Faculty of Engineering

PREDICTION OF AIR EMISSIONS FROM PALM OIL MILL

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PREDICTION OF AIR EMISSIONS FROM PALM OIL MILL

Prediction Of Air Emissions From Palm Oil Mill

NUR IZZATI BINTI MOHAMMAD ROSLI

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor of Engineering with Honours
(Chemical Engineering)

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Dedicated to my beloved parents (Ibu and Ayah), family members, and friends that who continuously give supports and encouragement

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ABSTRACT

Oil palm biomass, particularly mesocarp fibres and palm kernel shells are utilized as fuels in the boiler to generate steam for milling activities and converting the steam to electricity in the turbine. Indirect combustion of mesocarp fibres and palm kernel shells led to generation of particulate emission and dark smoke. In addition, continuous emission monitoring system (CEMS) is implemented in the boiler to control the air emission released, however, not all palm oil mills in Malaysia able to install it due to high installation and maintenance cost. As a result, in this study, an artificial neural network (ANN) model is implemented to predict air emission from palm oil mill by modelling its process input (stack temperature, stack pressure, stack velocity, turbine, steam pressure, sampling flowrate, temperature at gas meter, sample flowrate, isovolume, and velocity at sampling nozzle) and process output (total PM and opacity). The collected data were pre-processed using the nearest neighbour method and multiple imputation method using XLSTAT 2019.2.2 add-in software in Microsoft Excel. The pre-processed data then split into three datasets: 70% of data were used for training, 15% of data were used for validation, and the remaining 15% of data were used for testing. The ANN model was simulated using MATLAB with its Neural Network Toolbox. Then, the performance of the ANN model is verified using three statistical descriptors, which are R^2, RMSE, MAPE. Due to the number of output parameter is more than 1, two cases were employed in this study: a single output model and a multiple outputs model. Based on the trial-error-method, the optimum condition for the single output and multiple outputs model were determined. For the single output model, the ANN architecture was determined to be [10,8,1] and [10,3,1] for total PM of Boiler 1 and Boiler 2, respectively, [10,4,1] and [10,6,1] for opacity of Boiler 1 and Boiler 2, respectively. For the multiple outputs model, the ANN architecture was determined to be [10,7,2] and [10,3,3] for Boiler 1 and Boiler 2, respectively. Most of the chosen optimum conditions have a good performance in predicting total PM and opacity emissions that emit from the oil palm boiler because they produced a high correlation of R^2, lower RMSE and MAPE values. This indicates that the ANN model can be utilized as prediction tool in palm oil mill. The multiple outputs model outperforms the single output model for Boiler 1, while the single output model outperforms the multiple output model for Boiler 2. In conclusion, objectives in this study are successfully achieved.

