Date Received
For Administrative Use Only

PROJECT FINAL REPORT

Instructions:

- **Please note that making changes to the project without prior written consent from the funder(s) could constitute sufficient grounds for termination of funding.**
- This report must be a stand-alone report, *i.e.,* must be complete in and of itself. Scientific articles or other publications cannot be substituted for the report.
- A signed electronic copy of this report must be forwarded to the funders' representative on or before the due date, as per the investment agreement.
- A detailed, signed statement of revenues received and expenses incurred during the entire funding period of the project must be submitted along with this report, as per the investment agreement.
- For any questions regarding the preparation and submission of this report, please contact the funders' representative.

Section A: Project overview

1. Project number: BFR-16-060
2. Project title: Design and Application of a High-Pressure Microwave Drop-In Biofuel Reactor
3. Abbreviations: Define ALL abbreviations used. LTH: Lipid-to Hydrocarbon NSERC: Natural Sciences and Engineering Research Council of Canada ALMA: Alberta Livestock and Meat Agency WED: Western Economic Diversification Canada GC: Gas chromatograph FID: Flame Ionization detector MS: Mass Spectroscopy TCD: Thermal conductivity Detector PDF: Postdoctoral Fellow

HQP: Highly Qualified Personnel	
4. Project start date: (2016/04/01)	
5. Project completion date: (2021/03/31) Cancelled: 2020/04/07	
6. Final report submission date: (2020/06/01)	
7. Research and development team data	
a) Principal Investigator: (Requires personal data sheet (refer to Section 14) only if Principal Investigator has changed since last report.)	
Name	**Institution**
David Bressler	University of Alberta
b) Research team members (List all team members. For each new team member, *i.e.*, joined since the last report, include a personal data sheet. Additional rows may be added if necessary.)	
Name	**Institution**
Michael Chae	University of Alberta
Justice Asomaning	University of Alberta
Samuel Koranteng	University of Alberta
Susan Haupt	Technical University of Dresden
Maryam Hawk	University of Albert
John Hawk	University of Alberta
Bernardo Araujo Souto	Federal University of Itajuba

Section B: Non-technical summary (max 1 page)

Provide a summary of the project results which could be used by the funders for communication to industry stakeholders (*e.g.*, producers, processors, retailers, extension personnel, etc.) and/or the general public. This summary should give a brief background as to why the project was carried out, what were the principal outcomes and key messages, how these outcomes and key messages will advance the agriculture, bioindustrial, food or forestry industry, how they will impact industry stakeholders and/or consumers, and what are the economic benefits for the industry.

The conversion of low value lipids, including tall oil, brown grease, and yellow grease, to hydrocarbons without the use of hydrogen or catalyst has been patented and scaled up by our group (Forge Hydrocarbons). This project seeks to develop a step change improvement to the existing process by incorporating microwave dielectric heating to the reactor configuration. Through the optimization of the new reactor, and in collaboration with Forge staff, the new technology will be used in ongoing scale-up. The rapid volumetric heating that occurs through the use of microwave dielectric heating is expected to help overcome hot spot that is associate with conventional heating through the reactor wall. Thus, minimizing over cracking, aromatic compound formation that leads to coking. Whiles promoting the desirable deoxygenation reaction to produce hydrocarbons in the diesel and gasoline range.
The project resulted in the design and fabrication of a first of a kind high temperature high pressure microwave reactor system. Although the results from testing showed that direct

deoxygenation and pyrolysis of fatty acids was not achieved as these materials did not absorb enough microwave energy to reach pyrolytic temperatures. The use of heating aids such as activated carbon and silicon carbide helped achieve pyrolytic temperatures resulting in deoxygenation and cracking. A draw back of the use of solid heating aids is the generation of hot spots that result on over cracking and coke formation. Thus, eliminating the potential advantage of microwave di-electric heating to conventional heating. This implies commercial application of the technology to the LTH process will be non-beneficial or provide any advantage over conventional heating.

Section C: Project details

1. **Background (max 2 pages)**
   Describe the project background and include the relevant scientific and development work providing the impetus for the current project.

Traditionally microwaves have been used for rapid heating of polar solutions, primarily water-based mixtures. More recently, research groups have begun investigating the use of microwaves for the heating of lignocellulosic biomass into the pyrolytic regime (>400C) and finding success. In parallel, the Bressler laboratory has established itself as a world-class pyrolysis centre (1-15) that has developed, patented, and licensed out a lipid to hydrocarbon (LTH) pyrolysis technology to Forge Hydrocarbons (a University of Alberta spin-off company). The LTH technology, previously supported by NSERC, ALMA, WED, Alberta Innovation and Advanced Education, and AI-Bio, has been proven at 20L per hour scale, raised over $25M in strategic investment, and is moving to commercial scale over the next couple years. The one identified limiting aspect of the LTH technology is the relatively long holding time (ave. 1 hour) and the remaining optimization efforts seek to further reduce the residual short chain organic acid content in the final raw product.

Microwaves selectively heat polar molecules, and non-polar components in mixtures are subsequently heated only through conduction heating between molecules. This aspect of microwave heating implies a major opportunity for the LTH technology to rapidly target and preferentially drive energy into the specific molecules targeted for decarboxylation and cracking reactions, while potentially reducing the extent of condensation, aromatization, and over-cracking of the hydrocarbons already formed in the mixture. It is hypothesized on the molecular level that rapid heating of the mixture with microwaves will have several benefits including:

1) Increased rates of decarboxylation and decarbonylation (thus oxygen removal)
2) Increase rate of initial cracking to diesel and gasoline fraction molecules
3) Reduced over-cracking to light gases
4) Reduced comparative levels of coke formation

One aspect that has limited this investigation area worldwide is that research microwave systems are limited to either being non-pressurized or available only at low temperature regimes (<100C).

The Bressler group made contact with a custom microwave manufacturer capable to work with the Bressler lab to undertake the unique fabrication of a microwave system able to work in batch at pyrolytic temperatures. Additionally, the team identified the opportunity to work with a unique variable-wavelength microwave source that will allow the team to scan a wide range of wavelengths within the novel prototype microwave to fine tune the chemistry allowing an optimum regime for the desired reactions.

2. Objectives and deliverables (max 2 pages)

State what the original objective(s) and expected deliverable(s) of the project were. Also describe any modifications to the objective(s) and deliverable(s) which occurred over the course of the project.

The overall objective of this project was to develop a novel technology utilizing high pressure microwave heating for the free radical conversion of lipids to hydrocarbons and deliver the technology to our industry partner. The sub objectives of the project were to custom design, fabricate, commission and utilize a novel reactor and to train a PDF and a graduate student to become experts in the use of microwave chemistry at high reactor temperatures and pressures.

Key deliverables expected

Year 1 milestones included:

a. Retention of a new PDF and graduate student (PhD) (at launch)
b. Design, fabrication of the reactor (3 month point)
c. Completion of coursework by the student (End of year 1)
d. Installation, commissioning, and testing of the new reactor by PDF (end of first 6 months)
e. Initial testing of the effect of variable wavelengths conducted with model saturated and unsaturated fatty acids (i.e. stearic & oleic) to find optimum wavelengths and energy levels for optimum product composition at a given pressure and temperature. Comparison of microwave heating vs. traditional thermal heating on the lipid to hydrocarbon process. Extensive GC/MS chemical profiling and quantitation (GC/FID) of product compositions. (last 6 months of year 1)

DELIVERABLE YEAR 1:

i) Installed operating system, initial testing experiments, trained and online HQP active.
ii) A complete review of microwave heating will be assembled and submitted for publication (paper 1).
iii) Two completed papers on the heating of saturated (paper 2) and unsaturated (paper 3) model feedstocks at various wavelengths and energy levels.

Year 2 milestones include:

a. Optimization of temperature (paper 4) at the previously identified wavelengths (first 6 months) and then pressure (paper 5) and time (paper 6) variables (last 6 months) utilizing a series of independent variable response optimization designs to allow understanding of how each variable affects performance after extensive chemical characterization and quantitation, followed by an overall response surface optimization strategy (second half of year 2).

DELIVERABLE YEAR 2:
i) A completed study (papers 4,5&6) on the effect of time (minutes-hours), pressure (ambient to 1000 psi) and temperature (350˚C-500˚C) on the product composition of pyrolyzed saturated and unsaturated fatty acid systems at the optimized wavelengths.
ii) A report to Forge Hydrocarbons on the status and opportunities for microwave heating incorporation into the Forge process.

Year 3 milestones include:
a. Trials and testing of optimized reactor conditions tested out on real feedstocks including tall oil (forestry), brown grease (animal fats), and various algal, fungal and plant oils (canola, flax, and corn) (Optimization of a new feedstock every 2 months)

DELIVERABLE YEAR 3:
i) A completed study (paper 6) on the microwave processing of complex fatty acid systems.
ii) A final completed recommendation on the potential for microwave heating in the Forge Process.

3. **Research design and methodology (max 5 pages)**
   Describe and summarise the project design, methodology and methods of laboratory/field and statistical analysis that were actually used to carry out the project. Please provide sufficient detail to determine the experimental and statistical validity of the work and give reference to relevant literature where appropriate. For ease of evaluation, please structure this section according to the objectives cited above.

A custom high temperature high pressure microwave system was designed and fabricated in collaboration with Microwave Research and Applications, Inc (Carol Stream, Il, USA). The system was designed to operate at a working temperature up to 500 °C at pressures up to 1000 psi (6.9 MPa). The unit consisted of two independent magnetrons operating at 2.45 GHz capable of producing 2000 W and 5.8 GHz capable of producing 700 W, respectively (Figure 1 and 2). Pressure transducers allowed the real-time monitoring of reaction pressures and infra red sensors and thermocouples enabled the real-time monitoring of temperatures. The forward and reverse power measuring capabilities also allowed the real-time monitoring of input and reflected power respective providing a means of monitoring the energy use efficiency. The system was connected to a computer to provide system control and data logging for subsequent retrieval and analysis.

Stearic acid and oleic acid were used a model saturated and unsaturated fatty acid feedstock, respectively. The sample (20-100 g) was used for each experiment and reaction conditions varied for operating temperature (350 – 450 °C), initial pressure of ambient to 200 psi, and reaction times of 20 – 60 minutes. The effect of microwave power and frequency was tested using the two magnetrons. For each reaction, after the sample is leaded the reactor was closed and purged at 500 psi using nitrogen to develop an oxygen-free atmosphere. For reaction with initial pressure above ambient temperature, nitrogen was used to pressurize the system to the desired initial pressure after purging at 500 psi.

Reaction were also carried out where activated carbon, silicon carbide (SiC), and graphite were used as microwave heating aid. For these reaction, various heating aid ratios were tested under conditions similar to reactions where no microwave heating aids were employed.

After, the reaction was completed, the reactor was cooled to room temperature using a water bath set to -5 °C. The reaction product gas and liquid were sampled and analyzed following established protocol in our laboratory. Gas samples were analyzed using gas chromatograph (GC) coupled to thermal conductivity detector (TCD) for nonhydrocarbon gases, and flame ionization detector (FID) for hydrocarbon gas analysis. External standards of the non-hydrocarbon gases were used for quantification of the corresponding gas, whereas methane was used as an external standard to determine the amount of methane, which was them used as an internal standard to quantify the other hydrocarbon gases. Liquid products were analyzed on GC coupled to FID for quantification using internal standard, and mass spectroscopy for identification.

4. Results, discussion and conclusions (max 10 pages)

Present the project results and discuss their implications. Discuss any variance between expected targets and those achieved. Highlight the innovative, unique nature of the new knowledge generated. Describe implications of this knowledge for the advancement of agricultural, bioindustrial science or development. For ease of evaluation, please structure this section according to the objectives cited above.

NB: Tables, graphs, manuscripts, etc., may be included as appendices to this report.

Results from the initial testing and commissioning of the reactor showed that both oleic acid and stearic acid could not be heated to any appreciable temperature using microwave dielectric heating. This was tested on the 2.45 GHz as well as the 5.8 GHz systems at different power levels. Even at the maximum power on the two systems, reaction temperatures were below 100 °C after 30 min with high reverse power, which resulted in the tuners overheating. Based on these results, it was confirmed that heating aids will be necessary to achieve significant heating.

Based on literature, silicon carbide, activated carbon (activated charcoal), and graphite were tested as potential heating aids. Tests were conducted using oleic acid as well as stearic acid with different heating aids to feed ratios. The results showed that using activated carbon reaction temperature could be reached in under 2 mins when compared to conventional heating (Figure 3). Analysis of the gas product using GC-TCD showed the presence of deoxygenation products (Figure 4). Additional reactions were conducted using higher feed to heating aid ratio with activated carbon as heating aid. Similar results were obtained with reaction temperature being reached in under 20 min. Figure 5 shows the temperature profile as well as the forward and reverse power, and pressure profile of the reaction. The gas product is shown in Figure 6, which show the presence of deoxygenation products (CO and CO_2) as well as hydrocarbons, which were the result of cracking. Thus, activated carbon could potentially be used as a heating aid in the deoxygenation and pyrolysis of fatty acids.

Similar results were obtained when SiC was used as heating aid with oleic acid and stearic acid as feedstocks. However, the analysis of the liquid product formed showed low conversions and significant amounts of aromatic compounds (Figure 6 & 8). This pointed to the possibility of hot spots, due to inability to effectively conduct extra heat away from the localized regions adjacent to the heating aids during the microwave reaction. Evidence of hotspots can be seen when then reactor was open (Figure 9). Reactions were repeated with sodium oleate to further investigate the presence of hot spots. As shown in Figure 10, the presence of hot spots is evidenced and marked as red in the image.

The presence of hotspot when solid heating aids were used, was a great limitation of the technology as it negated the primary advantage of using microwave dielectric heating, which is fast volumetric heating. As such integration of microwave heating into the LTH technology will not offer any significant advantage over conventional heating as the presence of hot spots cannot be completely eliminated.

Given these limitations, in consultation with project funders, the decision to end the project early was made resulting in the cancellation of the project on April 07, 2020.

5. Literature cited

Provide complete reference information for all literature cited throughout the report.

6. Project team (max 1 page)

Describe the contribution of each member of the research and development team to the functioning of the project. Also describe any changes to the team which occurred over the course of the project.

David Bressler was the principal investigator and provided scientific direction and supervision of all aspects and personnel and HQPs. Michael Chae was the program manager overseeing the and supervising HQPs, procurements, and finances of the project. Justice Asomaning, Maryam Hawk and John Hawk were postdoctoral fellows (HQPs) the carried-out research experiments, designing and developing analytical protocols, troubleshooting, and finding solutions to issues identified, and training supervising summer students (HQPs). Susan Haupt and Bernardo Araujo Souto were summer students (HQPs) that helped conduct experiments, troubleshooting issues and designing experiments protocols.

