Experimental Investigation of the Pilot Scale Downdraft Gasifier

Ye Min Htut, Myo Min Win, and May Myat Khine

Abstract**—**The downdraft gasification technology has an increased interest among researchers worldwide due to the possibility to produce mechanical and electrical power from biomass in small-scale to an affordable price. The research is generally focused on improvement of our understanding of how downdraft gasifier system and its processes work. Additional objective is to develop an efficient gasifier system to produce clean gas, which is suitable for power generation. Production of clean gas will ensure the reliability of the system, ease of operation and maintenance. In this pilot scale experimental work, the gasifier system includes reactor with four air inlets and wet ash discharge system, cyclone, recycled water scrubber, two filters and gas holder. This configuration is considered as primary method to improve the quality of the producer gas, regarding its tar reduction. An optimized gasification process produces a considerably clean gas without impurities in the producer gas. The important parameters were examined during experiments and fuel consumption, specific gasification rate, specific gas production rate, lower heating value and energy efficiency were measured and calculated from the experimental data for further improvement in designing the large scale plants. From the tests, the best scheme of gasifier system was reactor, cyclone, water scrubber with recycle tank, two filters and gas holder for the current rural electrification plants in Myanmar that is suitable for environmental friendly and low cost gasifier system. Downdraft gasifier system for rice husk can be used to other biomasses such as waste wood, pellet, etc with a little change in reactor. Water scrubber is one of the most efficient cooling and cleaning unit in the rural gasifier. Recycle system should be used to mitigate environmental concern. Different types and size of filter materials (foam, china clay ring, rice husk and saw dust) could be used to eliminate tar and to clean the product gas. Fuel consumption, specific gasification rate, specific gas production rate, lower heating value and energy efficiency data from the experiment could be used for effective designing of large scale plants. In addition, the current pilot scale gasifier system can be used to study the gasification behavior of different types of biomass**.**

Index Terms**—** biomass, downdraft gasifier, gasification, parametric study of gasification processes**.**

I. INTRODUCTION

There are increasing calls for a change in the dependence on fossil fuels for the world's energy demands and instead more use of renewable sources of energy. This is due in part to the impending exhaustion of fossil fuel sources and the negative environmental impacts associated with the exploitation of fossil fuels in relation to greenhouse gas emissions and climate change. For example, fossil fuel combustion for power generation contributed to over 29% of world CO_2 emissions in 2004. Biomass has received renewed interest as a viable source for alternative energy since it is abundantly available worldwide and is regarded as a CO_2 neutral source.

Biomass has been one of the main energy sources for the mankind ever since the dawn of civilization, although its importance dwindled after the expansion in use of oil and coal in the late 19th century. There has been a resurgence of interest in the recent years in biomass energy in many countries considering the benefits it offers. It is renewable, widely available, and carbon-neutral and has the potential to provide significant productive employment in the rural areas.

In tropical countries like Myanmar, biomass grows more productively, which can be converted efficiently into modern energy carriers such as gaseous, liquid fuels and electricity that can be used in more affluent society. Presently, thermochemical gasification and biological conversion are largely complimentary technology, which are widely accepted for biomass utilization. Biological conversion is limited to non-lignaceous matter, while thermochemical conversion route can process any solid organic matter. Harnessing of biomass and urban wastes via thermochemical route is not only environmentally benign but also economically viable [1].

For air gasification, the gas quality or gas composition including tar (as a result of incomplete oxidation of volatiles) and quantity varies widely depending on the gasifier configuration, chemical composition, its moisture and ash content, its size and density, equivalence ratio, reaction temperature profile and turn down of power level. Out of different gasifier design, downdraft gasifier produces relatively low content of tars in the gas (wt 0.1%), therefore, it may be a preferable choice for small scale decentralized power generation systems via gas engine [2].

Downdraft gasifiers are commonly developed to convert highly volatile fuels with a low amount of tar. For this reason the syngas produced from downdraft gasifiers can be used directly in internal combustion engines. In downdraft gasifiers, biomass is fed from the top and air is introduced above the reduction zone. The air flows downward and reacts with the biomass hot bed and syngas exits at the bottom[3].

Condensation and deposition of tar are causes of more frequent maintenance and repair of engines. The water scrubber is the existing technique commonly used in many gasification plants to remove contaminants and tar[4]. The scrubbing process, also referred to as gas absorption process, is a unit operation in which one or more contaminants of gas stream are selectively absorbed into an absorbent. As per tar classification, it is concluded that light aromatic hydrocarbon tars (one-ring aromatic hydrocarbons) are not the cause of fouling or blocking in downstream equipments at the normal operation temperature, whereas heterocyclic compounds,

Manuscript received June 21, 2015. This work was supported in part by Mandalay Technological University , Yangon Technological University and Department of Research and Innovation.