ABSTRAK

Biojisim kelapa sawit, terutamanya gentian mesokarpa dan cengkerang sawit digunakan sebagai bahan api dalam dandang untuk menjana wap untuk aktiviti pengilangan dan menukarkan wap kepada elektrik dalam turbin. Pembakaran tidak langsung gentian mesokarpa dan cengkerang sawit membawa kepada penjanaan pelepasan zarah dan asap gelap. Selain itu, sistem pemantauan pelepasan berterusan (CEMS) dilaksanakan di dalam dandang bagi mengawal pelepasan udara yang dikeluarkan, namun tidak semua kilang kelapa sawit di Malaysia mampu memasangnya kerana kos pemasangan dan penyelenggaraan yang tinggi. Oleh itu, dalam kajian ini, model rangkaian saraf tiruan (ANN) dilaksanakan untuk meramalkan pelepasan udara dari kilang kelapa sawit dengan memodelkan input prosesnya (suhu tindanan, tekanan tindanan, halaju tindanan, turbin, tekanan wap, kadar alir pensampelan, suhu pada meter gas, kadar alir sampel, isipadu, dan halaju pada muncung pensampelan) dan output proses (jumlah pelepasan zarah dan kelegapan). Data yang dikumpul telah dipraproses menggunakan kaedah jiran terdekat dan kaedah imputasi berbilang menggunakan perisian tambahan XLSTAT 2019.2.2 dalam Microsoft Excel. Data pra-diproses kemudian dibahagikan kepada tiga set data: 70% data digunakan untuk latihan, 15% data digunakan untuk pengesahan, dan baki 15% data digunakan untuk ujian. Model ANN telah disimulasikan menggunakan MATLAB dengan Kotak Alat Rangkaian Neuralnya. Kemudian, prestasi model ANN disahkan menggunakan tiga deskriptor statistik, iaitu R^2, RMSE, MAPE. Disebabkan bilangan parameter keluaran adalah lebih daripada 1, dua kes telah digunakan dalam kajian ini: model keluaran tunggal dan model keluaran berbilang. Berdasarkan kaedah percubaan-ralat, keadaan optimum untuk model keluaran tunggal dan berbilang output telah ditentukan. Untuk model keluaran tunggal, seni bina ANN ditentukan sebagai [10,8,1] dan [10,3,1] untuk jumlah PM Dandang 1 dan Dandang 2, masing-masing, [10,4,1] dan [10 ,6,1] untuk kelegapan Dandang 1 dan Dandang 2, masing-masing. Untuk model berbilang output, seni bina ANN ditentukan masing-masing adalah [10,7,2] dan [10,3,3] untuk Dandang 1 dan Dandang 2. Kebanyakan keadaan optimum yang dipilih mempunyai prestasi yang baik dalam meramalkan jumlah pelepasan PM dan kelegapan yang dipancarkan daripada dandang kelapa sawit kerana ia menghasilkan korelasi tinggi R^2, nilai RMSE dan MAPE yang lebih rendah. Ini menunjukkan bahawa model ANN boleh digunakan sebagai alat ramalan dalam kilang kelapa sawit. Model keluaran berganda

mempunyai prestasi yang lebih baik daripada model keluaran tunggal untuk Dandang 1, manakala model keluaran tunggal mempunyai prestasi lebih baik daripada model keluaran berbilang untuk Dandang 2. Kesimpulannya, objektif dalam kajian ini berjaya dicapai.

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LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
API	-	Air Pollution Index
ARIMA	-	Autoregressive Integrated Moving Average
CEMS	-	Continuous Emission Monitoring System
CTM	-	Chemical Transport Model
DOE	-	Department of Environment
DOSM	-	Department of Statistics Malaysia
FFB	-	Fresh Fruit Bunch
GHG	-	Greenhouse Gases
LSSVM	-	Least Squares Support Vector Machine
LSTM	-	Long Short-Term Memory
MAAQG	-	Malaysian Ambient Air Quality Guidelines
MF	-	Mesocarp Fibre
MLP	-	Multilayer Perceptron
MLR	-	Multi-Linear Regression
OPF	-	Oil Palm Frond
OPT	-	Oil Palm Trunk
PKS	-	Palm Kernel Shell
POMBFA	-	Palm Oil Mill Boiler Fly Ash
POME	-	Palm Oil Mill Effluent
PSI	-	Pollutant Standard Index
RSM	-	Response Surface Methodology
SVR	-	Support Vector Machine

T-S	-	Takagi-Sukeno
UV	-	Ultraviolet

LIST OF SYMBOLS

℃	-	Degree Celsius
α	-	Learning Rate
%	-	Percent
mg/m^3	-	Megagram per Cubic Meter
mg/Nm^3	-	Megagram per Cubic Nanometre
$\mu g/m^3$	-	Microgram per Cubic Meter
C	-	Carbon
H	-	Hydrogen
MAE	-	Mean Absolute Error
$MAPE$	-	Mean Absolute Percentage Error
MRE	-	Mean Relative Error
MSE	-	Mean Square Error
Mt	-	Megatonne
O	-	Oxygen
PM	-	Particulate Matter
R	-	Coefficient of Correlation
RMSE	-	Root Mean Square Error
S	-	Sulphur
CO_2	-	Carbon Dioxide
CO	-	Carbon Monoxide
$C_6H_{12}0_5$	-	Deoxyglucose
H_2O	-	Water
NO_x	-	Nitric Oxide

NO_2	-	Nitrogen Dioxide
O_3	-	Ground Level Ozone
O_2	-	Oxygen Gas
$PM_{2.5}$	-	Particulate Matter with Less Than 2.5 Micron
PM_{10}	-	Particulate Matter with Less Than 10 Micron
SO_2	-	Sulphur Dioxide
NO_x	-	Nitric Oxide
NO_2	-	Nitrogen Dioxide
R^2	-	Coefficient of Determination

