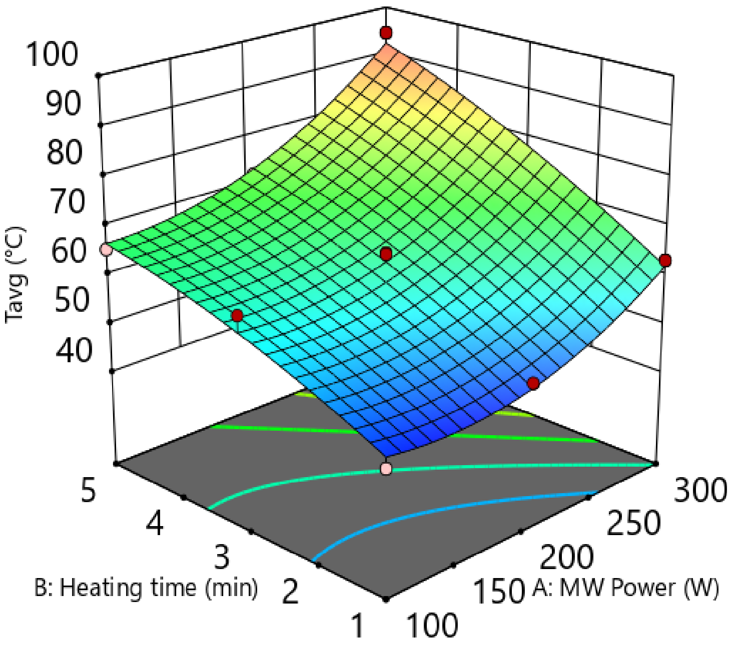




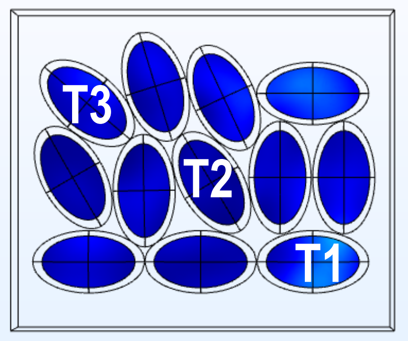


Results from Lab scale

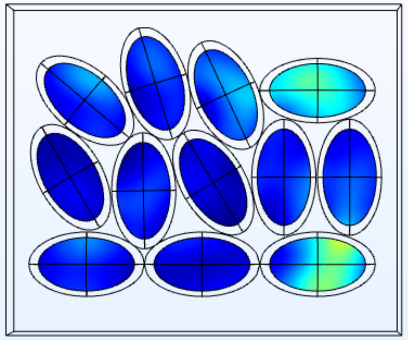
Temperature profile



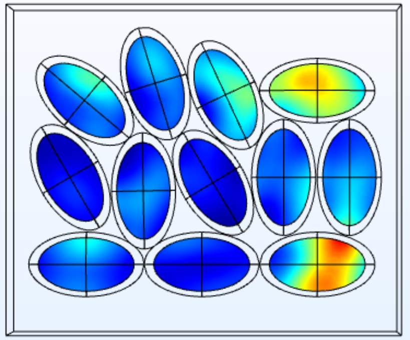
Single layer



100 W



200 W



300 W

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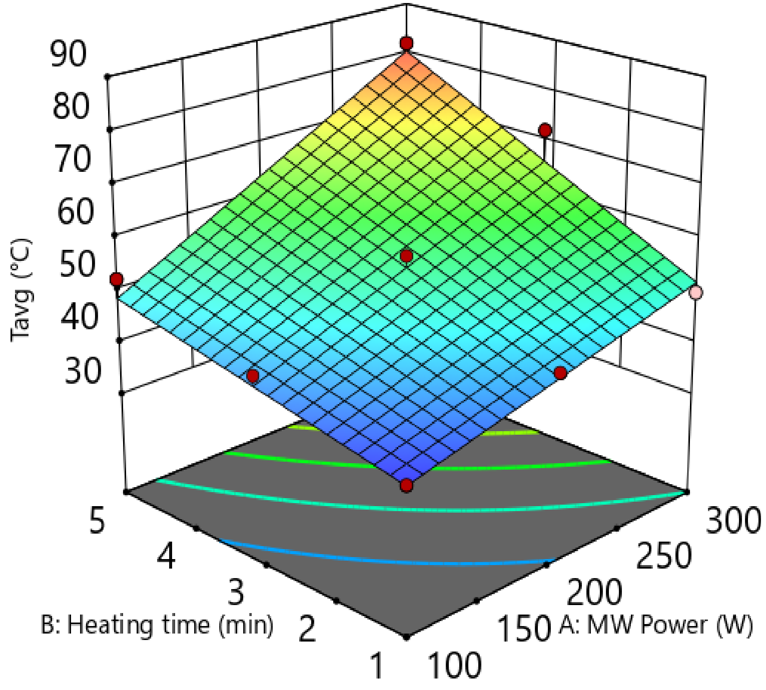
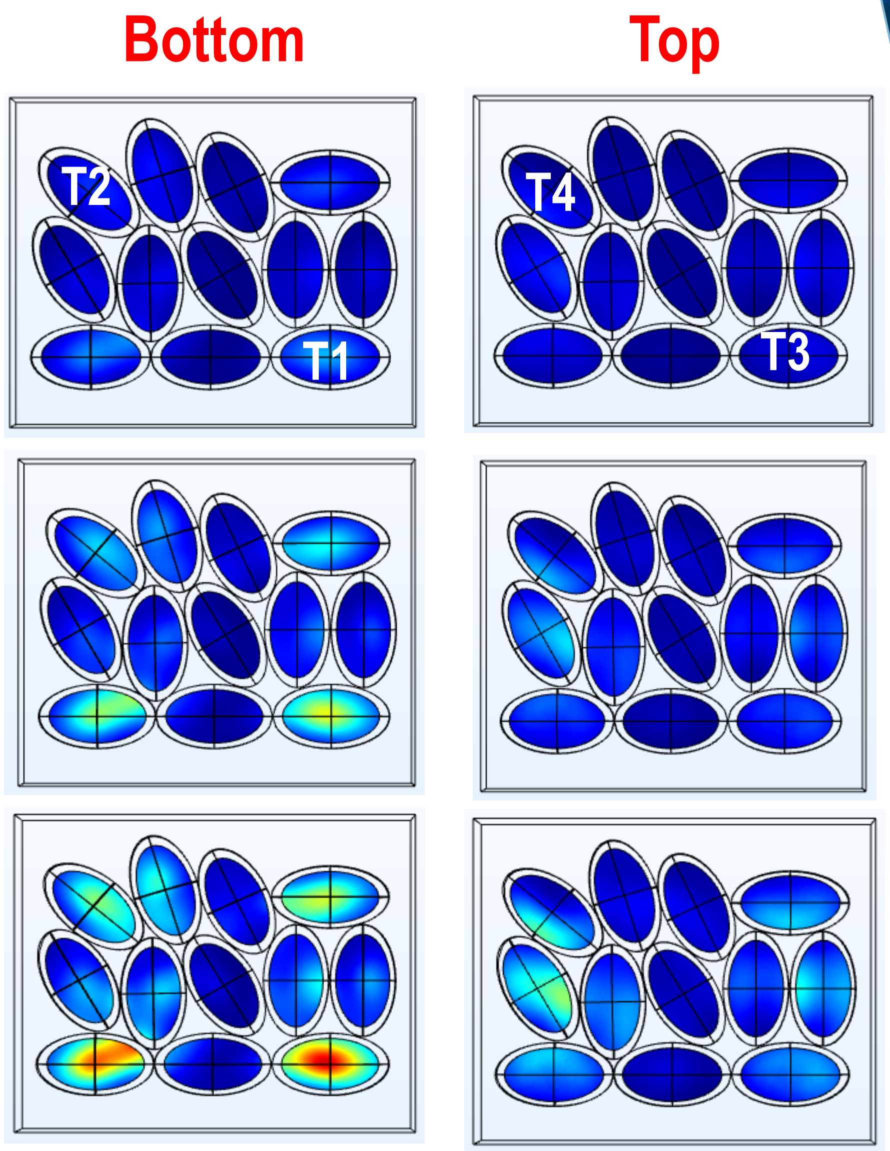
Results from Lab scale

