GRADUATE AND POSTDOCTORAL STUDIES

McGILL UNIVERSITY

FINAL ORAL EXAMINATION
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

OF

SHRIKALAA KANNAN
BIORESOURCE ENGINEERING
MICROWAVE AND CONVENTIONAL HYDROTHERMAL CARBONIZATION OF SEAFOOOD WASTE

April 11, 2018
1:15 pm

Building, Room MS 2-022
McGill University, Macdonald Campus

COMMITTEE:
Dr. J. Cardille (Pro-Dean) (Department of Natural Resource Sciences)
Dr. V. Orsat (Chair) (Department of Bioresource Engineering)
Dr. V. Raghavan (Supervisor) (Department of Bioresource Engineering)
Dr. M-J. Dumont (Internal Examiner) (Department of Bioresource Engineering)
Dr. Z. Qi (Internal Member) (Department of Bioresource Engineering)
Dr. V. Yaylayan (External Member) (Department of Food Science and Agricultural Chemistry)

Dr. Josephine Nalbantoglu, Dean of Graduate and Postdoctoral Studies
Members of the Faculty and Graduate Students
are invited to attend

ABSTRACT

Climate change has become one of the major challenges of our time that needs immediate action. Global warming resulting in rising sea levels is now recognized as a grave danger not only to humans but to life in general. Small islands are now going under the sea, the climate is becoming more extreme with every passing year. One of the prime contributors to climate change is the burning of fossil fuels that result in carbon emissions, which in turn results in global warming. This is forcing us to rethink our energy security strategy along with carbon management. In addition to this, there is a growing demand for energy while the fossil fuel reserves are depleting at an alarming rate posing a threat to energy security. In this scenario, developing alternate renewable sources of energy that are clean and environmental friendly is indispensable to achieve several global goals as dictated by the Sustainable Development Goals (SDGs) framed by the United Nations. Switching to energy production from sources such as waste-biomass which hitherto were not only wasted but also were disposed off such that they became an environmental hazard is the need of the hour. Therefore, it is essential to address the twin challenges of effective waste management and the need for eco-friendly energy resources. Moisture-rich seafood waste such as fish and shrimp waste are generated in large quantities every year in seafaring countries including Canada. The improper disposal of such wastes is detrimental to the environment, while their safe disposal is expensive. Current strategies of seafood waste utilization primarily involve the production of fish meal, silage, and bioactive extraction all of which utilize the seafood waste partially. One major disadvantage that is common to all these technologies is that they all leave behind or generate new wastes, which need further processing. Therefore, we need an alternate or supplemental technology to enable better and complete utilization of seafood waste. II Global seafood production has improved over the years, and our consumption of seafood is predicted to increase with increase in awareness of health benefits of lean protein consumption. Most seafood is processed, and processing leads to wastage of around 50% of the total mass of the raw material.

Therefore, utilizing the seafood waste for other purposes such as energy might be very attractive. Having said that, there are challenges that need to be overcome to utilize seafood waste for energy purposes. Seafood waste unlike plant derived lignocellulosic mass is primarily non-lignocellulosic, consisting of proteins and fats, where carbohydrates form only a very small fraction of the total mass. Most of the raw materials used by pyrolysis or other modern biomass conversion technologies employ lignocellulosic material that is rich in carbohydrates to achieve better yields. Further, seafood waste is moisture rich and is thus not suitable for direct pyrolysis. However, a process called hydrothermal carbonization (HTC) has been used as an efficient biomass conversion technology for mostly lignocellulosic waste by using water as a catalyst, suggesting that HTC might be suitable to process moisture rich wastes. HTC converts biomass into a coal-like material called hydrochar and an aqueous bio-crude liquor upon treatment at high temperature (150-250° C) for a few hours. More recently, HTC has been used to treat complex waste streams such as sewage sludge, human biowastes and municipal wastes that are moisture rich and are a mixture of lignocellulosic and non-lignocellulosic biomass. However, the suitability of seafood waste that is non-lignocellulosic in composition for HTC is unknown till now. This thesis aims to fill this gap. First, this thesis evaluated the suitability of seafood waste for processing by HTC. It was found that subjecting seafood waste to HTC directly or the use of inexpensive pre-treatment strategies such as acid or alkali hydrolysis proved to be ineffective. However, the use of an enzyme pre-treatment led to the production of hydrochar suggesting that it is critical to hydrolyze the seafood waste prior to HTC. Further optimization studies were III performed to maximize the hydrolysis of seafood waste. Second, having optimized the pretreatment process, a novel approach was employed to optimize the process condition of HTC to maximize the yield of hydrochar. The optimization of modern microwave hydrothermal carbonization (MHTC) process of seafood waste preceded the more traditional conventional hydrothermal carbonization (CHTC) process. It was reasoned that MHTC that works on the principle of dielectric heating, heats the material from within which will result in short come up times and thus would increase the efficiency of the process. Following this, to test the efficacy of using MHTC, we optimized the CHTC process and compared the properties of the end-products to that produced from MHTC. MHTC and CHTC of seafood waste yielded hydrochar of elemental, proximate, energy, and surface properties that are largely comparable to hydrochar produced from lignocellulosic wastes such as saw dust, and mixed wastes such as sewage. However, as hypothesized MHTC resulted in shorter come up times, and better hydrochar yield in the case of shrimp waste. Third, the bio-crude liquor left behind after the MHTC and CHTC processes was also found to be rich in organic compounds. Taken together, both MHTC and CHTC produced compounds of potential commercial value in the bio-crude liquor in addition to good quality hydrochar. This makes the HTC process doubly attractive as it may yield multifaceted benefits to the processing industry. Our study therefore has shown for the first time in the world that HTC can be used to produce hydrochar and bio-crude liquor as value added products from nonlignocellulosic seafood waste. This study paves the way for utilization of other such underused wastes such as meat wastes, and leather industry wastes that are protein rich and low in carbohydrates. Finally, this study has opened the possibility for future research on HTC on a more holistic basis not only for treating complex waste biomass irrespective of their composition but also for the environmental friendly and sustainable production of value added products.