7. **Benefits to the industry (max 2 pages; respond to sections *a)* and *b)* separately)**
   a) Describe the impact of the project results on the Alberta agriculture, bioindustrial, food or forestry industry (results achieved and potential short-term, medium-term and long-term outcomes).

The custom high temperature high pressure microwave reactor was commissioned that demonstrates the possibility of utilizing this in pyrolysis reactions requiring temperatures above 300 °C and elevated pressure. Due to their microwave non-absorbing nature, fatty acid pyrolysis without the use of heating aids is limited. However, there is potential for future use in areas where lignocellulosic materials are to be pyrolyzed into bio-oil as these materials have polar compounds that are capable of absorbing and will not require the use of heating aids.

   b) Quantify the potential economic impact of the project results (*e.g.,* cost-benefit analysis, potential size of market, improvement in efficiency, etc.).

There is no direct application of this microwave approach. However, the negative result learnings have had immediate commercial impact as they have informed strategic engineering design of the initial Forge Commercial facility.

8. **Contribution to training of highly qualified personnel (max 2 pages)**
   Specify the number of highly qualified personnel (*e.g.*, students, post-doctoral fellows, technicians, research associates, etc.) who were trained over the course of the project.

   The research project resulted in the training of 3 postdoctoral research fellow and provided them with an opportunity to gain industrial experience through the partnership with Forge Hydrocarbons Inc. and Mitacs. Two summer students were also trained through this project one of which is currently enrolled in graduate studies with the Bressler group. Finally, the project provided training to one graduate student who is in the process of completing his masters.

   As part of the Mitacs program, postdoctoral fellow (Justice Asomaning) spent half of his time working with our industry partner (Forge Hydrocarbons Inc.) on pilot trial runs, along with process optimizations and development. Also, he also performed sample analysis, data analysis and report writing, and participated in meeting with companies regarding the design of Forge Hydrocarbons' commercial facility. The time was also spent in developing methodologies and processes for removing and recovering residual acids from the crude product to meet strict acid number regulations. Some of the processes were tested at the pilot scale and is currently being scaled for the first commercial plant.

9. **Knowledge transfer/technology transfer/commercialisation (max 2 pages)**
   Describe how the project results were communicated to the scientific community, to industry stakeholders, and to the general public. Please ensure that you include descriptive information, such as the date, location, etc. Organise according to the following categories as applicable:

N.B. Any publications and/or presentations should acknowledge the contribution of each of the funders of the project, as per the investment agreement.

a) Scientific publications (*e.g.*, scientific journals); attach copies of any publications as an appendix to this final report

Asomaning, J.; Haupt, S.; Chae, M.; Bressler, D. C. Recent developments in microwave-assisted thermal conversion of biomass for fuels and chemicals. Renewable and Sustainable Energy Reviews 2018,92, 642-657

b) Industry-oriented publications (*e.g.*, agribusiness trade press, popular press, etc.); attach copies of any publications as an appendix to this final report

c) Scientific presentations (*e.g.*, posters, talks, seminars, workshops, etc.); attach copies of any presentations as an appendix to this final report

Asomaning J.; Chae, M.; Bressler, D. C. Production of drop-in biofuels using microwave assisted pyrolysis. Sparks Conference, November 6-8, 2017, Edmonton, AB

Koranteng, S.; Asomaning J.; Chae, M.; Bressler, D. C. Microwave-assisted pyrolysis to deoxygenate fatty acids to hydrocarbon fuels. ALES graduate students Symposium, University of Alberta, 12 March, 2020, Edmonton, AB.

Souto B.A.; Asomaning J.; Chae, M.; Bressler, D. C. Production of biofuels using a novel microwave technology. University of Alberta Research Experience (UARE) Symposium, 22 August, 2019.

d) Industry-oriented presentations (*e.g.*, posters, talks, seminars, workshops, etc.); attach copies of any presentations as an appendix to this final report

Koranteng, S.; Ghoraishi M.S.; Asomaning J.; Chae, M.; Bressler, D. C. Application of high-pressure high-temperature microwave reactor system for drop-in biofuels production. Biomass Energy Network Launch event, 23 May, 2019, Edmonton, AB.

e) Media activities (*e.g.*, radio, television, internet, etc.)
f) Any commercialisation activities or patents

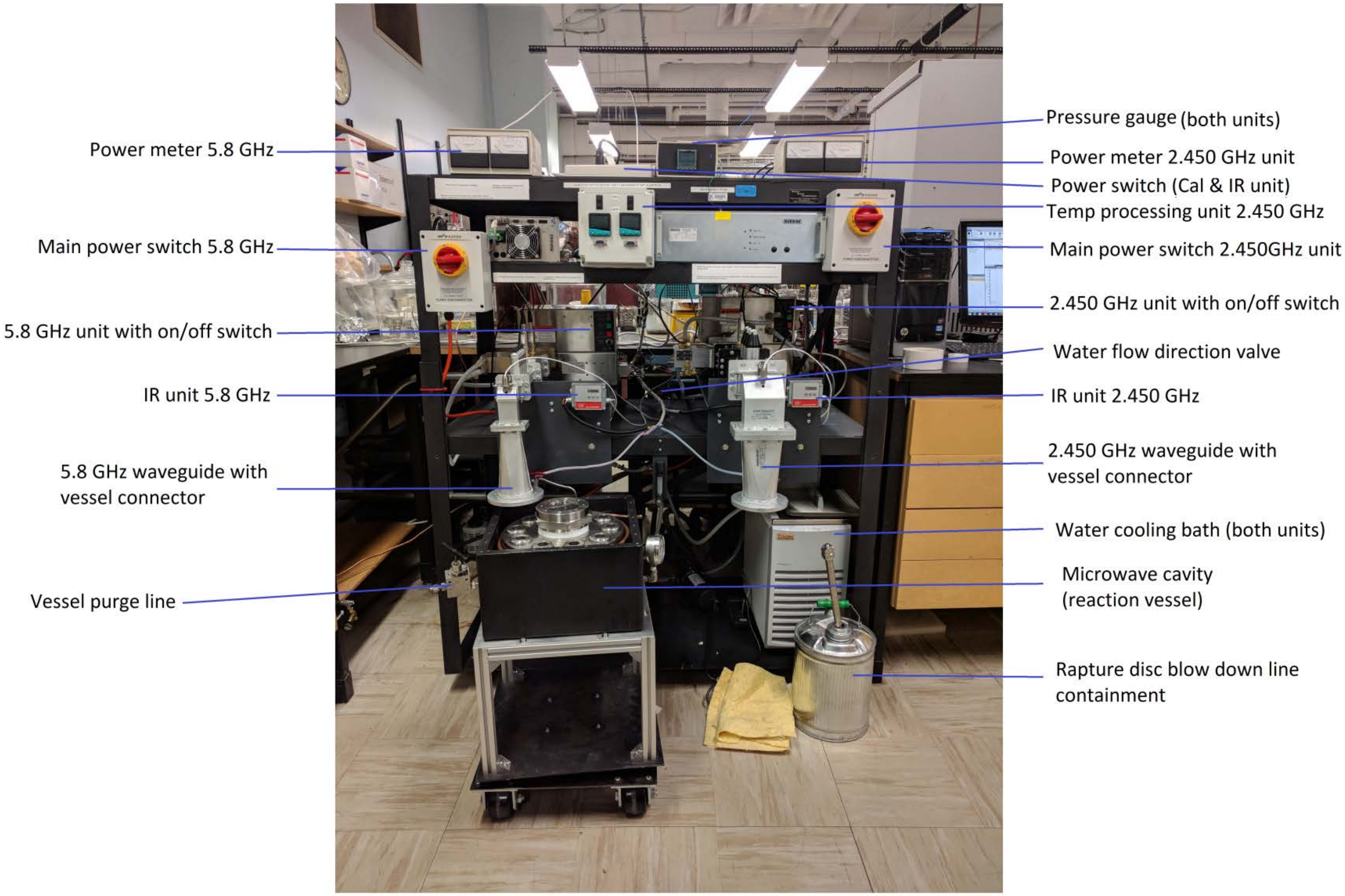


Figure 1: Picture showing the microwave reactor set up with main components labelled

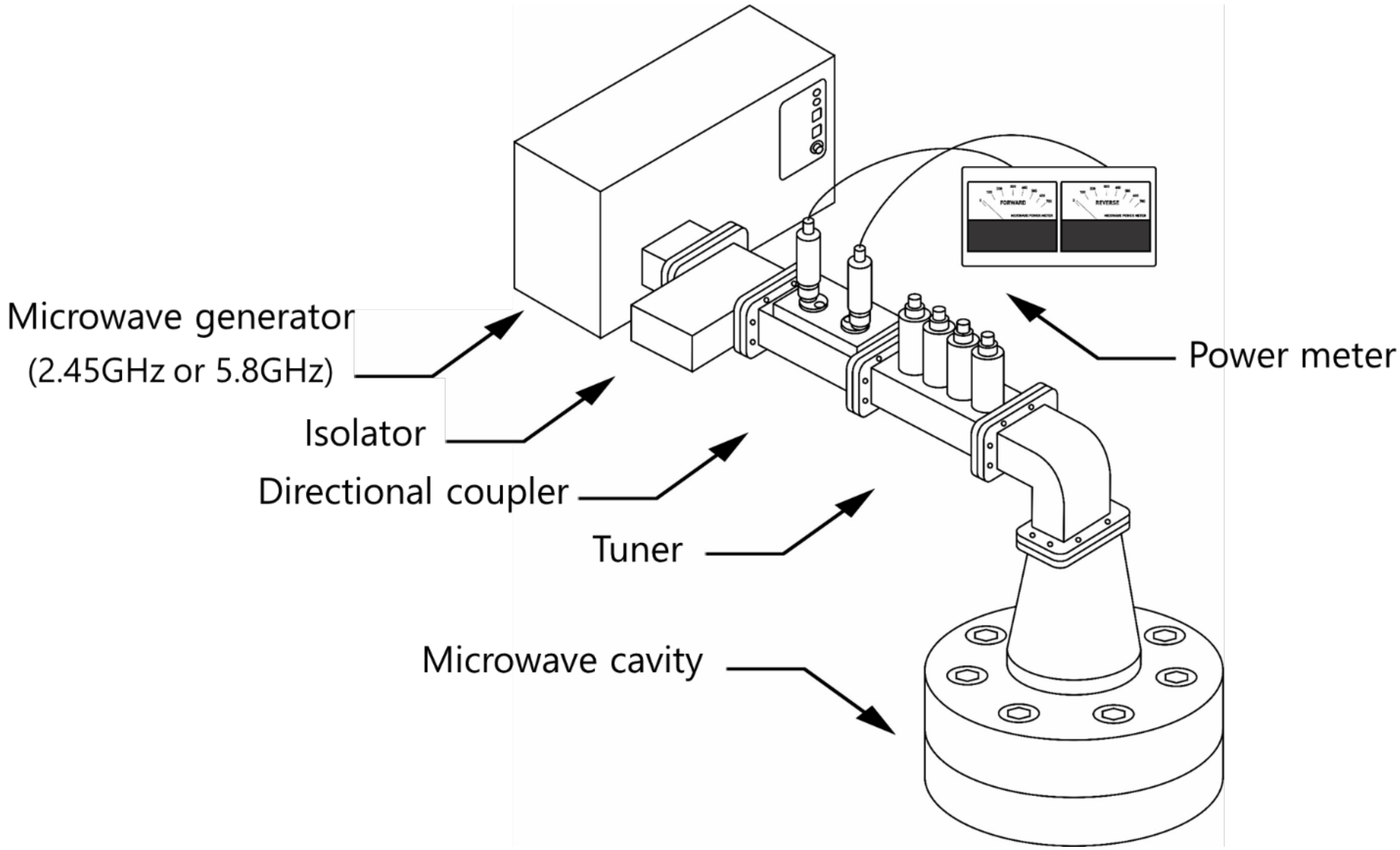


Figure 2: Diagram of microwave system with the different components labelled

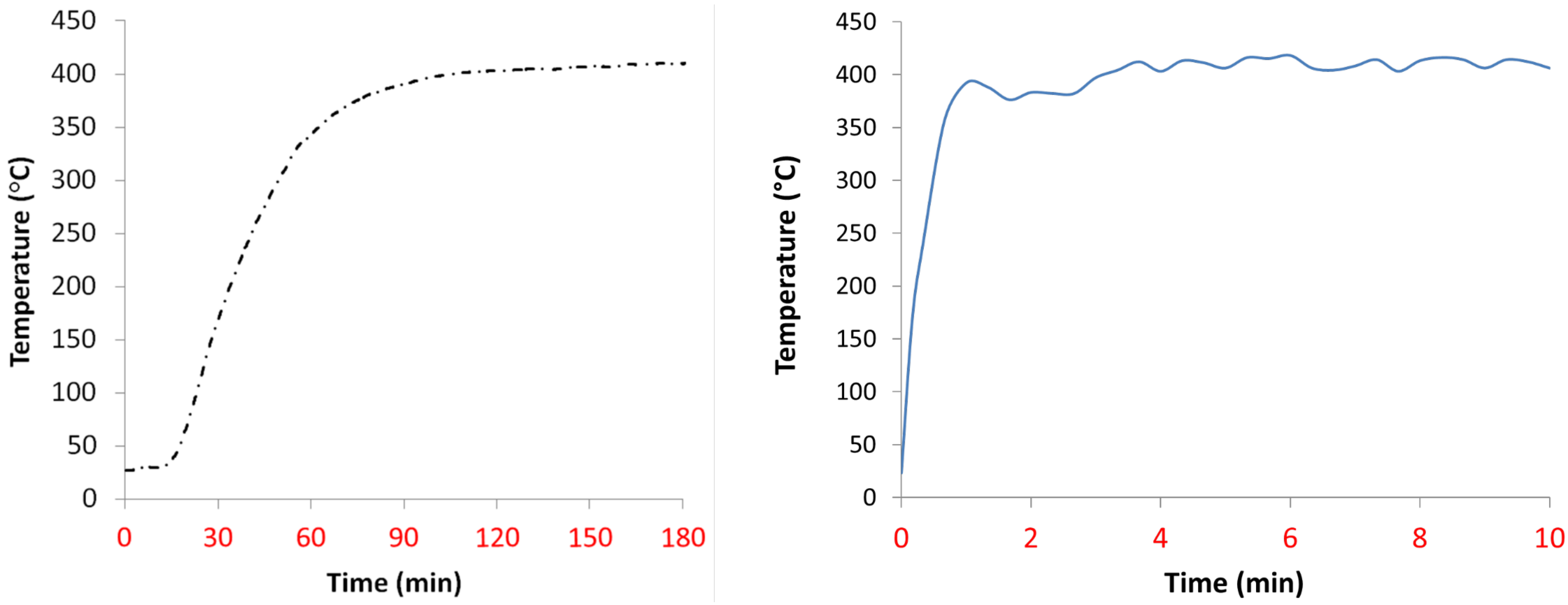


Figure 3: Graph showing the temperature during reaction of lipid feedstock using conventional heating in a 1L Parr CSTR operated in batch mode (left) and microwave dielectric heating using activated carbon as heating aid