Temperature profile



Stacked layer

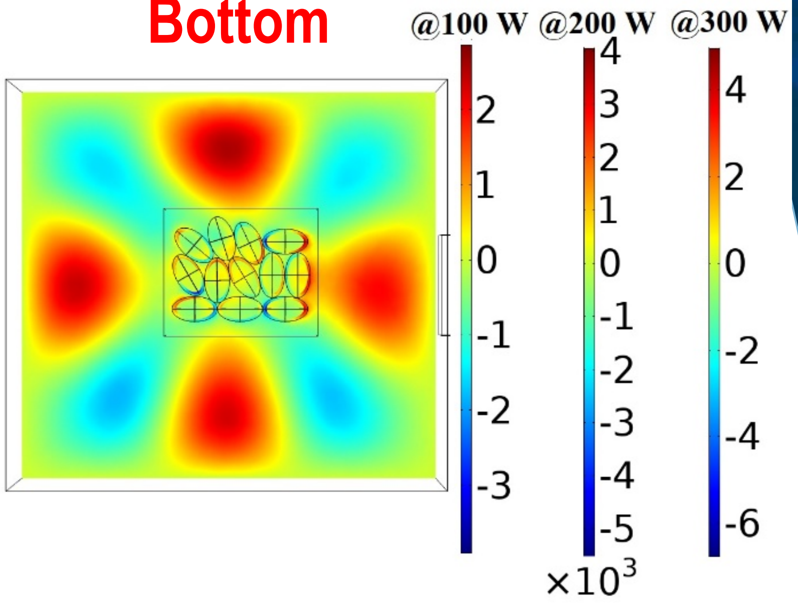


MW sterilization

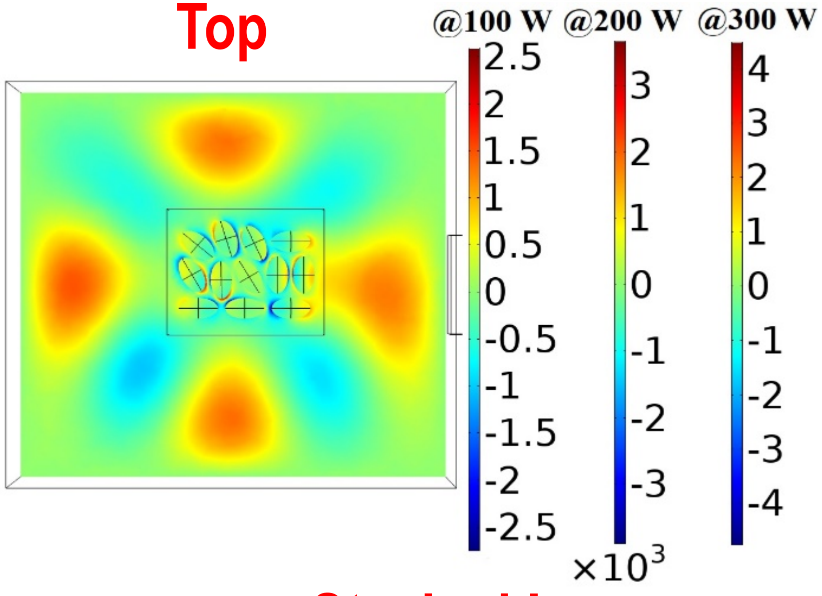
Results from Lab scale

MW electric field, V/m

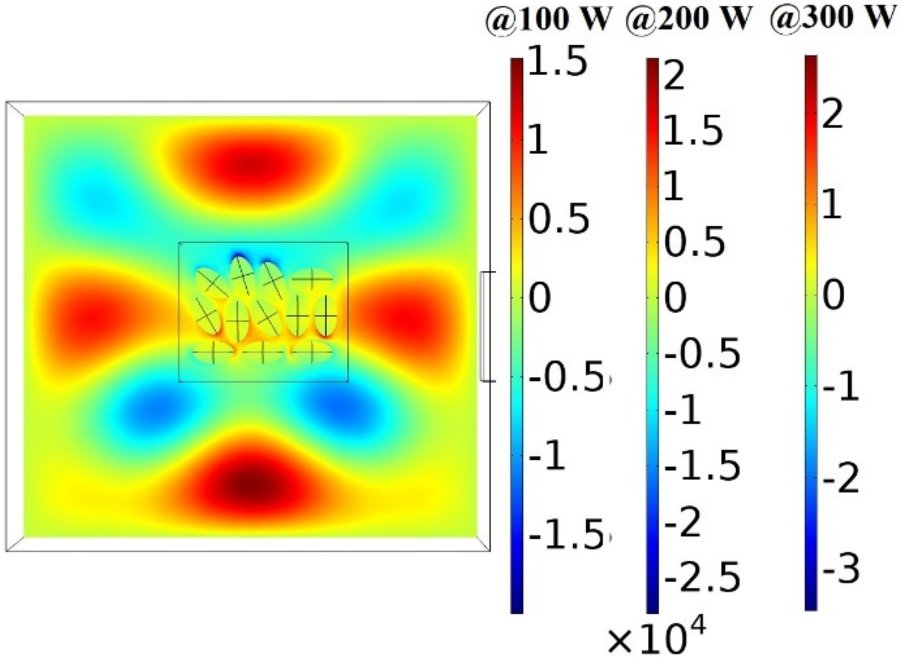
Bottom



Top



Stacked layer



Single layer

MW Biomass Processing

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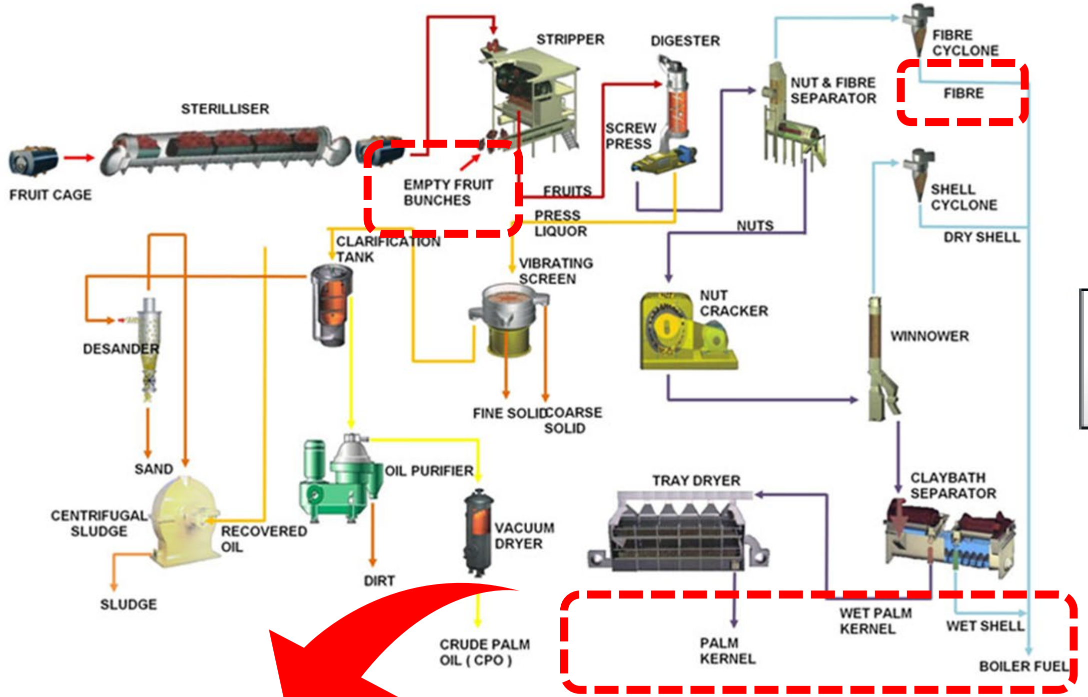
Biomass: A by-product of palm oil mill

