Integrated process development for microalgae assisted coal mine effluent treatment and microalgae-low rank coal blended fuel production

Thesis submitted in partial fulfilment
for the award of degree
Doctor of philosophy

By

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I, **Shweta Rawat**, certify that the work embodied in this thesis is my own bona fide work and carried out by me under the supervision of **Dr. Sanjay Kumar** from **January 2021** to **August 2024**, at the **School of Biochemical Engineering, Indian Institute of Technology, Varanasi**. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, *etc*., reported in journals, books, magazines, reports dissertations, theses, *etc*., or available at websites and have not included them in this thesis and have not cited as my own work.

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Dedicated to my mentors, parents, family and extended family

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Date:

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ALG	De-oiled microalgae
AMD	Acid mine drainage
ANN	Artificial neural network
ANOVA	Analysis of variance
APHA	American Public Health Association
ASTM	American society for testing materials
BCR	Bubble column reactor
BET	Brunauer-Emmett-Teller
CCD	Central composite design
CL	Low rank coal
CLALG	Coal and de-oiled microalgae blend
CME	Coal mine effluent
CN	Cetane number
COD	Chemical oxygen demand
Conv1D	One-dimensional convolutional neural network
CR	Coats Redfern
DAEM	Distributed activation energy model
DCW	Dry cell weight
DTA	Differential thermal analysis
DTG	Derivative thermogravimetric
DNN	Deep neural network
EC	Electric conductivity
EDS	Energy dispersive X-ray spectroscopy
EPA	Environmental protection agency
FAME	Fatty acid methyl esters
FAO	Food and agriculture organization
FFBP	Feed-forward backpropagation
FTIR	Fourier transform infrared spectroscopy
GCV	Gross calorific value
GC-MS	Gas chromatography-mass spectrometry
GHGs	Greenhouse gas emission
HHV	High heating value
HRT	Hydraulic retention time
ICP-MS	Inductively coupled plasma mass spectrometry
IV	Iodine value
KAS	Kissinger- Akahira-Sunose
LHV	Low heating value
LM	Levenberg-Marquardt
LSTM	Long short-term memory
MBCCs	Microalgae-blended coal composites
MAE	Mean absolute error
MSE	Mean square error
MOGA	Multi-objective genetic algorithm
MUFA	Monounsaturated fatty acid
NSCME	Nutrient supplemented coal mine effluent
ORP	Open raceway pond
PAH	Polyaromatic hydrocarbon
PHA	polyhydroxyalkanoates

PReLU	Parametric rectified linear unit
PUFA	Polyunsaturated fatty acids
RSM	Response surface methodology
RMSE	Root mean square error
SDGs	Sustainable development goals
SEM	Scanning electron microscopy
SFA	Saturated fatty acids
STK	Starink
SV	Saponification value
TGA	Thermogravimetric analysis
TEM	Transmission electron microscopy
TDS	Total dissolved solid
TOC	Total organic carbon
WRI	Water resistance index
XRD	X-ray diffraction

NOTATIONS

A	Pre-exponential factor
α	Conversion degree
β	Heating rate
cSt	Centistokes
E_a	Activation energy
pH	Potential of hydrogen
h	Planck's constant
k	Boltzmann constant
ΔH	Enthalpy change
ΔG	Gibbs free energy change
ΔS	Entropy change
k	Rate constant
MPa	Mega pascal
R	Universal gas constant
R^2	Regression coefficient
rpm	Revolution per minute
T	Absolute temperature
t_d	Doubling time
Ti	Ignition temperature
Tp	Peak temperature
Tb	Burnout temperature
Tp_1, Tp_2 and Tp_3	Temperature of first, second and third peak in DTG curve
r_s	Spearman's rank correlation coefficient
μ	Specific growth rate
k	Rate constant
v/v	Volume by volume
g/g	Gram per gram
m^2/g	Square meter per gram
kJ/mol	Kilojoule per mole
J/s	Joule per second
J/K	Joule per kelvin
J/mol•K	Joule per mole per kelvin
MJ/Kg	Megajoule per kilogram
MJ/m^3	Megajoule per cubic meter
kg/m^3	Kilogram per cubic meter
μVs/mg	Microvolts per milligram
%/ ºC	Percent per degree celsius
°C/min	Degree Celsius per minute
μmol photon/m^2/s	Micromole photons per meter square per second
wt.%/ ºC	Weight percent per degree celsius
mmol/g	Millimol per gram
mL/min	Milliliter per minute
$g\ L^{-1}$	Gram per liter
d^{-1}	Per day
cm^{-1}	Per centimeter
$mg\ L^{-1}\ d^{-1}$	Milligram per liter per day
$kg\ m^{-2}\ d^{-1}$	Kilogram per square meter per day
$kg\ d^{-1}$	Kilogram per day

mS cm^{-1}	Millisiemens per centimeter
t yr^{-1}	Ton per year
min	Minute
s	Second
h	Hour
ha	Hectare
L	Liter
ml	Milliliter
cm	Centimeter
µm	Micrometer
nm	Nanometer
%	Percent
°C	Degree Celsius
K	Kelvin
kV	Kilo volt
µL	Microliter
yr	Year