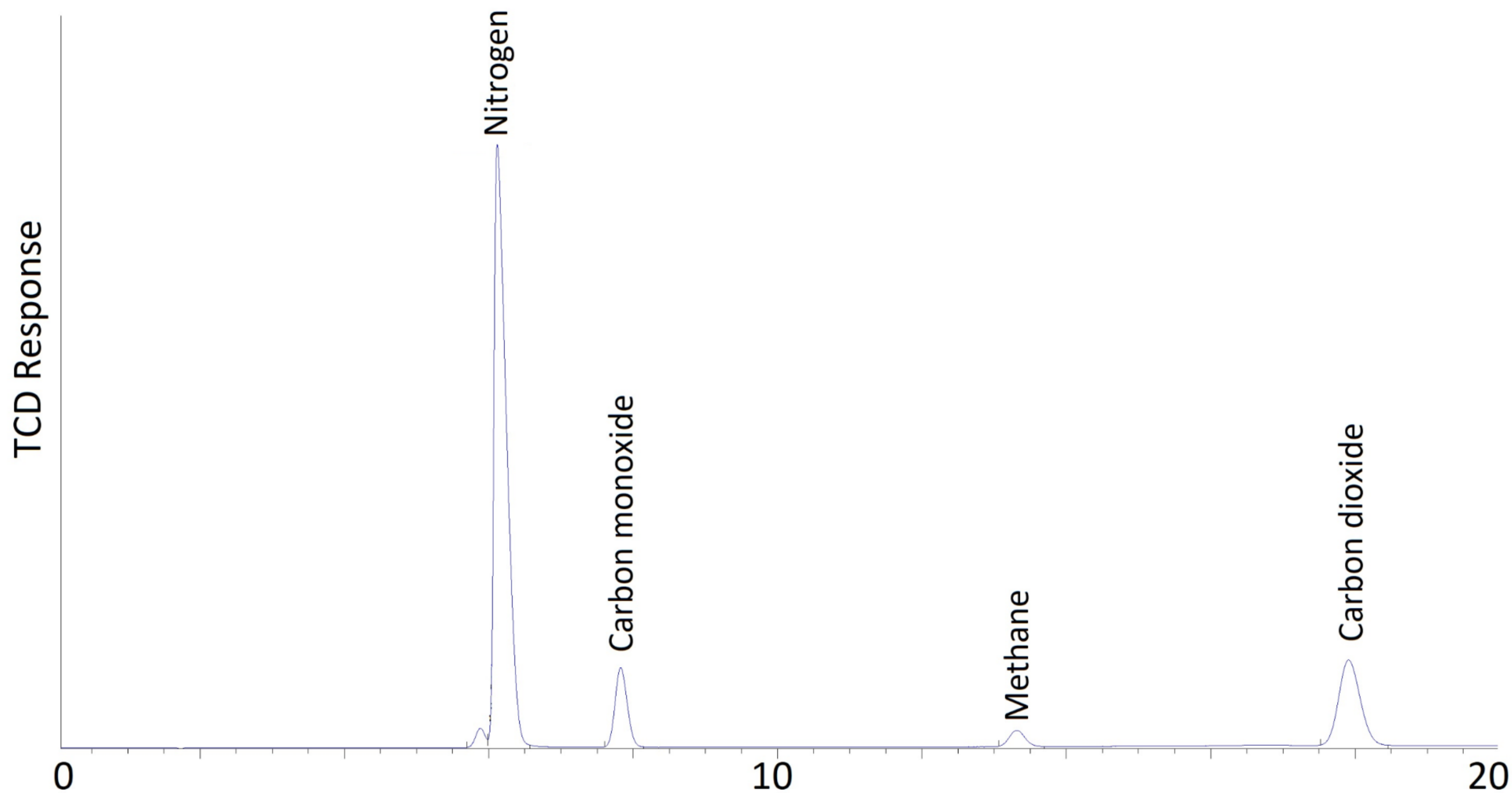


Figure 4: GC-TCD chromatogram showing fatty acids deoxygenation products (CO and CO2) in the gas product of microwave-assisted pyrolysis with activated carbon as heating aid

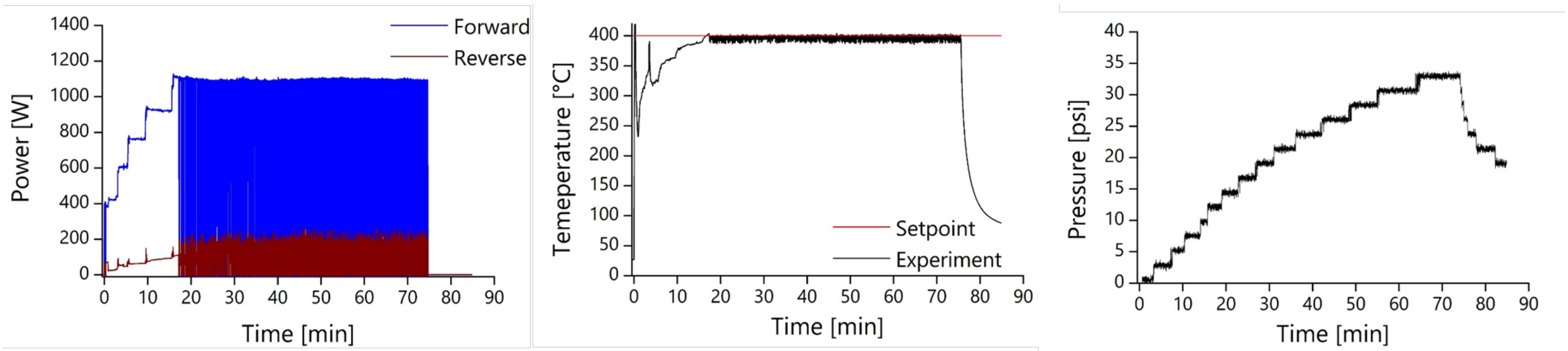


Figure 5: Forward and Reverse power (left), temperature (middle) and pressure (right) profiles of microwave-assisted pyrolysis reaction using oleic acid as feed and activated carbon as heating aid in a mass ratio 4:1.

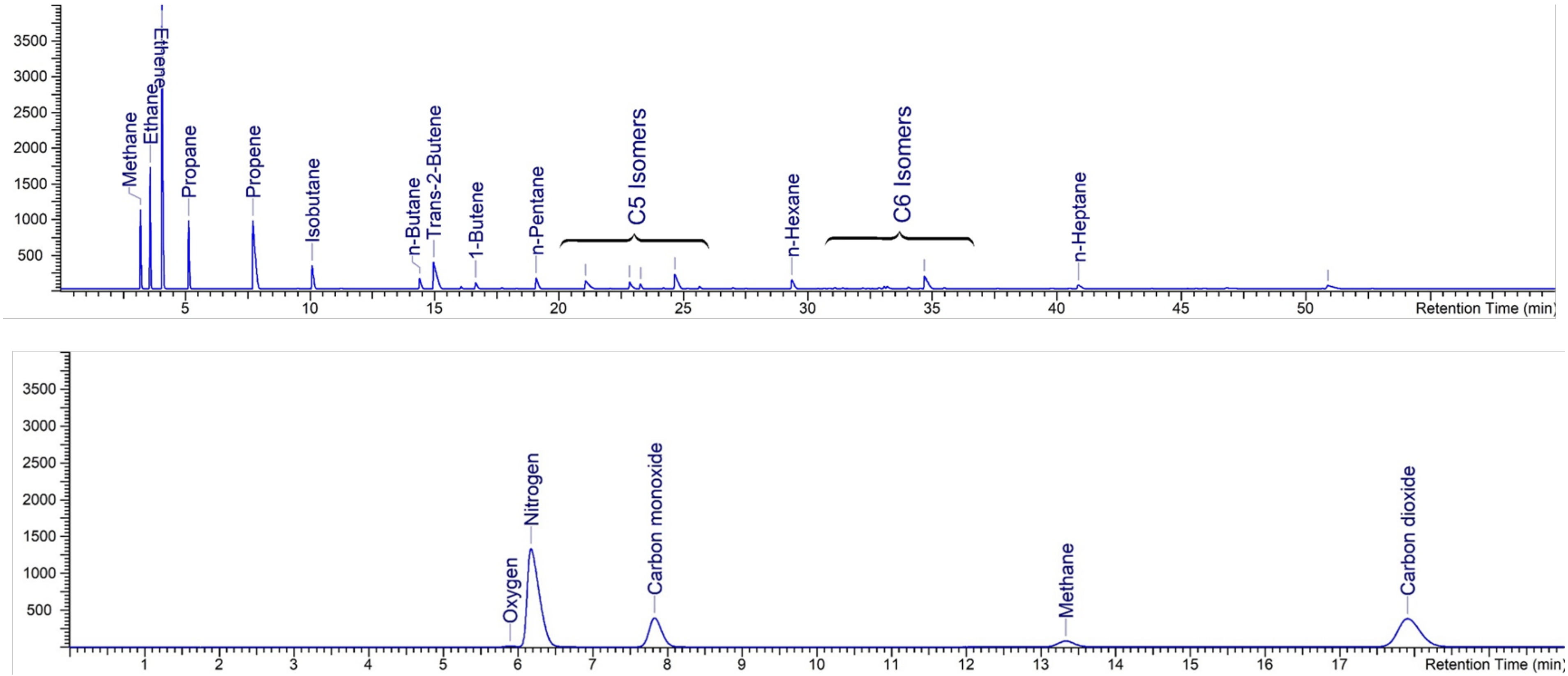


Figure 6: GC-FID (top) showing hydrocarbons in the gas and GC-TCD (bottom) showing deoxygenation product from the microwave-assisted pyrolysis reaction using oleic acid as feed and activated carbon as heating aid in a mass ratio 4:1.

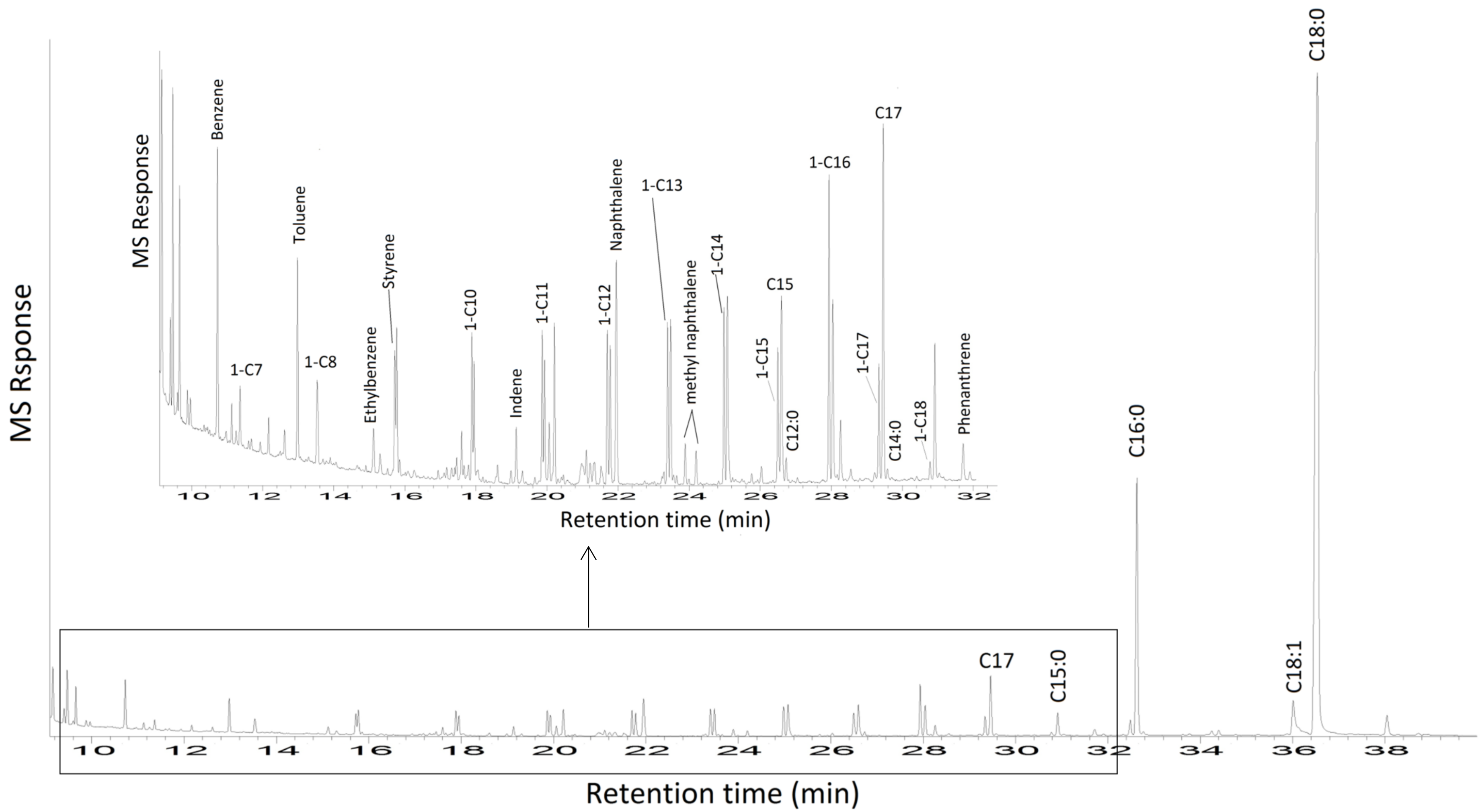


Figure 7: GC-FID chromatogram of stearic acid condensable product. Reaction was carried out on the 2.45GHz system with SiC as heating aid.