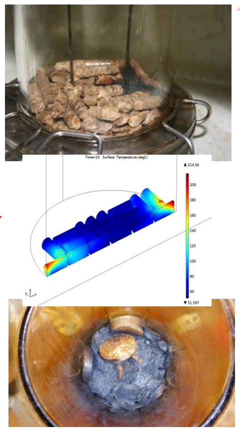


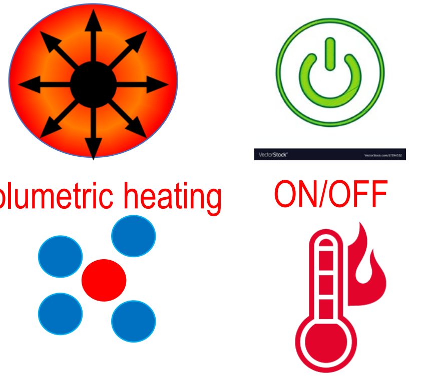
Solution: Value added products

Bio-oil

Bio-char

Product Gas





Volumetric heating

ON/OFF

Selective heating

Rapid heating

~~Problem~~ Opportunity: Biomass

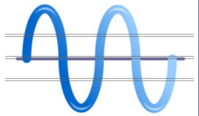
Technology: Pyrolysis/Gasification/ Combustion

Dielectric properties of biomass

Will the material heat well under the MW?

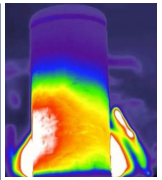
What type and geometry of applicator is best suited?

Will microwave absorption characteristics change during the processing?



What will be best frequency to process the biomass under MW?

How uniform will the heating?



Will thermal runaway be a problem?

Does the biomass will absorb or reflect microwave power?

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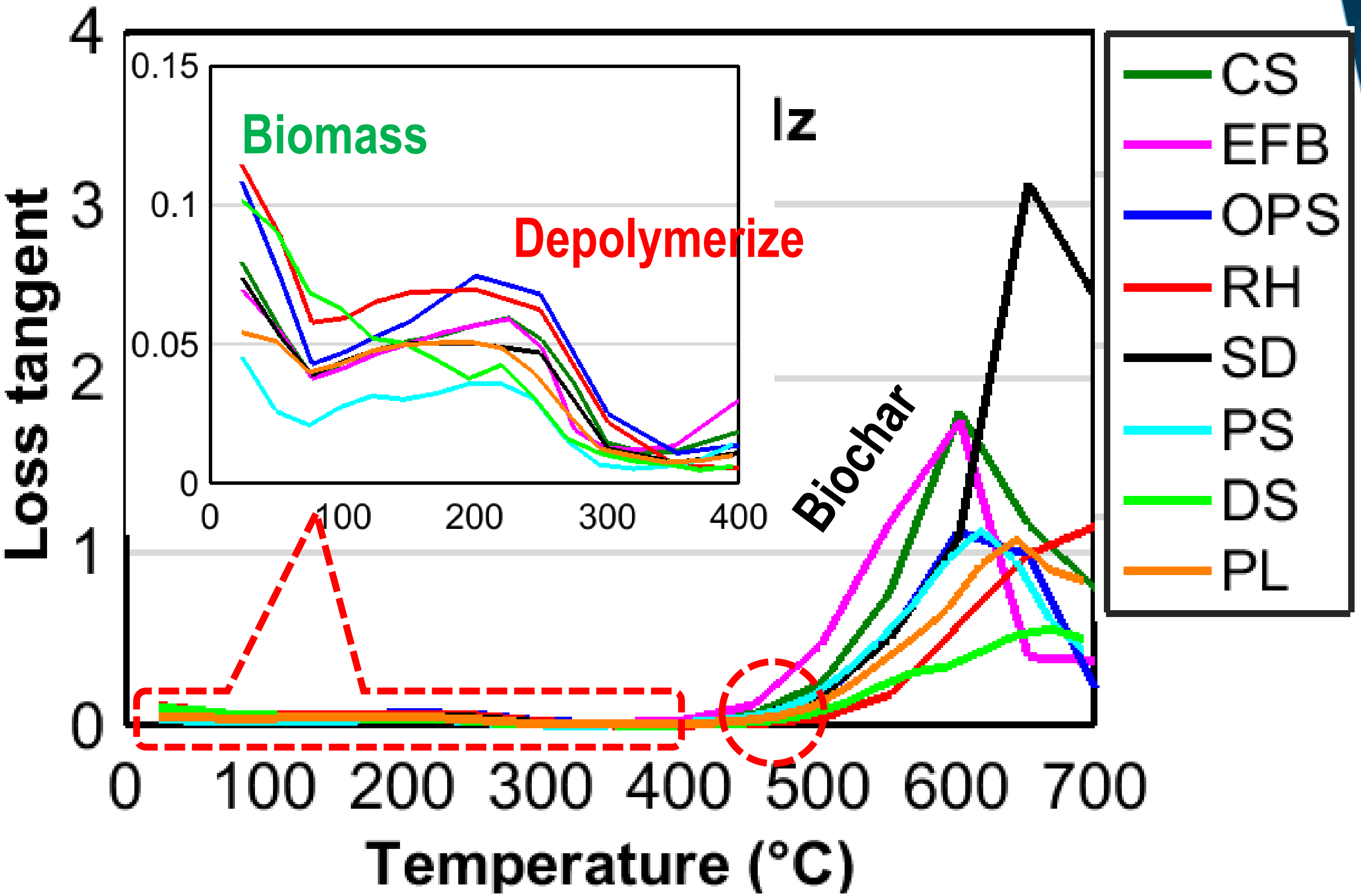
Dielectric property Vs Temperature