CURRICULUM VITAE

UNIVERSITY EDUCATION

2013- PRESENT	Ph.D. in Bioresource Engineering (McGill University, Canada)
2010-2012	M.Sc. in Bioresource Engineering (McGill University, Canada)
2006-2010	B. Tech. in Biotechnology (Anna University, India)

AWARDS

2012	CSBE Graduate Thesis Award – M.Sc. Category (Canadian Society for Bioengineering)
2013-2014	Schulich Graduate Fellowship (McGill University)
2014	Graduate Teaching Assistant Excellence (Faculty of Agricultural and environmental sciences, McGill University)
2014-2016	Schlumberger Faculty for the Future Award (Schlumberger Foundation)

PUBLICATIONS

1. Dev SR, **Kannan S**, Gariepy Y, Raghavan VG. Optimization of radiofrequency heating of in-shell eggs through finite element modeling and experimental trials. Progress In Electromagnetics Research. 2012;45:203-22.

2. **Kannan S**, Dev SR, Gariépy Y, Raghavan VG. Effect of radiofrequency heating on the dielectric and physical properties of eggs. Progress In Electromagnetics Research. 2013;51:201-20.

3. **Kannan S**, Gariepy Y, Raghavan V. Optimization of enzyme hydrolysis of seafood waste for microwave hydrothermal carbonization. Energy & Fuels. 2015;29(12):8006-16.

4. **Kannan S**, Lyew D, Raghavan V. Transformed traditional storage of crops in India–Challenges and potential impacts. Horticulture.2016; 20:0.

5. **Kannan S**, Gariepy Y, Raghavan GV. Optimization and characterization of hydrochar derived from shrimp waste. Energy & Fuels. 2017;31(4):4068-77.

6. **Kannan S**, Gariepy Y, Raghavan GV. Optimization and characterization of hydrochar produced from microwave hydrothermal carbonization of fish waste. Waste Management. 2017;65:159-68.

7. **Kannan S**, Gariepy Y, Raghavan GV. Conventional Hydrothermal Carbonization of Shrimp Waste. Energy & Fuels. 2018.

8. **Kannan S**, Gariepy Y, Raghavan GV. Optimization of Conventional Hydrothermal Carbonization to Produce Hydrochar from Fish Waste. Biomass Conversion and Biorefinery (under review).

9. **Kannan S**, Burelle I, Orsat V, Raghavan GV. Characterization of Biocrude Liquor and Bio-oil Produced by Hydrothermal Carbonization of Seafood Waste. Waste and Biomass Valorization (submitted).

Book Chapters

1. **Kannan S**, Raghavan G.S.V. Green extraction and processing of medicinal plants using electro-technology. Recent Progress in Medicinal Plants. 41.

2. **Kannan S**, Gariepy Y, Raghavan G.S.V. Precooling and refrigerated storage. Novel Postharvest Treatments of Fresh Produce. 2017; 403-432.

3. **Kannan S**, Gariepy Y, Lyew D, Orsat V, Raghavan G.S.V. Effective post production systems for agricultural sustainability. Science, Technology and Innovation for Meeting Sustainable Development Goals. Under review.

Patents

Raghavan V, Kannan S, Gariepy Y. System and method for processing non-lignocellulosic waste. Google Patents; 2016.

NEWS Articles

1. "Researchers turn fish waste into a coffee-scented biofuel", Chemical and Engineering news, ACS Publications, December 15, 2015. (https://cen.acs.org/articles/93/web/2015/12/Researchers-Turn-Fish-Waste-Coffee.html)

2. "McGill University Researchers produce biofuel from seafood waste", Crop Biotech Update, Biofuels Supplement (January 13, 2016), published by International Service for the acquisition of Agri-biotech applications. (http://www.biofuelsdigest.com/bdigest/2015/12/16/mcgill-university-researchers-develop-method-to-produce-biofuel-from-fish-waste-using-htc/)

Selected Conferences

1. **Kannan S**, Gariepy Y, Raghavan G.S.V. Microwave hydrothermal carbonization of seafood waste to generate hydrochar and bio-oil. Talk presented at the 4th Climate Change Technology Conference, Montreal, May 2015.

2. **Kannan S**, Gariepy Y, Raghavan G.S.V. Pre-treatment and microwave hydrothermal carbonization of seafood waste. Poster presented at the annual Americal Society of Agricultural and Biological Engineers (ASABE) meeting, Orlando, July 2016.

3. **Kannan S**, Gariepy Y, Raghavan G.S.V. Production of hydrochar from seafood waste using microwave hydrothermal carbonization. Poster presented at the annual Canadian Society for Bioengineering meeting, Halifax, July 2016.

4. **Kannan S**, Gariepy Y, Raghavan G.S.V. Characterization of hydrochars derived from fish and shrimp waste using microwave hydrothermal carbonization. Poster presented at the annual Canadian Society for Bioengineering meeting, Winnipeg, August 2017.