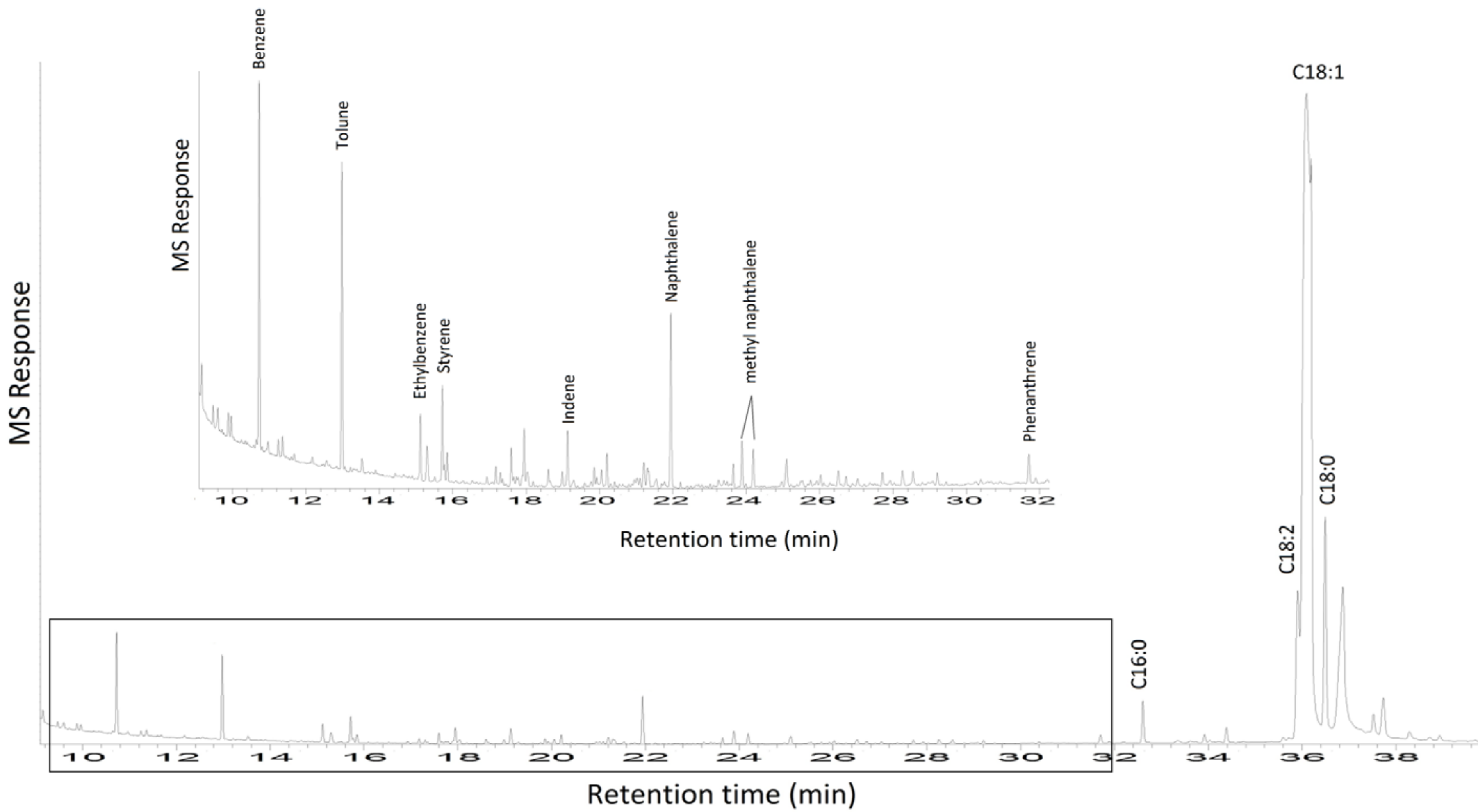


Figure 8: GC-FID chromatogram of oleic acid condensable product. Reaction was carried out on the 2.45GHz system with SiC as heating aid.

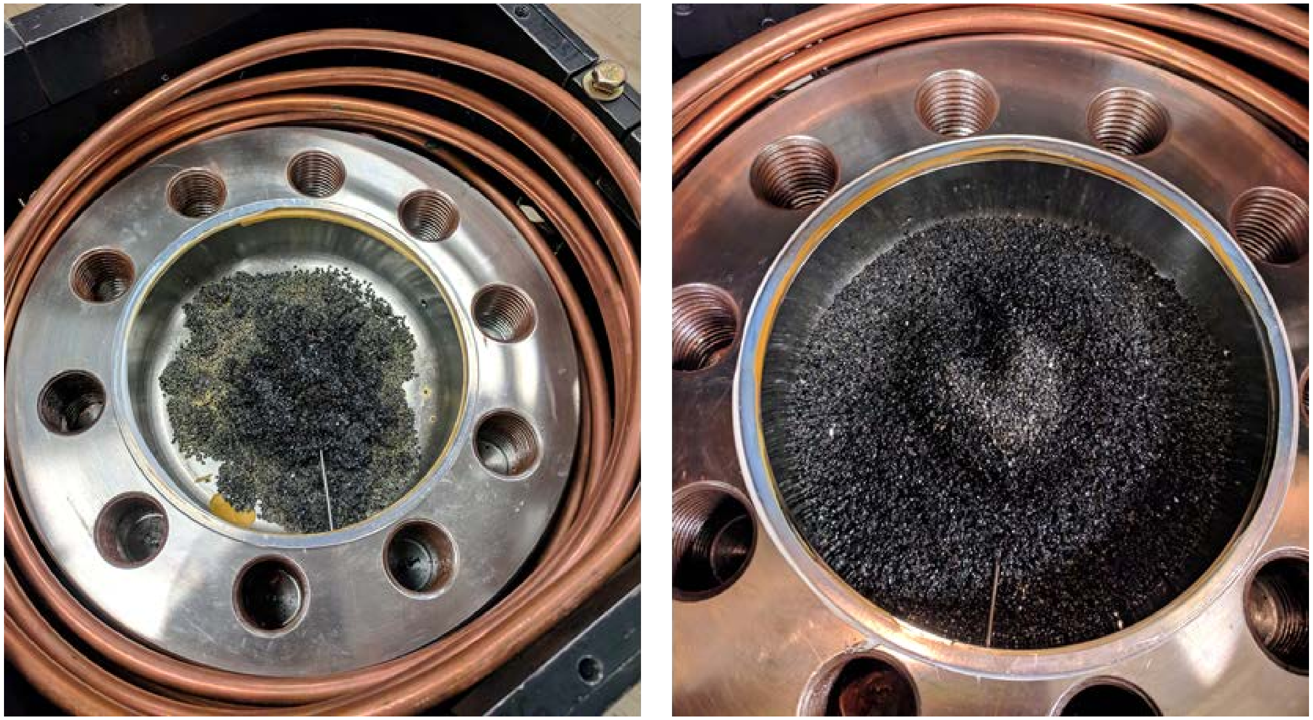


Figure 9: Picture of showing the reactor content after reaction. Left – Stearic acid was used as feedstock with SiC as heating aid; Right – Oleic acid was used as feedstock with SIC as heating aid on the 2.45GHz system. Evidence of hotspot can be seen as the scotched areas near the centre of the SiC.

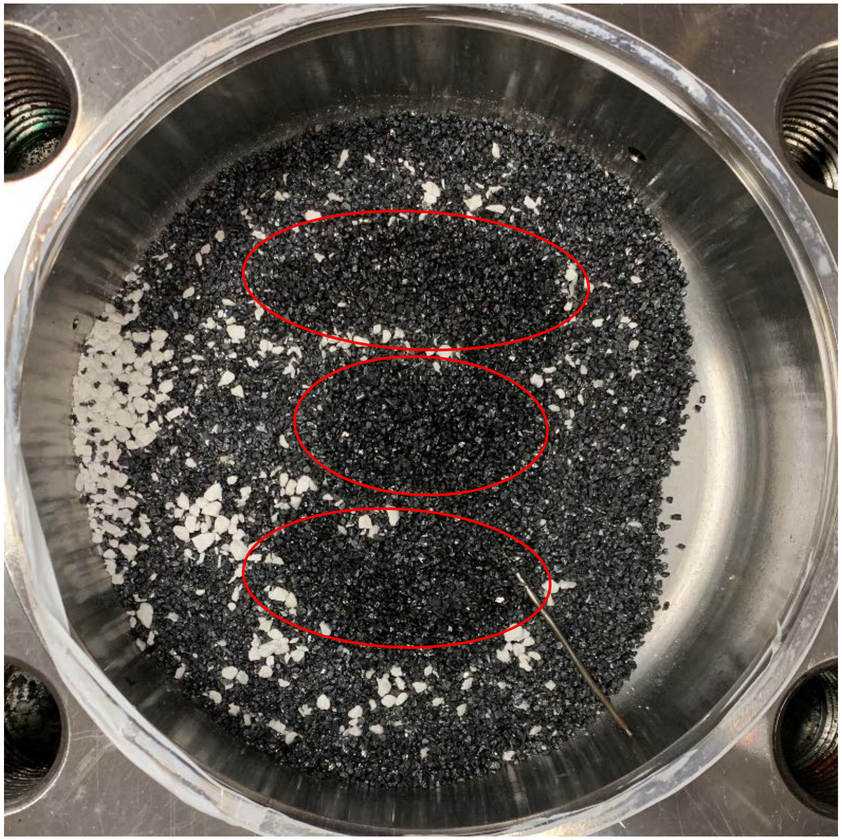


Figure 10: Picture of showing the reactor content after reaction when sodium oleate was used as feedstock and SiC as heating aid. Evidence of hot spots are marked red.

Production of drop-in biofuels using microwave-assisted pyrolysis

Justice Asomaning, Michael Chae & David C. Bressler

Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5

INTRODUCTION

The need to reduce our carbon footprint is becoming increasingly important now more than ever due to socio-economic and environmental concerns over the negative impact of over reliance on fossil derived fuels. In light of these concerns, the development of renewable alternatives to fossil derived fuels has seen significant increases over the past decades. Several technology platforms for the development of renewable alternatives are available, one of which is pyrolysis of biomass to produce renewable chemicals and fuels.

Our research group has patented[1] and is working extensively on a two-stage thermal conversion of lipid to renewable hydrocarbon technology (**Fig 1**).

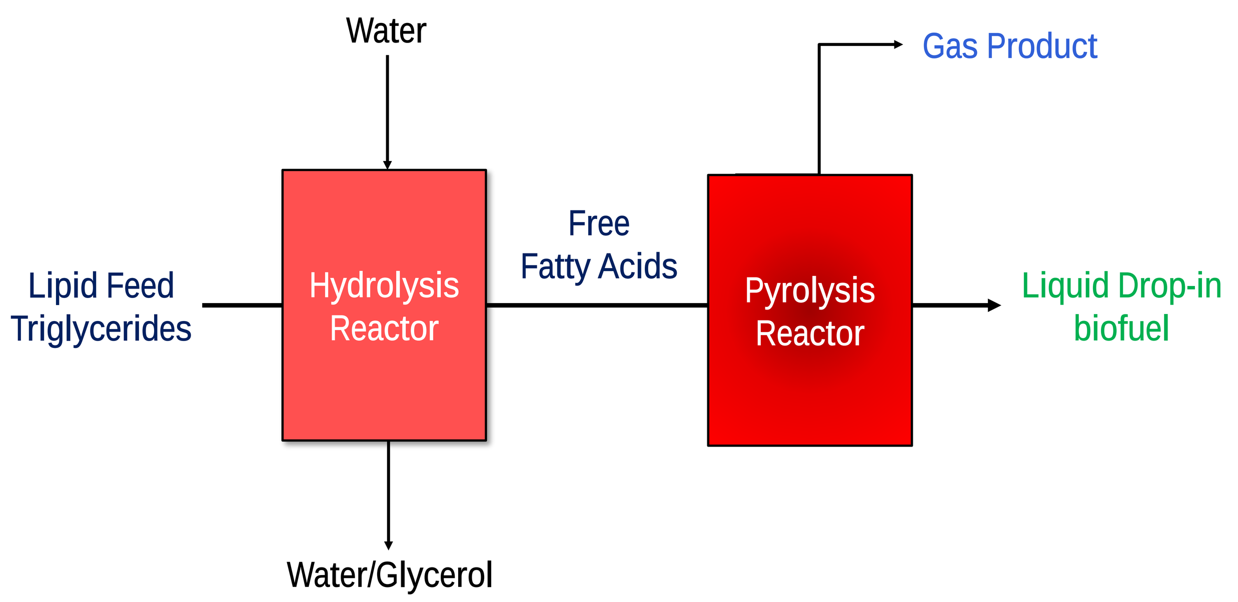


Fig 1. Schematic of the patented thermal conversion process

The use of microwave dielectric heating has several advantages over conventional heating such as faster heating rate, volumetric heating with greater uniformity, etc.

The aim of this study was to evaluate the use microwave dielectric heating in our lipid pyrolysis platform.