2.45 GHz, Nitrogen environment



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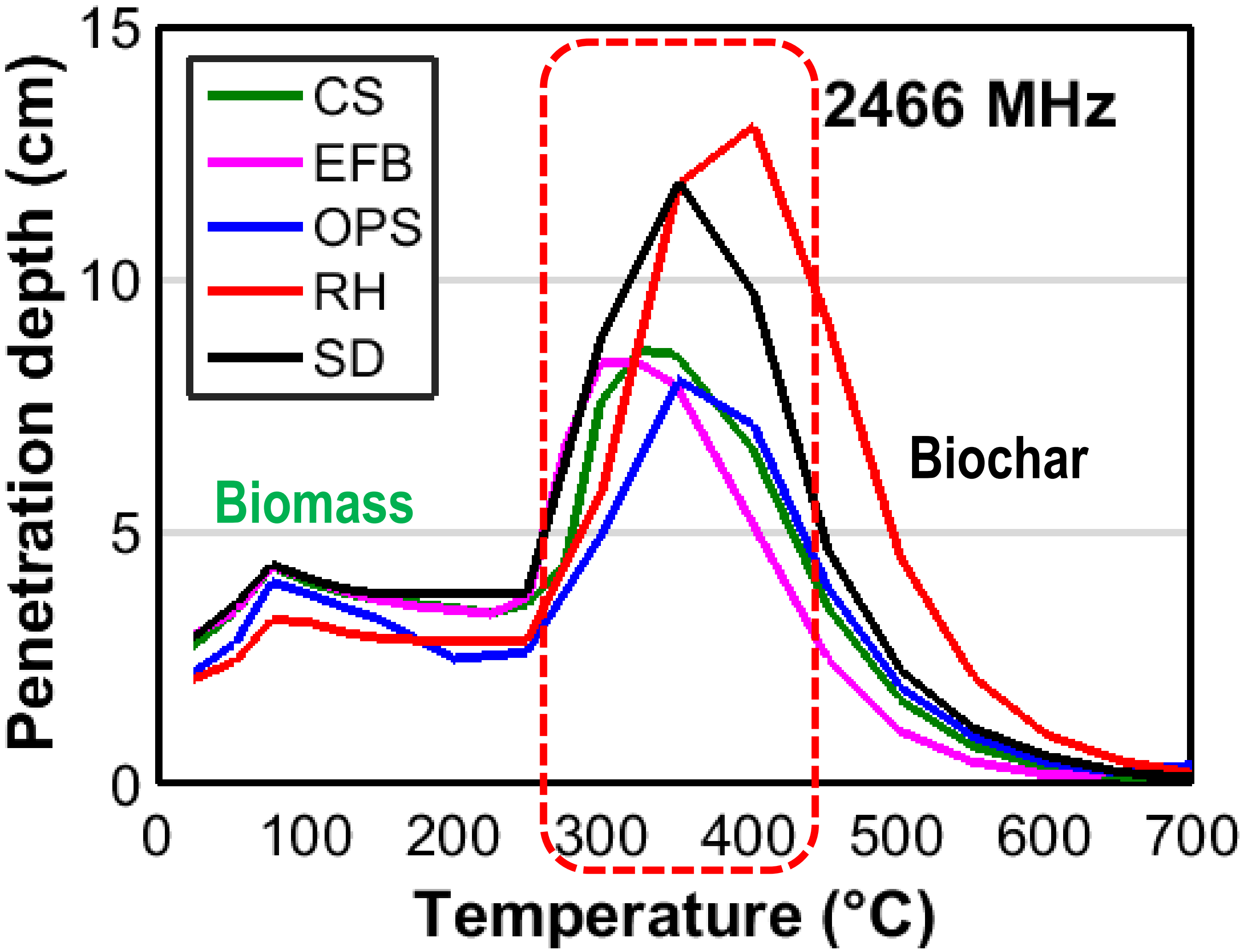
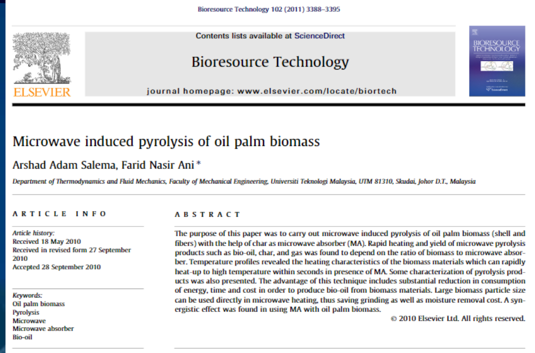
Penetration depth Vs Temperature

Highly depends on dielectric properties



Lab scale MW pyrolysis system

Quartz glass reactor


Bioresource Technology 102 (2011) 3388–3395

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Microwave induced pyrolysis of oil palm biomass

Arshad Adam Salema, Farid Nasir Ani *

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ARTICLE INFO

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Received 18 May 2010
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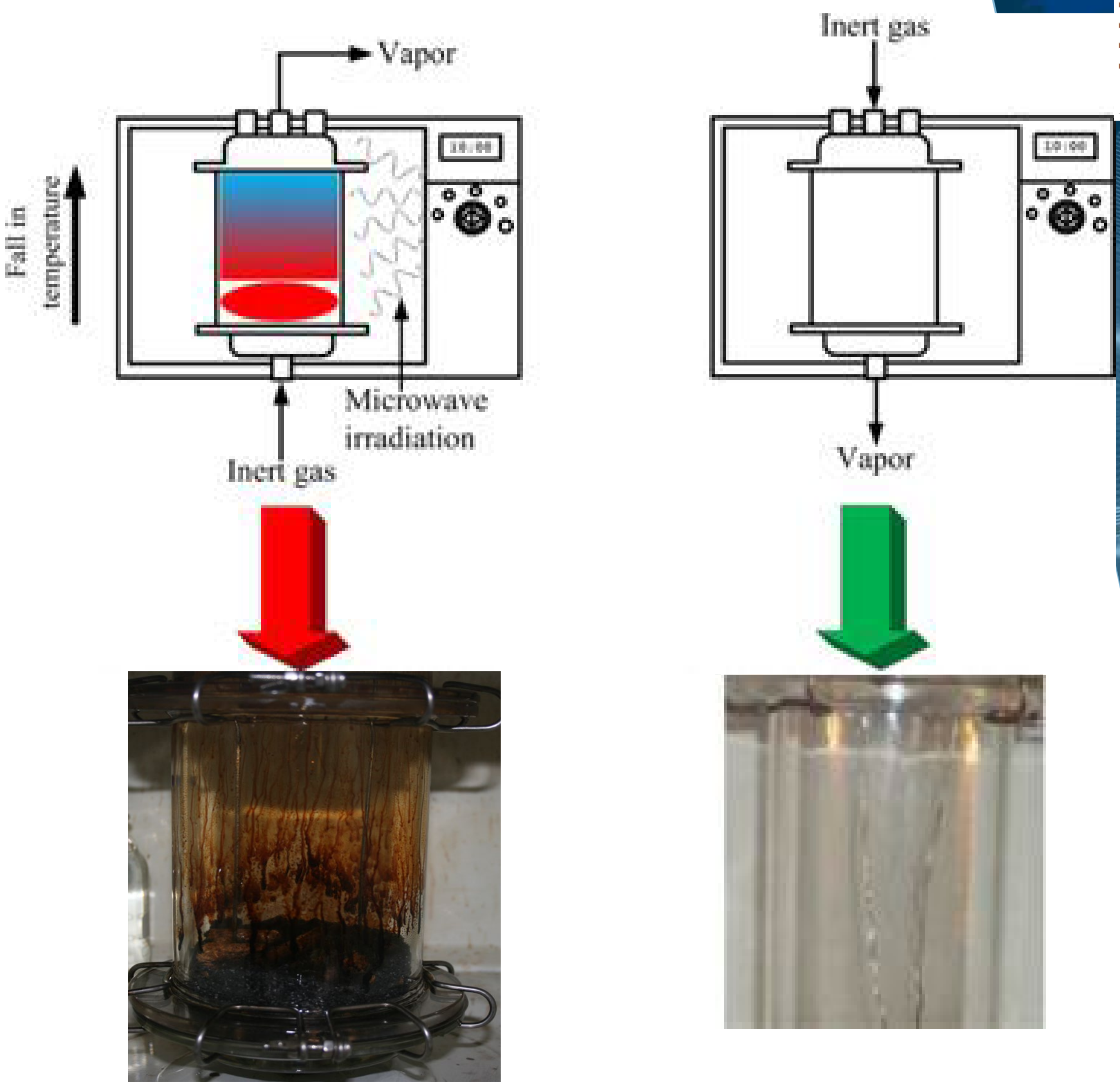
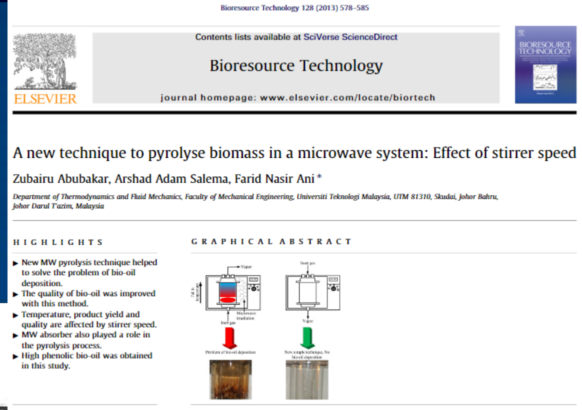
Keywords:
Oil palm biomass
Pyrolysis
Microwave
Microwave absorber
Bio-oil