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Conventional fossil fuels, such as coal, oil, and natural gas, are the primary source of carbon dioxide emissions, contributing to environmental issues such as climate change, acid rain, and greenhouse gas emissions. Furthermore, Malaysia relies heavily on conventional fossil fuels as its primary source of energy generation. As a result, in order to alleviate environmental difficulties in Malaysia, biomass must be used as an alternative fossil fuel. This is due to Malaysia's tropical and humid environment, which is ideal for agricultural and forest plantation, and biomass can be easily obtained as renewable energy (Rashidi et al., 2022). In addition, biomass is classified as "theoretically carbon neutral", meaning it takes carbon dioxide during photosynthesis and releases the same amount of carbon when burned (Kaniapan et al., 2021). Oil palm biomass is a renewable resource to make electricity because it is plentiful, long-lasting, and capable of doing so.

Crude palm oil (CPO) generation is predicted to increase in 2022 as Malaysia's palm oil sector has expanded tremendously. Massive amounts of CPO will result in immense amounts of oil palm biomass. Oil palm biomass is a subsidiary product of oil palm cultivation and milling activities (Onoja et al., 2019). Numerous kinds of oil palm biomass are produced: Oil palm trunks (OPT) and oil palm fronds (OPF) are generated through oil palm cultivation, whereas empty fruit bunches (EFB), mesocarp fibres (MF), palm kernel shells (PKS), and palm oil mill effluents (POME) are generated through palm oil mill processes. Indeed, palm oil mills produced just 10% of CPO, while the remaining 90% is oil palm biomass. Awalludin et al. (2015) estimate that 5 tonnes of fresh fruit bunches (FFB) were operated in the mill will yield 1 tonne of CPO, while the remaining 4 tonnes will be oil palm biomass. As a result, manufacturing CPO from the raw materials, FFBs, creates a lot of oil palm biomass, which is hard to get rid of (Abdullah and Sulaiman, 2013).

Oil palm biomass is a dependable resource owing to its abundance, consistency, and capability to provide renewable energy solutions (Abdullah and Sulaiman, 2013). In addition, oil palm biomass may be used to generate its own energy, making it one of Malaysia's unique renewable energy sources. This is because 25% of oil palm biomass, specifically mesocarp fibres and palm kernel shells, is utilized as fuel to create steam for milling activities and to convert the steam to electricity in a turbine. Biofuels are oils derived from plant products and biomass waste (Rahardja et al., 2019). Due to their low moisture content and high combustion efficiency, both mesocarp fibres and palm kernel shells make excellent biofuels. Furthermore, 60 ton/hr FFBs processed on approximately 10,000 hectares of palm oil mill land may create more than enough electricity to meet a palm oil mill's energy requirement (Abdullah and Sulaiman, 2013).

Since 2006, the palm oil sector in Malaysia has grown to be the second largest producer and exporter of palm oil in the world. Malaysia operated 451 palm oil mills on 6,262,590 hectares of land for CPO production and by-products in 2021 (Malaysian Palm Oil Board, 2022). In addition, Malaysia has produced 19.6 million tonnes of CPO (MPOC, 2022) and will export 4,556,857 tonnes of CPO in 2021 (MPOC, 2022). It is also projected that the number of mills will increase each year, followed by population growth, food industrialization, and chemical industrialization. Consequently, as the amount of palm oil mills increases, so does the amount of CPO produced, resulting in a substantial amount of oil palm biomass. As a result, the amount of oil palm biomass in 2020 is projected to increase by 85-110 million tonnes of solid wastes (OPT, OPF, MF, PKS, EFB) and 70-110 million tonnes of liquid manure (POME).