MATERIALS AND METHODS

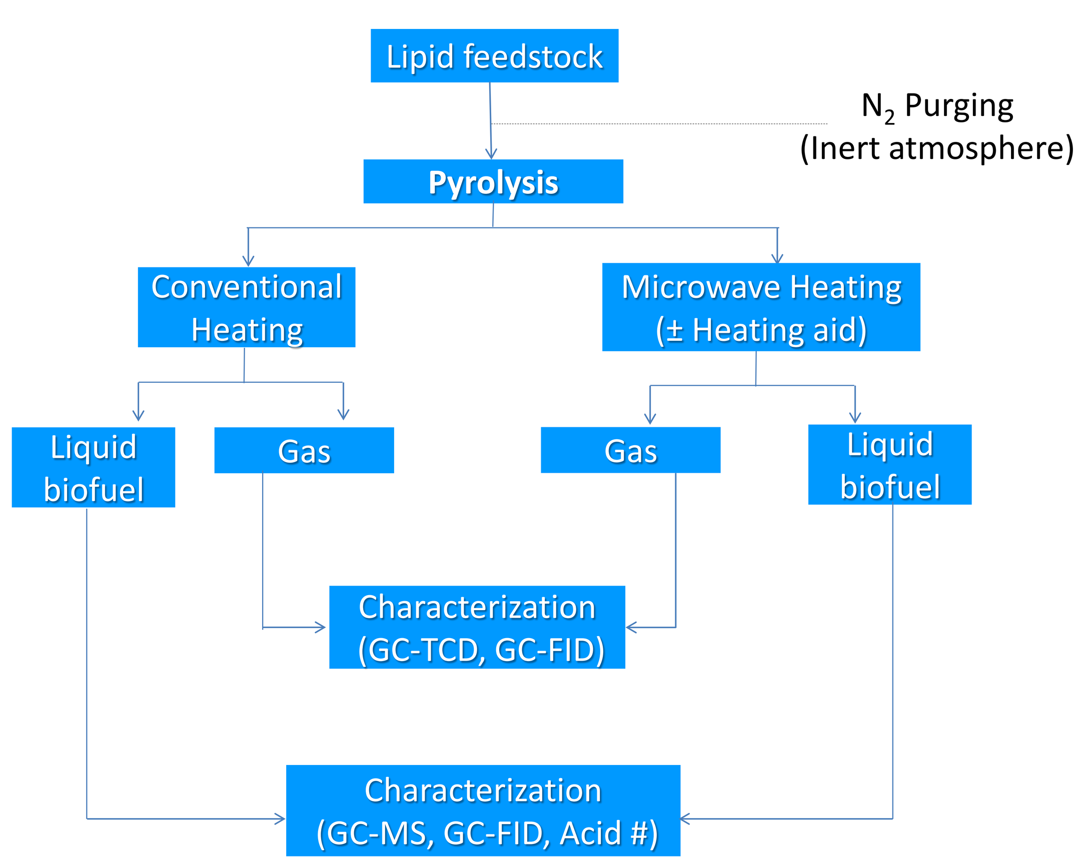


Fig 2. Flow chart of experiment

MICROWAVE REACTOR SYSTEM

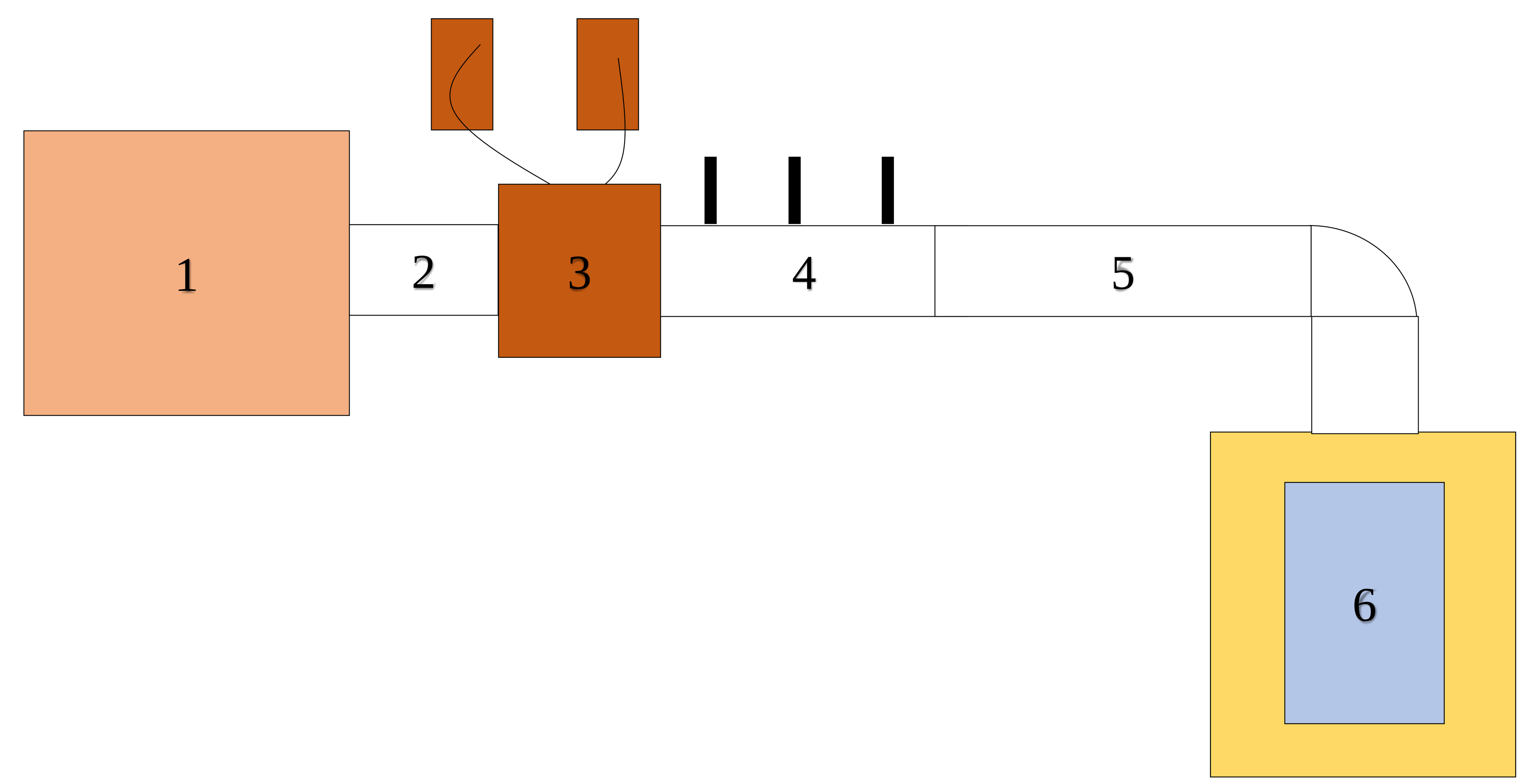


Fig 3. Schematic diagram of custom-built microwave reactor system. 1 – Microwave power supply and magnetron; 2 – microwave isolator; 3 – microwave power meter with dual directional coupler for forward and reverse power; 4 – tuner; 5 – wave guide; 6 – microwave cavity (~ 1L reaction vessel).

RESULTS

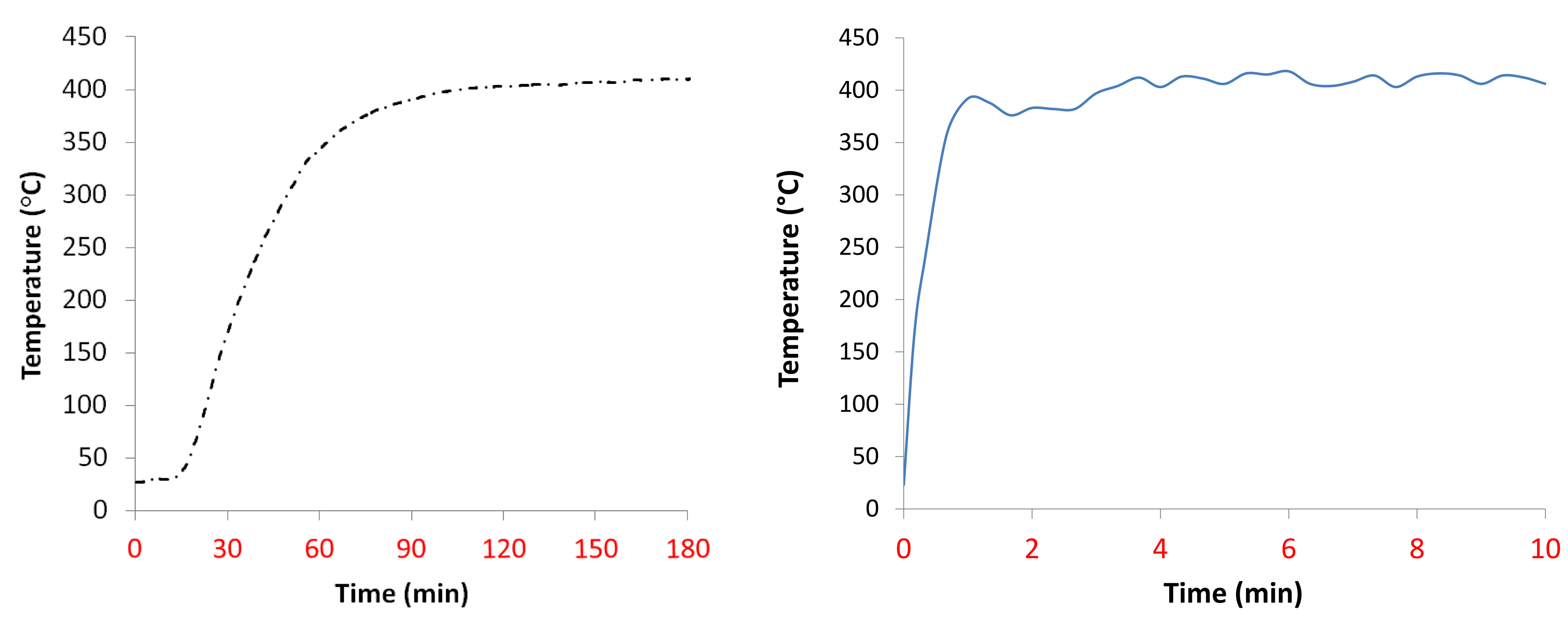


Fig 4. Graph showing the temperature during reaction of lipid feedstock using conventional heating in a 1L Parr CSTR operated in batch mode (left)[2] and microwave dielectric heating using activated carbon as heating aid. The data shows the significant decrease in the time necessary for reaching the desired reaction temperature (410°C). Whereas the conventional heating method required approximately 90 min to get to desired temperature, the microwave dielectric heating with the use of heating aid required approximately 2 min.

RESULTS

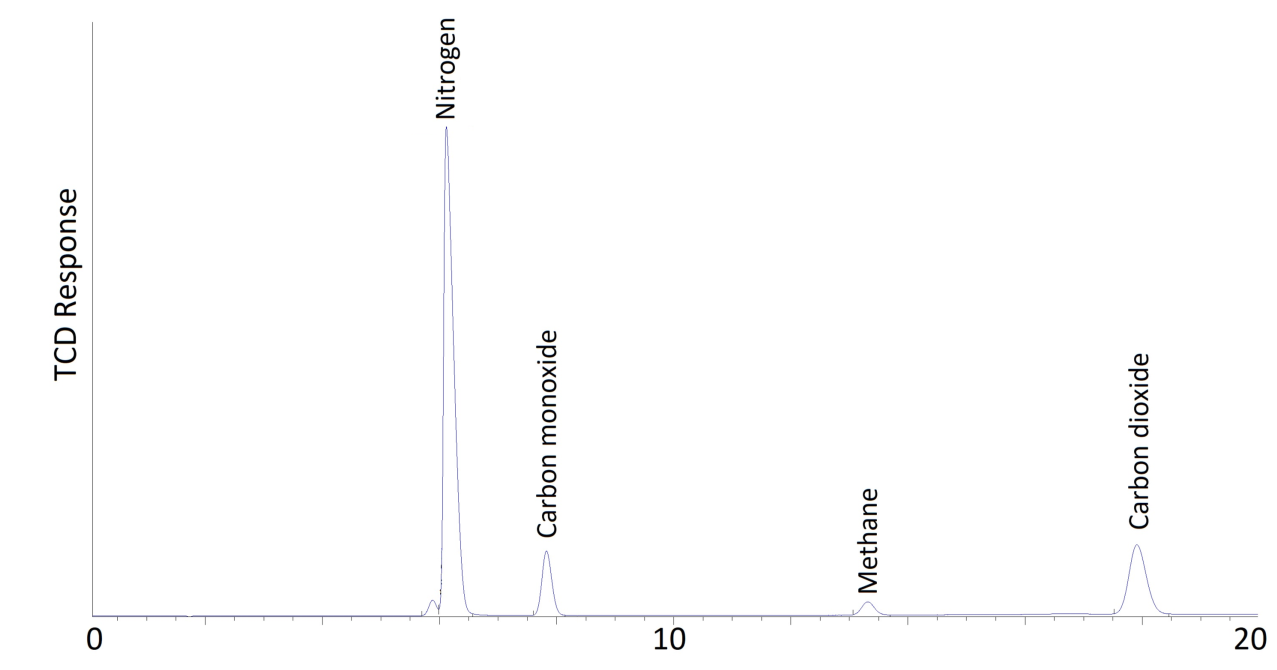


Fig 5. GC-TCD chromatogram showing fatty acids deoxygenation products (CO and CO_2) in the gas product of microwave-assisted pyrolysis with activated carbon as heating aid.

CONCLUSIONS

Microwave dielectric heating was successfully utilized to significantly decrease the time required to heat lipids to the desired pyrolysis temperature. The presence of CO and CO_2, which are the products of deoxygenation of fatty acids in the gas product stream of the microwave-assisted pyrolysis, indicates that microwave dielectric heating can be used in the production of deoxygenated hydrocarbons from lipids. Thus, microwave dielectric heating can be integrated into the patented lipid conversion technology to improve process economics.

BIBLIOGRAPHY

1. Bressler DC. Methods for producing fuels and solvents. US Patent US8067653B2. 2012.
2. Asomaning J, Mussone P & Bressler DC. Two-stage thermal conversion of inedible lipid feedstocks to renewable chemicals and fuels. Bioresource technology (2014) 158: 55-62.

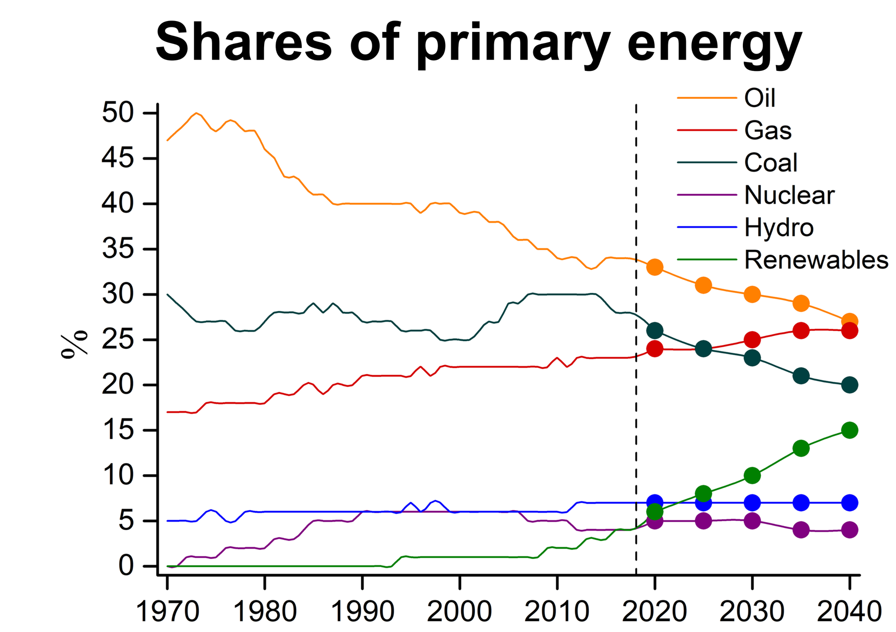
ACKNOWLEDGEMENTS

NSERC CRSNG
ALBERTA INNOVATES
FORGE HYDROCARBONS
Mitacs Accelerate

Production of biofuels using a novel microwave technology

Bernardo A. Souto, Justice Asomaning, Michael Chae, David C. Bressler
Biorefining Conversions and Fermentation Laboratory, Faculty of Agricultural, Food & Nutritional Science, University of Alberta

Energy Outlook



BP. BP Energy Outlook, 2019 edition. London, United Kingdom, 2019.