ABSTRACT

The purpose of this paper was to carry out microwave induced pyrolysis of oil palm biomass (shell and fibers) with the help of char as microwave absorber (MA). Rapid heating and yield of microwave pyrolysis products such as bio-oil, char, and gas was found to depend on the ratio of biomass to microwave absorber. Temperature profiles revealed the heating characteristics of the biomass materials which can rapidly heat-up to high temperature within seconds in presence of MA. Some characterization of pyrolysis products was also presented. The advantage of this technique includes substantial reduction in consumption of energy, time and cost in order to produce bio-oil from biomass materials. Large biomass particle size can be used directly in microwave heating, thus saving grinding as well as moisture removal cost. A synergistic effect was found in using MA with oil palm biomass.

Lab scale MW pyrolysis system




Bioresource Technology 128 (2013) 578–585
Contents lists available at SciVerse ScienceDirect
Bioresource Technology
journal homepage: www.elsevier.com/locate/biortech

A new technique to pyrolyse biomass in a microwave system: Effect of stirrer speed

Zubairu Abubakar, Arshad Adam Salema, Farid Nasir Ani *
Department of Thermodynamics and Fluid Mechanics, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, UTM 81310, Skudai, Johor Bahru, Johor Darul T'azim, Malaysia

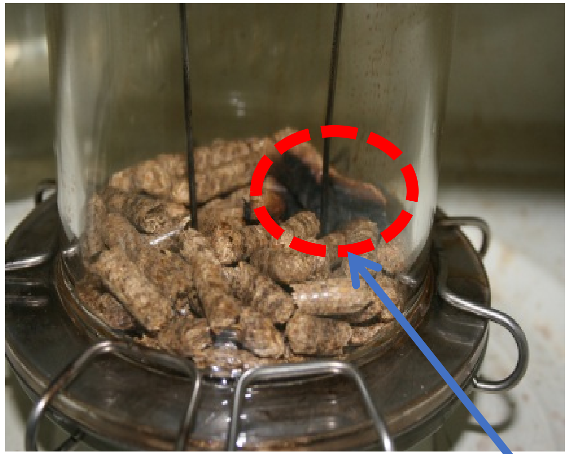
HIGHLIGHTS

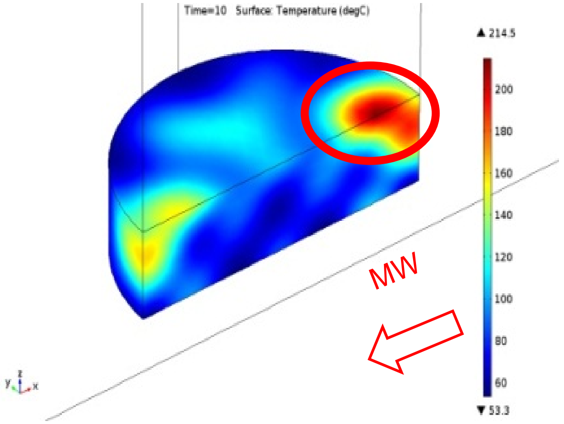
- New MW pyrolysis technique helped to solve the problem of bio-oil deposition.
- The quality of bio-oil was improved with this method.
- Temperature, product yield and quality are affected by stirrer speed.
- MW absorber also played a role in the pyrolysis process.
- High phenolic bio-oil was obtained in this study.

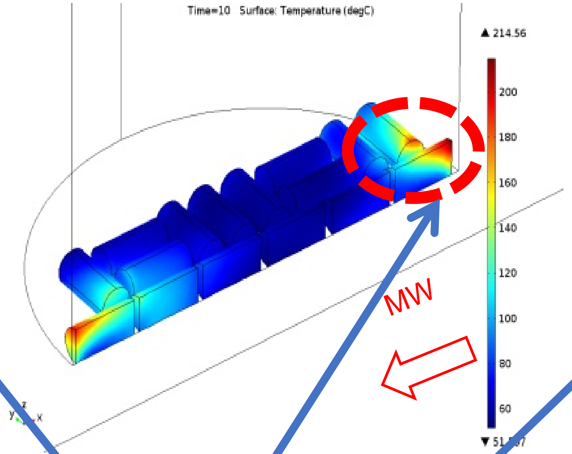
GRAPHICAL ABSTRACT

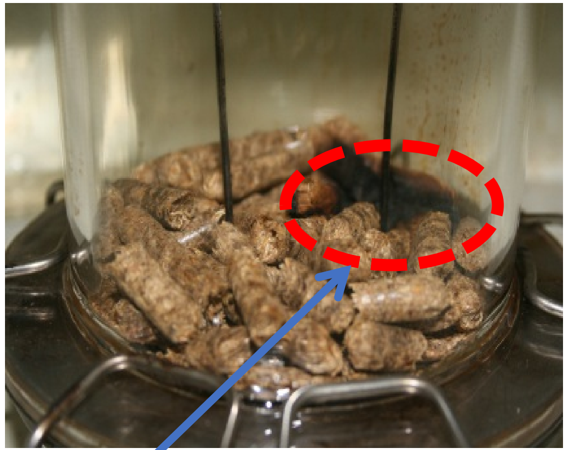
Hot spot (localised heating)

Computational simulation and experimental results









Hot spot

Bioresource Technology 125 (2012) 102–107

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Pyrolysis of oil palm empty fruit bunch biomass pellets using multimode microwave irradiation

Arshad Adam Salema, Farid Nasir Ani *

Department of Thermodynamics and Fluid Mechanics, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, UTM 81310 Skudai, Johor D.T., Malaysia

H I G H L I G H T S

- Ball lightnings were observed during microwave (MW) pyrolysis of biomass pellets.
- EFB pellets were pyrolysed in a multimode MW system even in absence of MW absorber.
- Biomass to MW absorber ratio affected the temperature profiles of the pyrolysis.
- The properties of bio-oil and bio-char were also found to depend on this ratio.

A R T I C L E I N F O

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Keywords:
Biomass
Microwave pyrolysis
Bio-oil
Bio-char
Phenolic

A B S T R A C T

Oil palm empty fruit bunch pellets were subjected to pyrolysis in a multimode microwave (MW) system (1 kW and 2.45 GHz frequency) with and without the MW absorber, activated carbon. The ratio of biomass to MW absorber not only affected the temperature profiles of the EFB but also pyrolysis products such as bio-oil, char, and gas. The highest bio-oil yield of about 21 wt.% was obtained with 25% MW absorber. The bio-oil consisted of phenolic compounds of about 60–70 area% as detected by GC–MS and confirmed by FT-IR analysis. Ball lightning (plasma arc) occurred due to residual palm oil in the EFB biomass without using an MW absorber. The bio-char can be utilized as potential alternative fuel because of its heating value (25 MJ/kg).