Direct combustion of both mesocarp fibres and palm kernel shells as fuels in the boiler to create steam and electricity is capable of reducing reliance on fossil fuels and waste generated during the milling activities. Nonetheless, the combustion of both residues also has a substantial impact on the environment. This is because incomplete combustion of residues in the boiler emits a high amount of particulate matter and dark smoke. Incomplete combustion occurs because of the fuel being substantially wet and lumpy, inconsistent fuel supply, and insufficient fuel distribution on the boiler's furnace grate (Kun and Abdullah, 2013). Lack of air supply is also one of the sources of incomplete combustion that will produce carbon monoxide (CO) emissions and water condensation in the boiler (Yusoff and Abdul Aziz, 2004). Hence, it is vital to control and monitor the air emission from oil palm boiler in order to take action to control the pollutant concentrations.

Continuous emission monitor system (CEMS) is placed at the oil palm boilers to monitor the pollutant emitted from the boiler due to combustion reaction. The Department of Environmental Malaysia (DOE) defines CEMS as any equipment necessary to sample, condition, and maintain a permanent computer record of pollutant concentrations. It will offer data that conforms with regulatory standards for the control, monitoring, and reporting of pollutant emissions that have been endorsed by DOE and linked to iRemote. However, CEMS needed numerous amounts of money for installation and maintenance, so researchers have employed a number of techniques to ascertain the air emissions in the palm oil mill using machine-learning models.

Monitoring emission using a prediction model is one of the easiest and most appropriate ways. In fact, it is cheaper compared to CEMS in terms of installation and maintenance (Yusoff and Aziz, 2009). Hence, various researchers undertook research on predicting boiler emissions using air quality prediction models, notably machine-learning models. Due to nonlinear relationships and complex data relationships between the inputs and the outputs, an artificial neural network (ANN) model is suitable in forecasting air pollution from oil palm boiler. The nonlinear relationship within the boiler is related to the fluctuation of properties on the plant load, specifically on the mesocarp fibres and palm kernel shells loaded into the boiler, as it depends on the amount of these residues generated during the milling processes. As a result, the ANN model is implemented in this study to predict the total particulate matter (PM) and smoke emission (opacity) for an oil palm boiler.

1.2 Problem Statement

The world is considered to be threatened by the depletion of conventional fossil fuels, which adds to the environmental issues such as global warming, acid rain, and greenhouse gas emissions. Because of this, switching from traditional fossil fuels to renewable energy sources like biomass can help to alleviate these problems. Oil palm biomass has an ability to serve as a renewable resource in Malaysia due to its abundancy, durability, and capability to do so. The production of CPO in Malaysia has increased dramatically, as the amount of palm oil mills incrase. Consequently, the production of oil palm biomass would also significantly increase. Oil palm biomass needs to be utilized either as electricity generation or fuel in order to reduce the environmental impact and waste.

Oil palm biomass, notably mesocarp fibres and palm kernel shells, are utilized as fuels in the oil palm boiler to generate steam for milling activities and to convert the steam to electricity via a turbine. Because of their low moisture level, high lignin content, and high calorific values, they are considered the most suitable residues to utilized as fuels in the boiler. As oil palm biomass is a feasible fuel power source, this decreases dependency on fossil fuels for steam generation in the boilers. Nonetheless, incomplete combustion in the boilers will increase the emission of pollutants into the atmosphere, such as dark smoke and particulate matter (PM), which have an effect on human health and the environment. As a result, most palm oil mills in Malaysia installed CEMS on their boilers to monitor pollutants released into the environment. Nonetheless, due to the high cost of installation and maintenance, some palm oil mills are not able to install CEMS. Furthermore, CEMS cannot be used during boiler maintenance or while milling activities are halted.

Numerous researchers have investigated the use of machine-learning models to predict the air emission from boilers, including the Takagi-Sugeno (T-S) model, the artificial neural network (ANN) model, the multi-linear regression (MLR) model, the least squares support vector machine (LSSVM) model, the long short-term memory (LSTM) model, and the support vector regression (SVR) model. Nonetheless, there is a limited study on predicting air emissions from oil palm boilers. The majority of researchers use these models to predict air emission from boilers in power plants. As a result, this study will focus on utilizing an ANN model to predict air emissions from an oil palm boiler.

1.3 Research Questions

This study focuses on predicting air emissions from oil palm boilers using CEMS data, and the followings are the research questions that are related to this study.

i. Which model is suitable for predicting air emissions from oil palm boilers using CEMS data?
ii. How to verify whether the chosen model is successful or not in predicting the air emissions from oil palm boilers?