Thermal Conversion

Alternative method of producing renewable bio-based products.

Pyrolysis

Convert biomass to solid, liquid, and gaseous fuels.

Conventional | Microwave

Maher, K.D., Bressler, D.C., 2007. Pyrolysis of triglyceride materials for the production of renewable fuels and chemicals. Bioresour. Technol. 98, 2351–2368.

Microwave Assisted

- Conversion electromagnetic energy into thermal energy;
- Selective material and non-contact heating;
- Increases in energy efficiency and reductions in reaction time.

Asomaning, J., Haupt, S., Chae, M., Bressler, D.C., 2018. Recent developments in microwave-assisted thermal conversion of biomass for fuels and chemicals. Renew. Sustain. Energy Rev. 92, 642–657.

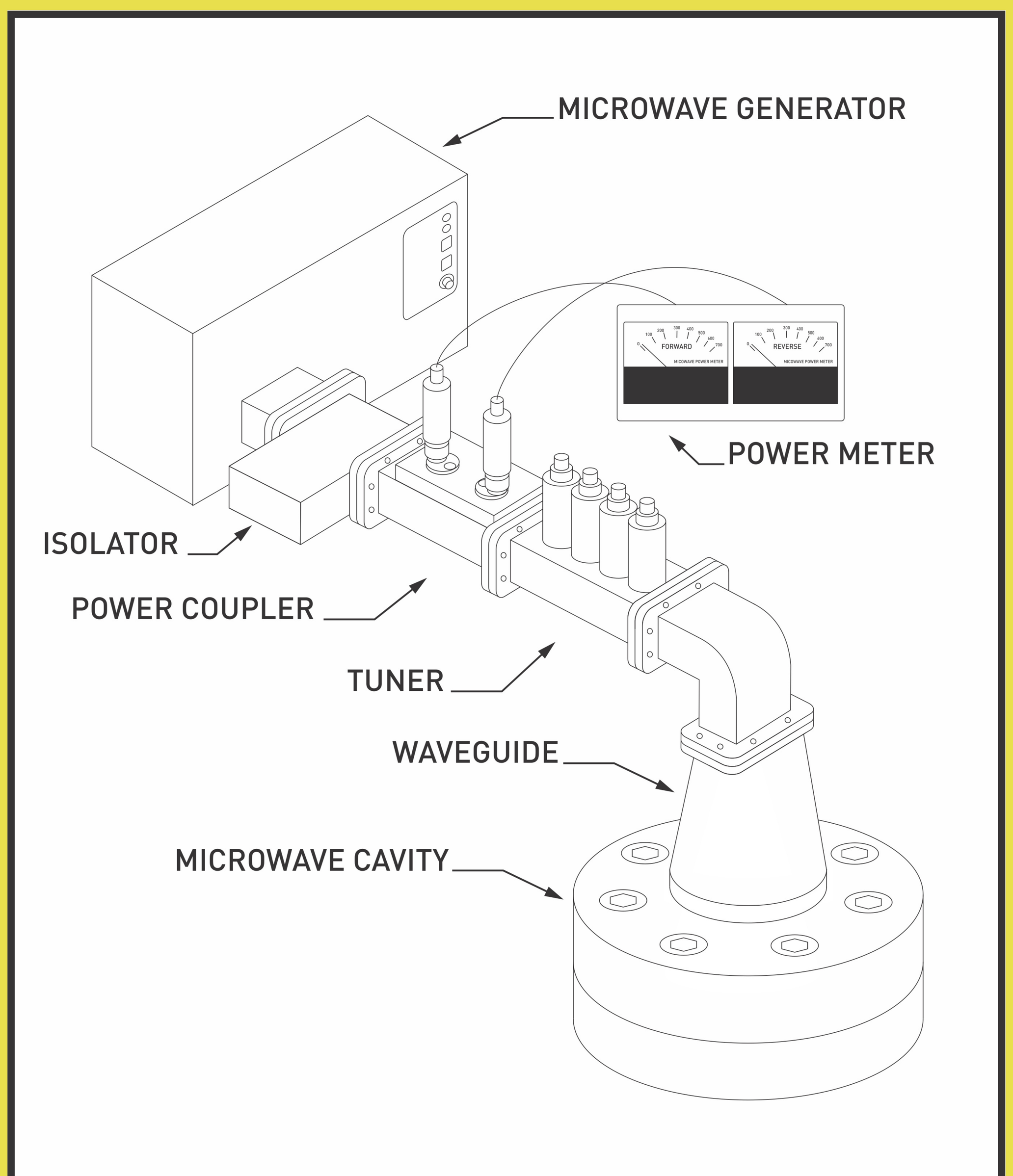
Goals

- Calibration of power coupler, to record forward and reverse power;
- Heat the oleic acid to 400 ºC (pyrolysis temperature) with silicon carbide.

Materials

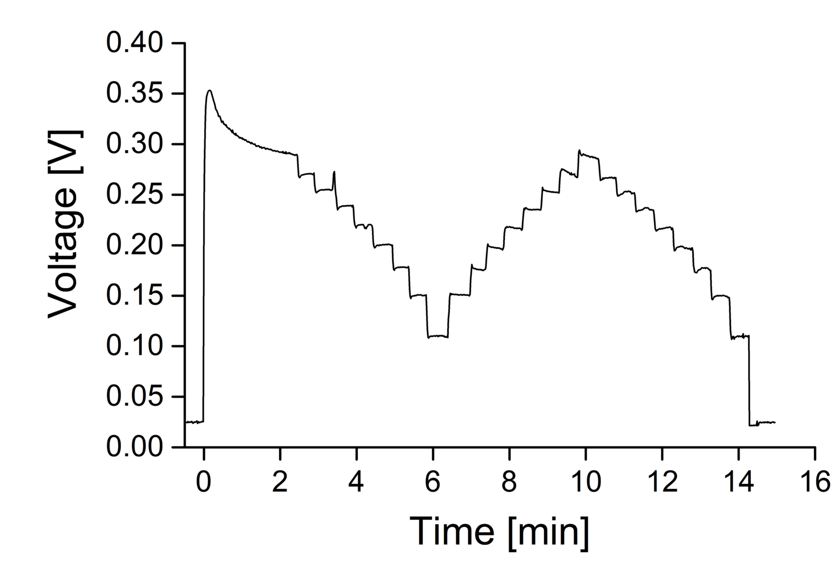
Oleic acid (OA)

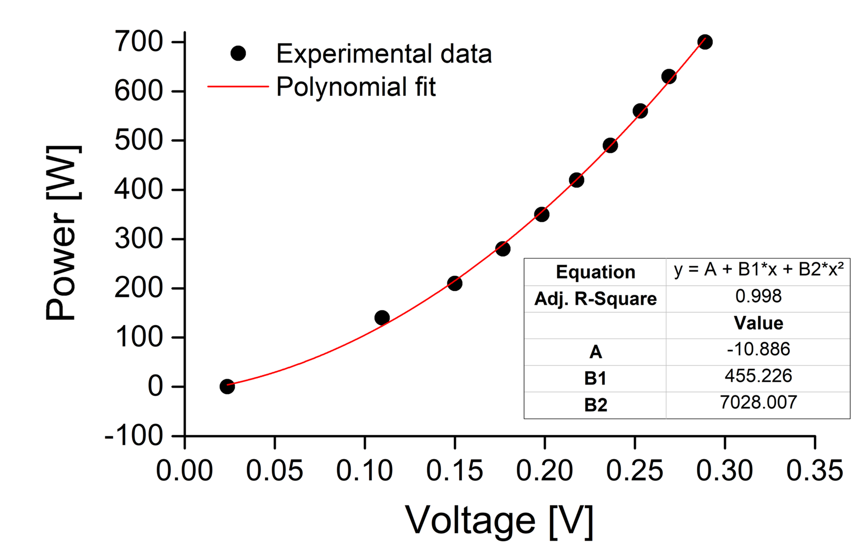
Silicon carbide (SiC)



Scheme of microwave reactor set up

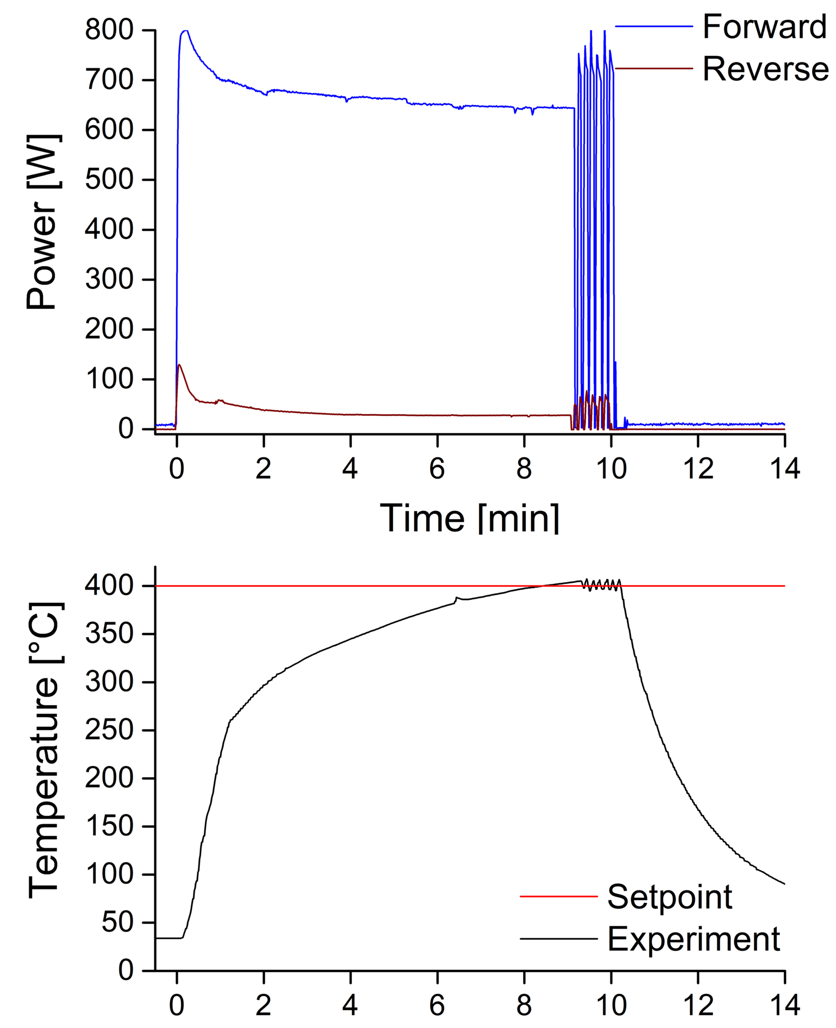
Calibration of Power Coupler



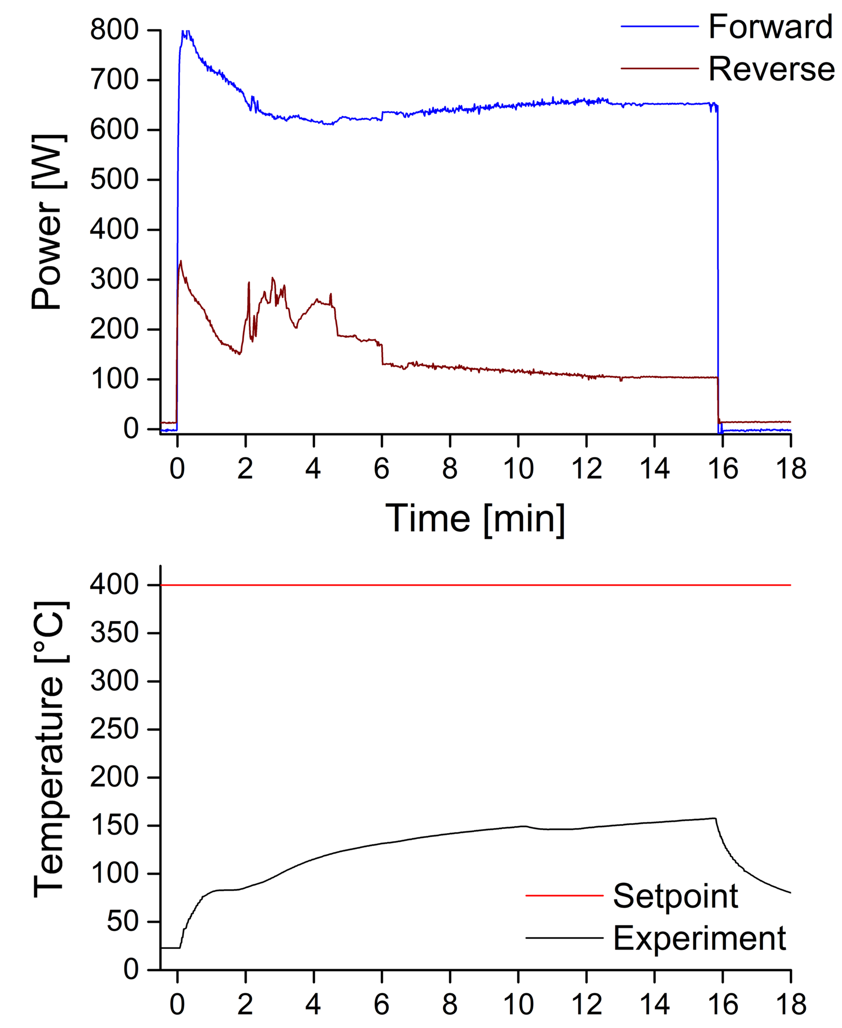


Experiments with silicon carbide (SiC) and oleic acid (OA)