International Journal of Thermal Sciences 91 (2015) 12–24

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Numerical simulation of heating behaviour in biomass bed and pellets under multimode microwave system

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1 January 2015
Accepted 4 January 2015
Available online 3 February 2015

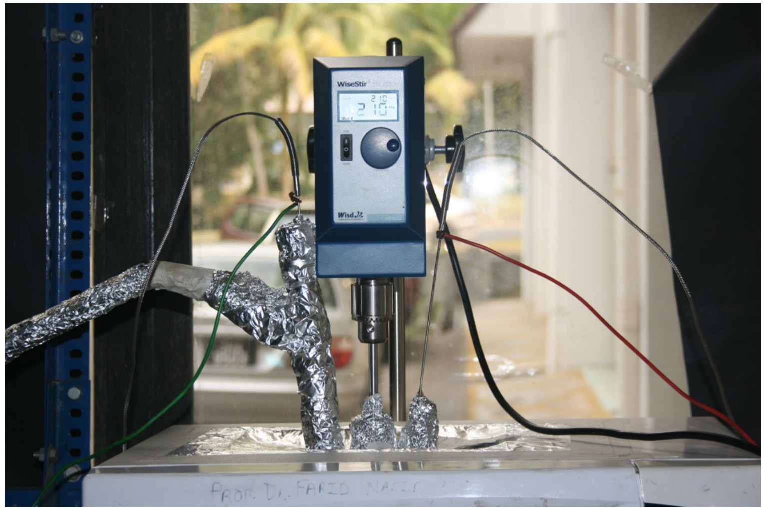
Keywords:
Microwave
Simulation
Biomass
Pellet
Temperature
Electric fields

A B S T R A C T

Domestic multimode microwave (MW) systems have been extensively used to process biomass materials for proof of concept. However, one of the major drawbacks for these systems is the non-uniform heating. Therefore, the aim of this article was to predict the heating behavior of empty fruit bunch (EFB) biomass in both bed and pellet form using finite element based COMSOL Multiphysics software. The temperature data from a modified domestic multimode MW system at 2.45 GHz frequency was used. Quantitative validation of 10 s heating profile was performed by comparing the simulated temperature profile with the experimental temperature. The agreement of simulated temperature profiles depended on various factors such as biomass loading bed height, defining specific heat capacity value and form of biomass shape (bed or pellet). Interestingly, the location of local hot spots during MW heating of EFB bed and pellets were almost close enough in both simulation and experimental study. An optimal biomass loading height was found whereby maximum MW energy is absorbed by the sample. The effect of biomass loading height on the distribution of electromagnetic fields is discussed in the paper. This study provides a framework and required model parameters to predict temperature and optimum biomass loading for a specific geometry of MW cavity. Further, the model can be effectively used to identify hot and cold spots in the biomass material during MW heating and thereby help to design and optimize the MW applicators in terms of heating uniformity. The proposed model can also be useful to identify the electromagnetic field distribution inside the cavity.

MW pyrolysis with mechanical stirrer

Affected the bio-oil quality



Journal of Analytical and Applied Pyrolysis 96 (2012) 162–172

Contents lists available at SciVerse ScienceDirect

Journal of Analytical and Applied Pyrolysis

journal homepage: www.elsevier.com/locate/jaap

Microwave-assisted pyrolysis of oil palm shell biomass using an overhead stirrer

Arshad Adam Salema, Farid Nasir Ani*

Department of Thermodynamics and Fluid Mechanics, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, UTM 81310, Skudai, Johor Bahru, Johor Darul T'azim, Malaysia

ARTICLE INFO

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Received 20 December 2011
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Available online 12 April 2012

Keywords:
Biomass
Microwave pyrolysis
Stirrer
Bio-oil
Phenol
Carbon percentage

ABSTRACT

Oil palm shell biomass contains a high amount of lignin and thus has the potential to be converted into value-added products. If this biomass is not utilised efficiently, significant loss of valuable chemical products may occur, which otherwise can be recovered. In this paper, a new technique using an overhead stirrer to pyrolyse biomass under microwave (MW) irradiation was investigated. The ratio of biomass to activated carbon was varied to investigate its effect on the temperature profile, product yield and phenol content of the bio-oil. Interestingly, the microwave pyrolysis temperature could be controlled by varying the biomass to carbon ratio. The highest bio-oil yield and phenol content in bio-oil were obtained at a biomass to carbon ratio of 1:0.5. Chemical analyses of bio-oil were performed using FT-IR, GC–MS and ^1H NMR techniques. These results indicate that bio-oil consists mainly of aliphatic and aromatic compounds with high amounts of phenol in the bio-oil. Thus, MW pyrolysis with a stirrer successfully produced high-phenol bio-oil compared to other methods. This significant increase in bio-oil quality could either partially or wholly replace petroleum-derived phenol in many phenol-based applications.

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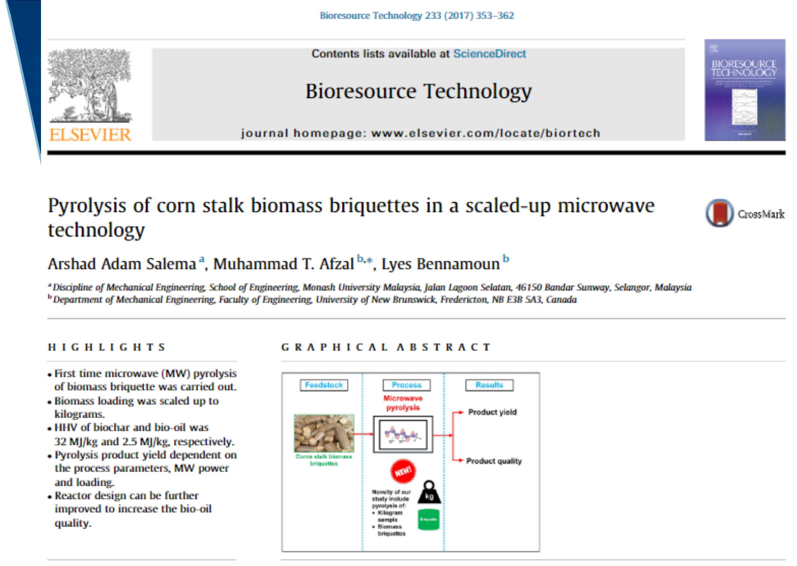
Bench scale MW pyrolysis system

Pellets

Briquettes

1 kg to 10 kg

UNB, Canada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Pyrolysis of corn stalk biomass briquettes in a scaled-up microwave technology

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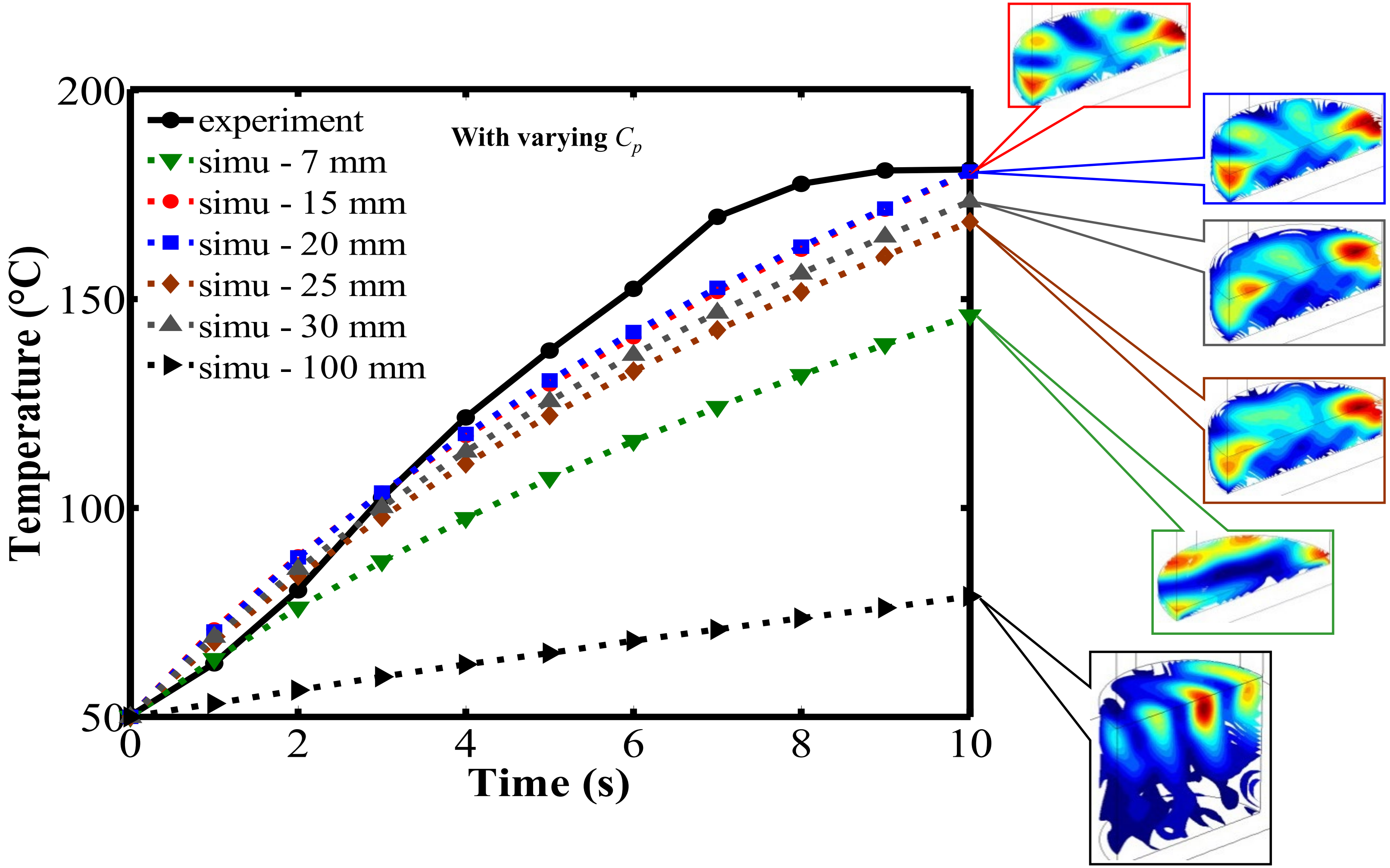
HIGHLIGHTS

- First time microwave (MW) pyrolysis of biomass briquette was carried out.
- Biomass loading was scaled up to kilograms.
- HHV of biochar and bio-oil was 32 MJ/kg and 2.5 MJ/kg, respectively.
- Pyrolysis product yield dependent on the process parameters, MW power and loading.
- Reactor design can be further improved to increase the bio-oil quality.

GRAPHICAL ABSTRACT

Effect of biomass loading

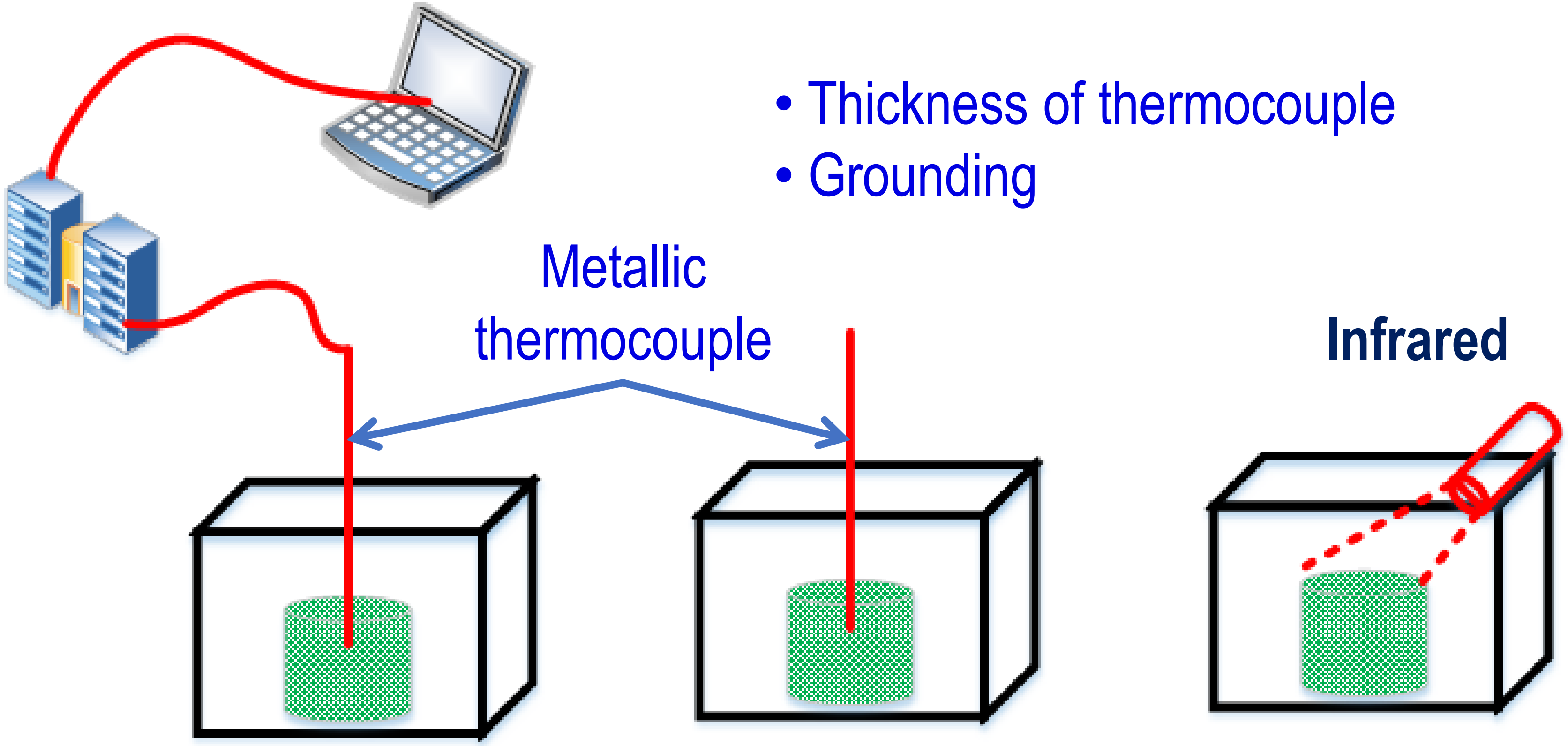
On the heat transfer under MW irradiation