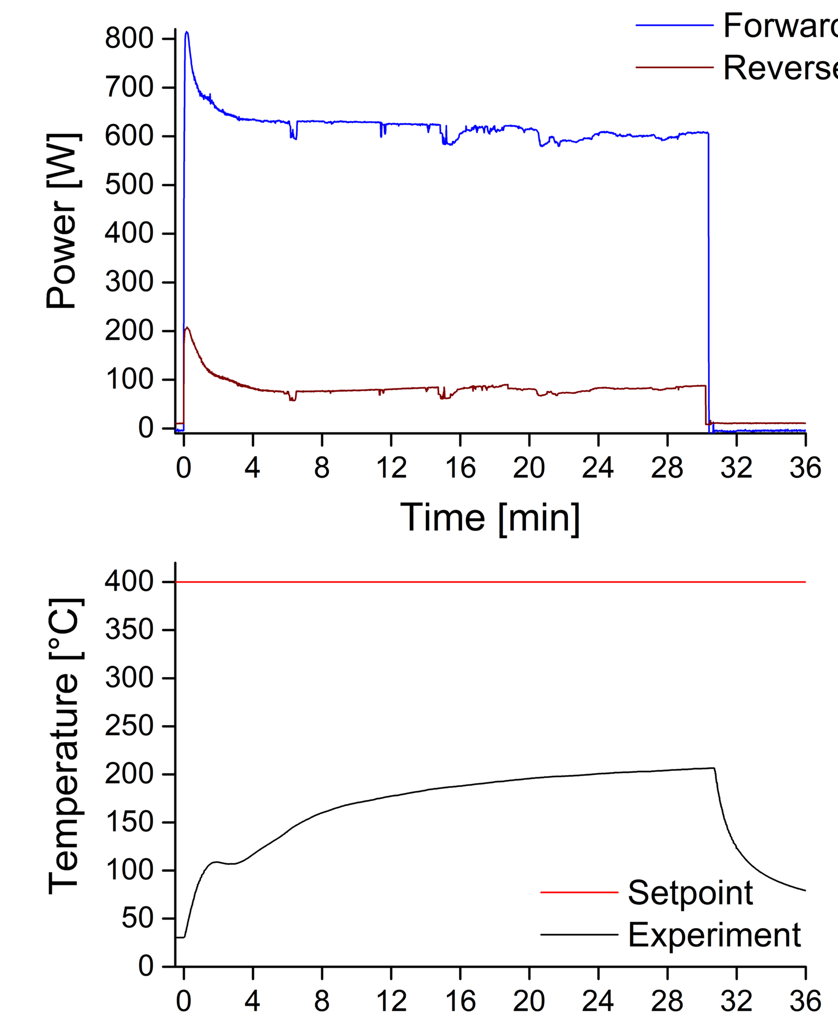
SiC:OA (1:0)



SiC:OA (5:1)



SiC:OA (10:1)



Future Plans

- Increase the ratio of silicon carbide and oleic acid;
- Change the type of absorber (silicon carbide);
- Change the setpoint temperature.

Aknowledgements

UNIVERSITY OF ALBERTA FUTURE ENERGY SYSTEMS
ALBERTA INNOVATES
Mitacs

Microwave-assisted pyrolysis to deoxygenate fatty acids into hydrocarbon fuels

Samuel Koranteng, Justice Asomaning, Michael Chae, David C. Bressler

Introduction

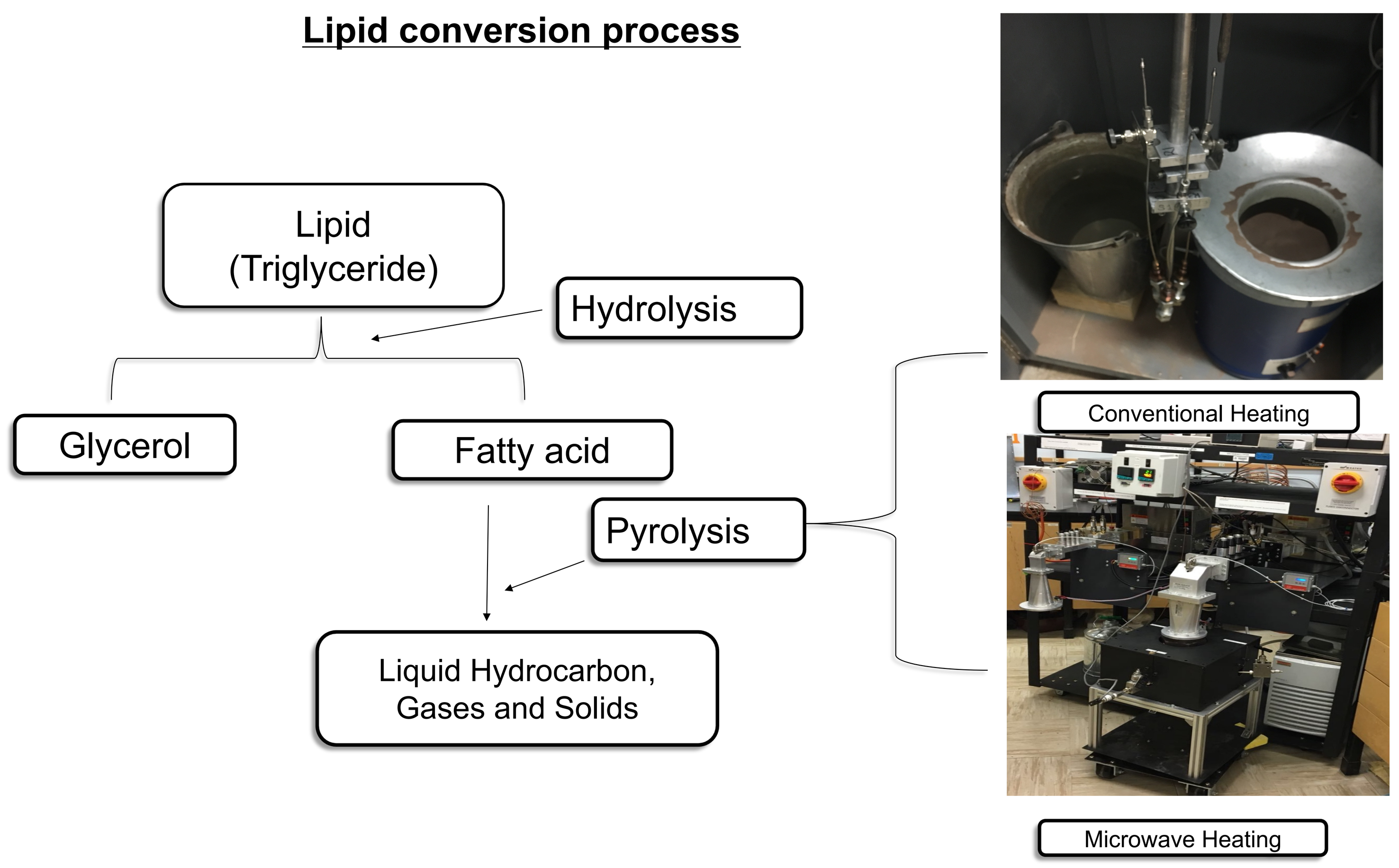
Renewable fuel generated from lipid biomass has a potential application in the energy sector to serve as alternative fuel energy.
Its application can be profound in the following sector industries.


Chemical and solvent


Aviation


Automotive transport

Lipid conversion process



Advantages of microwave heating over conventional heating

Application of microwave heating offers several advantages over conventional heating[1].

- Rapid and controlled heating
- Material selective heating
- Non-contact heating
- Quick start-up and stopping
- Volumetric heating

The microwave reactor system

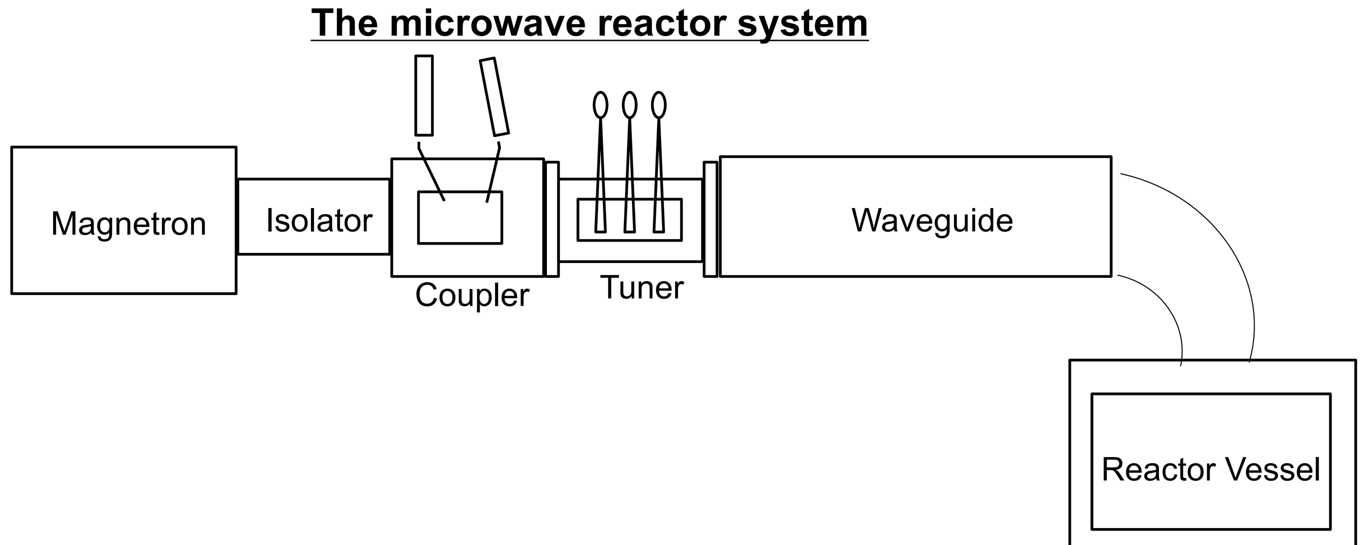


Figure 1. Schematic diagram of the microwave reactor system.

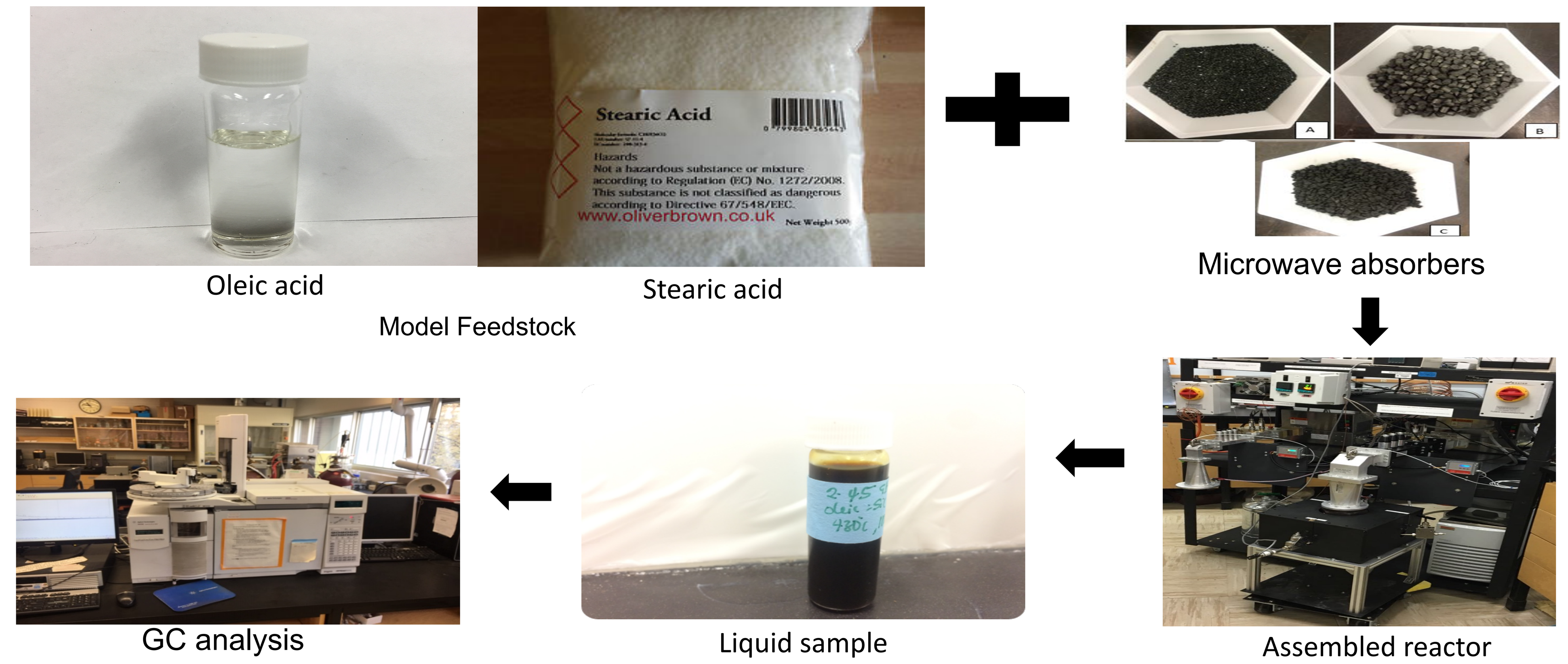
Overall Objective

- To develop an innovative approach, employing microwave energy as a means of accelerating the pyrolytic process for the production of hydrocarbons with similar characteristics of fossil fuel.

Hypothesis

- We hypothesized that the application of microwave heating to pyrolysis conversion process to lipid feedstock will preferentially target the polar end molecules (carboxyl group) to result in the deoxygenation of the model lipid feedstock.