Temperature measurement

During MW heating

- Thickness of thermocouple
- Grounding



In-situ and continuous

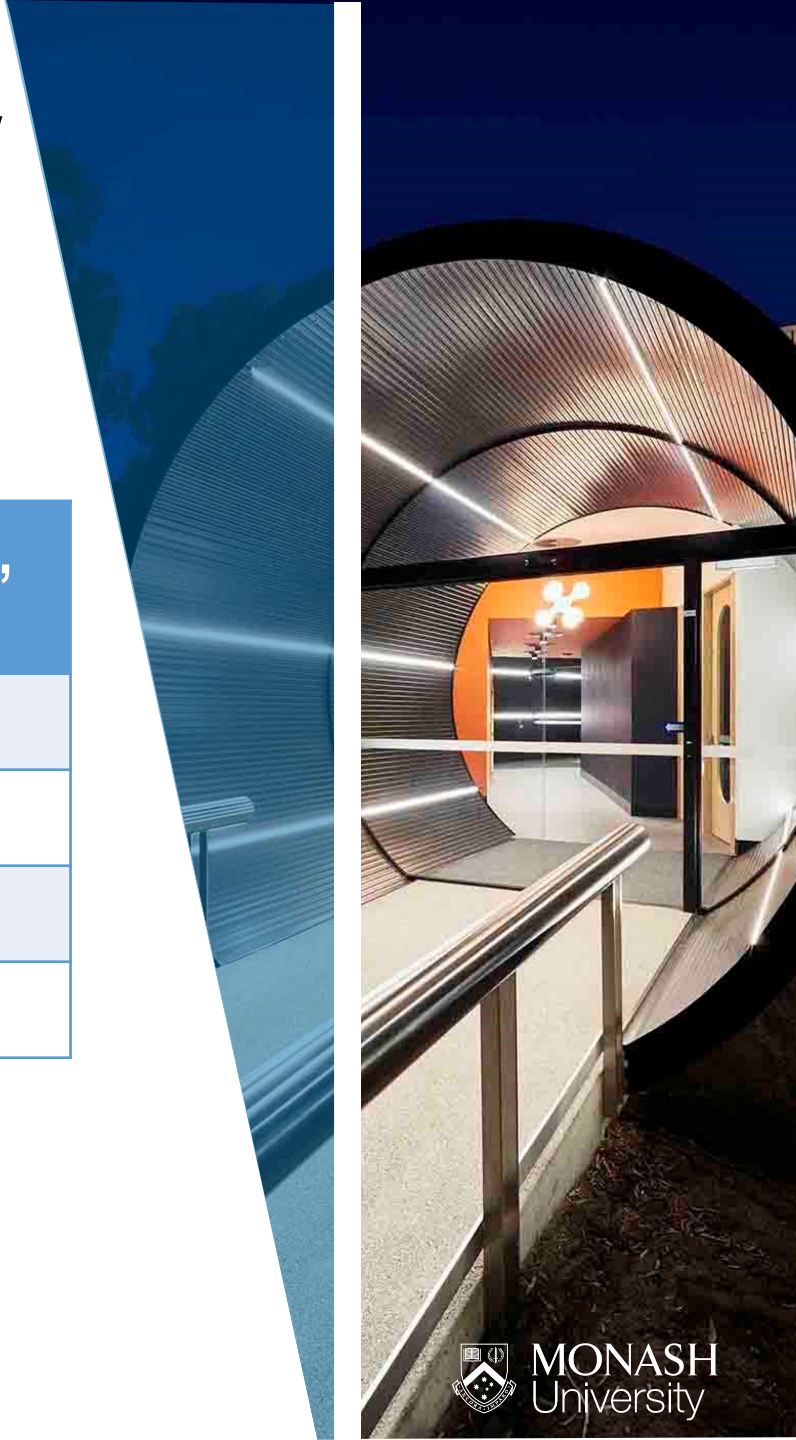
Ex-situ and intermittent

Remote sensing

Product quality in different technology

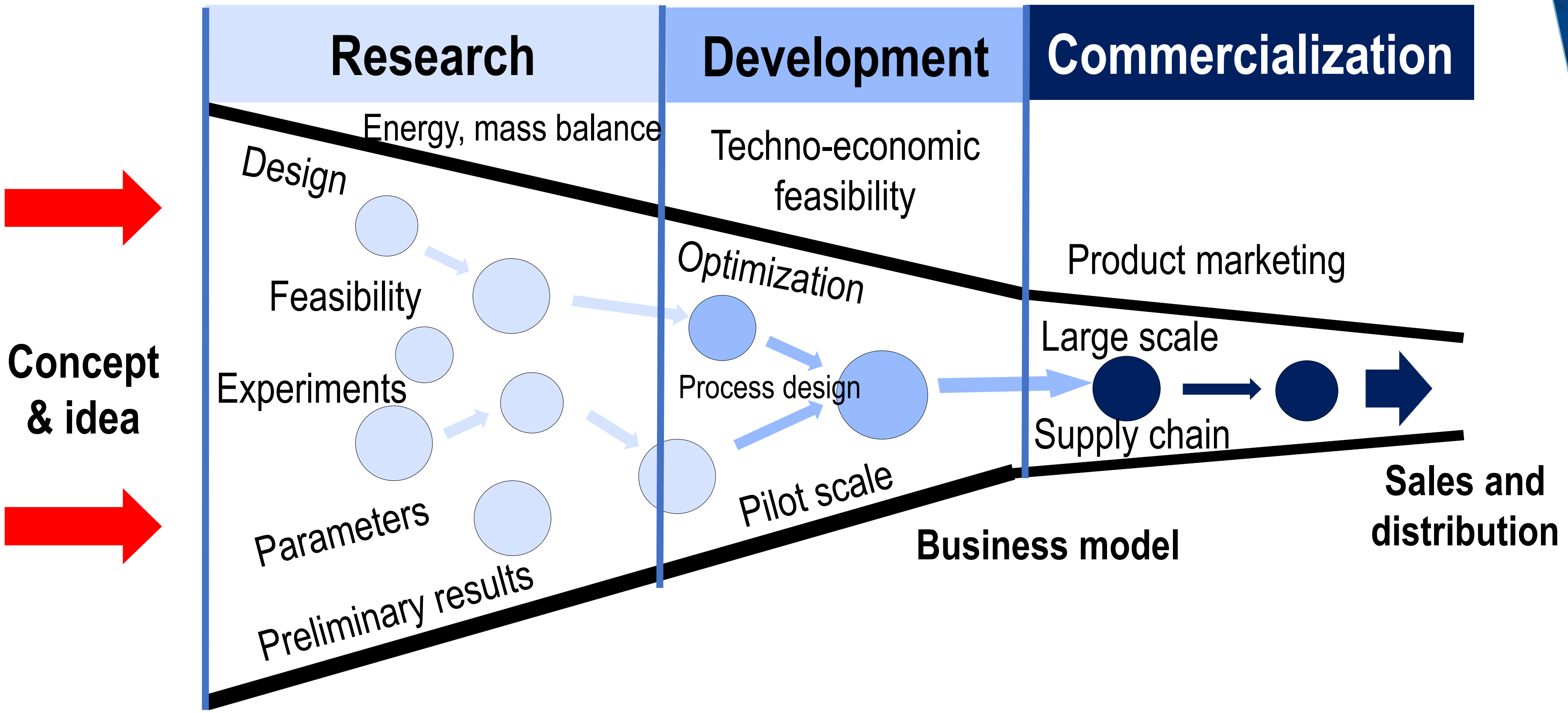
Bio-oil from OPS biomass

Biomass, Reference	Technology	Temperature, °C	Phenol, area%
OPS, Salema et al 2012	Microwave	500	**72.0**
OPS, Islam et al 1999	Fluidized bed	500	28.3
OPS, Kim et al 2010	Fluidized bed	453	22.1
OPS, Abnisa et al 2011	Fixed bed	500	13.4



Status Quo

MW biomass processing technology



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