Methodology



- A- Silicon carbide, B- Graphite rods , C- Activated charcoal

Results and Discussions

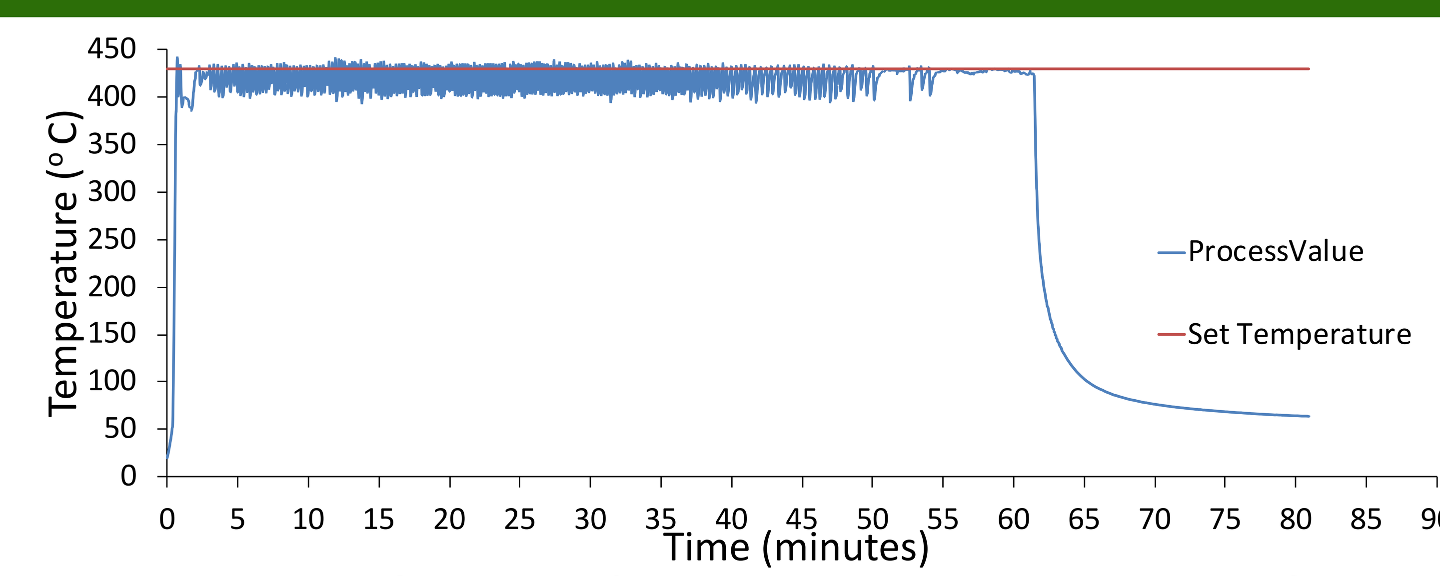


Figure 2. Temperature profile obtained from the microwave-assisted pyrolysis of stearic acid.

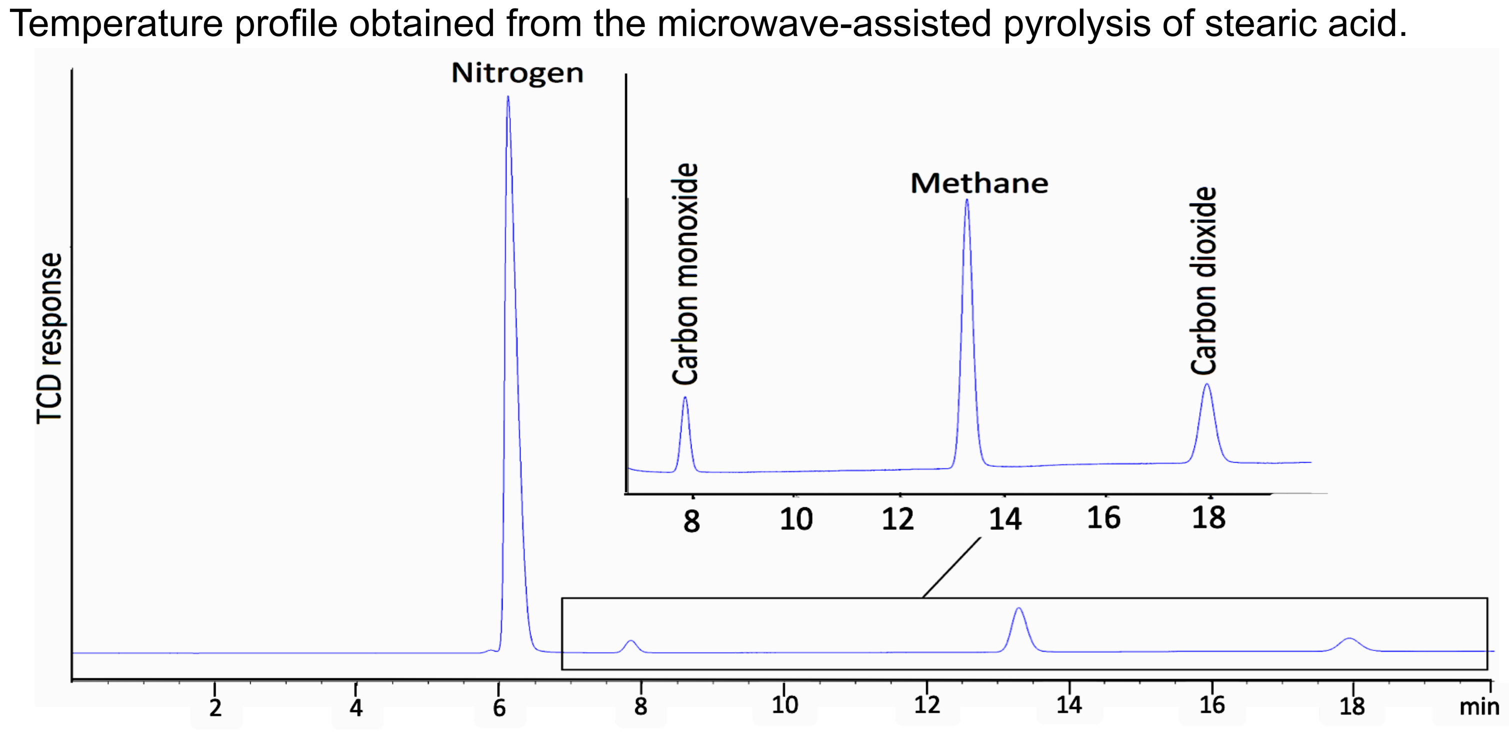


Figure 3. GC-TCD chromatogram showing deoxygenated compounds of carbon dioxide (CO_2) and carbon monoxide (CO) in the gas fraction of stearic acid microwave-assisted pyrolysis product.

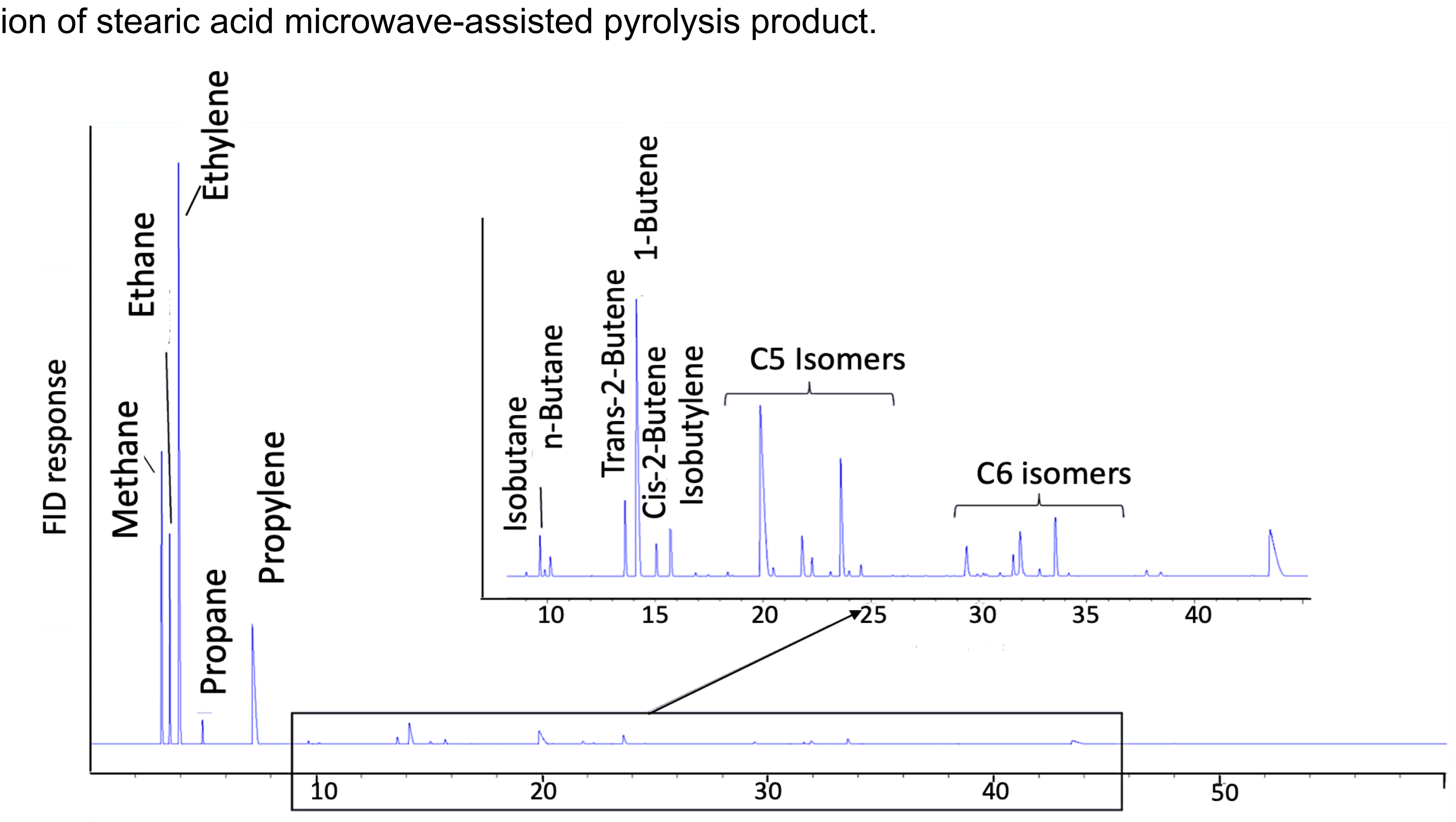


Figure 4. GC-FID chromatogram showing the occurrence of hydrocarbons in the gas fraction of stearic acid microwave-assisted pyrolysis product.

Results and Discussions

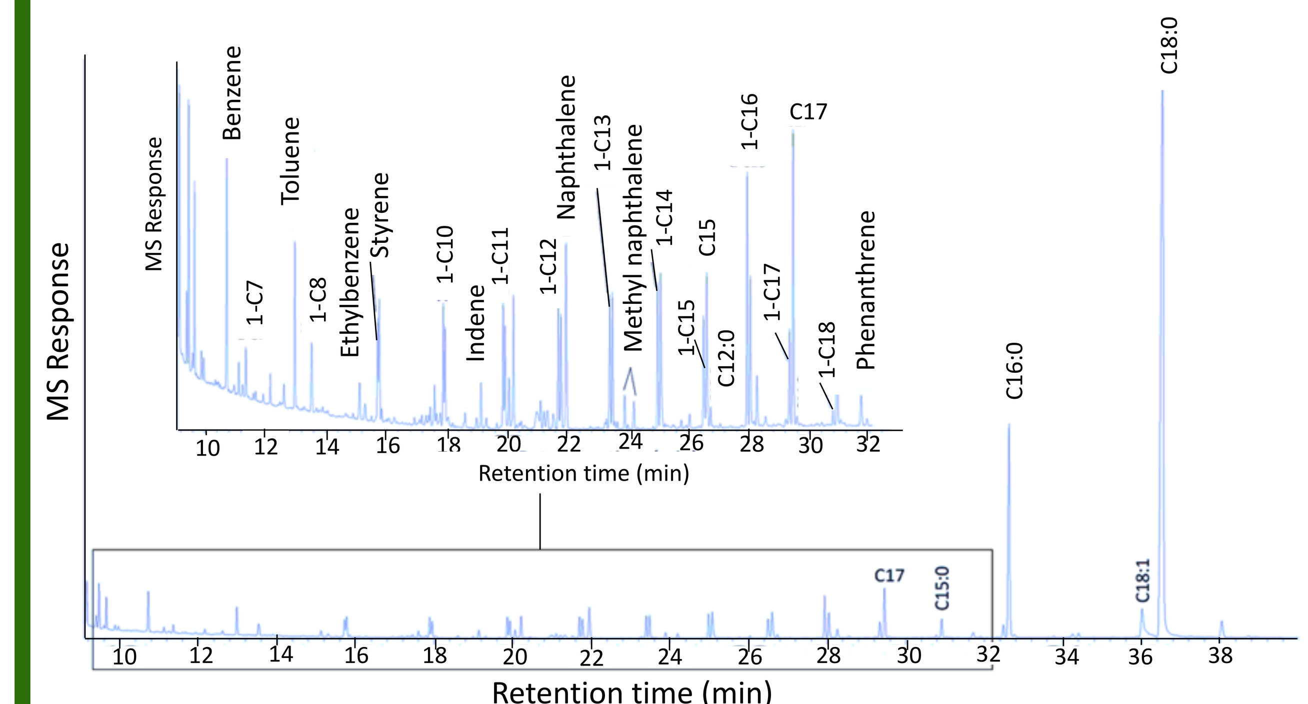


Figure 5. GC-MS chromatogram showing hydrocarbon compounds in the condensable fraction of the microwave-assisted pyrolysis of stearic acid product.

- The hydrocarbon compounds in the condensable fraction indicates cracking of the long chain fatty acid[2-3]
- The presence of aromatics can be attributed to hotspots formed in the microwave cavity.

Conclusions

- The presence of carbon dioxide (CO_2) and carbon monoxide (CO) in the gas product confirms that the application of microwave heating to pyrolysis conversion process resulted in the deoxygenation of the lipid feedstock.

Acknowledgement

NSERC CRSNG
ALBERTA INNOVATES
Mitacs
FORGE HYDROCARBONS
UNIVERSITY OF ALBERTA

References

1. K.E. Haque Microwave energy for mineral treatment processes – a brief review Int J Min Process, 57 (1999), pp. 1-24

2. A. Kubatova, J. St'avova, W.S. Seames, Y. Luo, S.M. Sadrameli, M.J. Lin- nen, G.V. Baglayeva, I.P. Smoliakova, E.I. Kozliak, Triacylglyceride thermal cracking: pathways to cyclic hydrocarbons, Energy and Fuels 26 (2012) 672–685

3. Asomaning, J., Mussone, P. & Bressler, D. C. Thermal deoxygenation and pyrolysis of oleic acid. J. Anal. Appl. Pyrolysis 105, 1–7 (2014).

Images of aviation, chemical solvent and transportation obtained from https://ccsearch.creativecommons.org/photos/1034c05e-09ee-4b77-a2e4-f57587ee5c5a

Contact

Samuel Koranteng
MSc. Bioresource Technology
Department of Agricultural, Food and Nutritional Science
Faculty of Agricultural, Life & Environmental Sciences
2-38 Agriculture Forestry Bldg. University of Alberta
Edmonton, Alberta, Canada, T6G 2PS
Koranten@ualberta.ca (780)-720-5697