Ye Min Htut, author, is a lecturer in Renewable Energy Training Centre in Department of Research and Innovation, Yangon, Myanmar

Myo Min Win is an associate professor in Department of Chemical Engineering, Yangon Technological University.

May Myat Khine is an associate professor in Department of Chemical Engineering, Mandalay Technological University.

light polyaromatic hydrocarbons (PAH), and heavier hydrocarbons easily condense and must be removed in order to prevent fouling problems. Therefore, selection of an absorbent to remove biomass tar should be made with a focus on the removal of light PAH tars [5]. In this system, water scrubber was used to clean the producer gas. Further gas cleaning is made with filtration technique which not only removes tar but also strips the gas of particulate matters and cools it to room temperature. These filters materials clean the gas adequately, making it acceptable to most gas engines. One major problem with filter is that as it grows in thickness, the removal efficiency of filters materials decreases. Thus provision is made for its occasional replacement.

Currently some Myanmar rice husk gasifiers find problems related with technology, trouble free operation and environmental concern. Complicated parameter variation makes restriction to develop this technology. When solving the issues related to gas quality, it is equally important to take care of the financial and practical viability of the technology. A gasifier system producing high quality gas demanding more capital investment and complex operation and maintenance will not be able to promote. The present research work is focused to optimize the gasifier system, with consideration of practical, environmental and economic viability.

II. Materials And Methods

Rice husk and rice husk briquette were used in all experiments. Photographs of the assembled gasifier, gasifier components and auxiliary equipment are shown in Fig 1, 3-7.

The following methods are used to understand the characteristics of the gasifier system.

A. Fuel Consumption Rate

Biomass consumption of the reactor is important for designing the power output of the system. It is calculated as follow.

$$\text{Fuel Comsumption} = \frac{\text{Weight of rice husk added (kg)}}{\text{Running Time(h)}} \qquad (1)$$

B. Lower Heating Value (LHV)

It determines the quality of producer gas. LHV of producer gas was calculated from the gas composition by using the values of 11.2MN/Nm^3 for H_2, 13.1MJ/Nm^3 for CO and 37.1MJ/Nm^3 for CH_4.

$$\text{LHV} = \sum x_i \text{LHV}_i \qquad (2)$$

where i = combustible gas component

x_i = volume fraction of gas component

LHV_i = lower heating value of gas

C. Specific gas production rate (SGPR)

Specific gas production rate (SGPR) is the rate of producer gas generation at NTP per unit cross-sectional area of the gasifier.

$$\text{SGPR} = \frac{\text{Producer gas production rate (Nm}^3\text{/h)}}{\text{Cross sectional area of the reactor (m}^2)} \qquad (3)$$

D. Specific gasification rate (SGR)

Specific gasification rate (SGR) was calculated using the weight of dry rice husk gasified for a run, net operating period and the cross sectional area of the reactor using the following relations.

$$\text{SGR} = \frac{\text{Weight of husk used (kg/h)}}{\text{Cross sectional area of the reactor (m}^2)} \qquad (4)$$

E. Energy efficiency (η)

Gasification efficiency is the percentage energy of rice husk converted into cold producer gas (free from tar).

$$\eta = \frac{\text{Amount of gas produced} \times \text{LHV of gas}}{\text{Amount of husk used} \times \text{LHV of husk}} \times 100\% \qquad (5)$$

III. Results And Discussion

The performance of the current biomass gasifier system is determined in terms of biomass consumption rate, LHV, SGR, SGPR and energy efficiency. The quality and quantity of the producer gas depends on various factors such as system components, reactor size and configuration, the moisture content of the feed, the air flow rate into the gasifier, the size and bulk density of the biomass, the position of the air inlet nozzle, zone temperature, load and skill of operator etc. A total number of 11 runs are conducted during the period of the study.

A. Gasifier Reactor

The reactor was constructed with the cast iron body (6mm thickness) and insulated with mixture of fire clay and natural clay to prevent heat loss. Insulation layer plays an important role to reduce the heat loss through the sidewall of the reactor. Insulation layer is provided to withstand high temperature up to 1600°C. Wet ash removal grate system was handled from the top of the reactor.

Fig 1 Gasifier Reactor

But it finds difficulty for the rotation of the grate at high temperature and high density biomass such as rice husk briquette. Myanmar small scale rice husk gasifiers use such type of grate because rice husk has low impact in grate rotation.

Other types used in Myanmar are manual grate handled at the bottom and motor driven grate. Motor connected grates are suitable for larger gasifier plants (>50kW).

There are two types of ash removal: wet and dry. Wet ash removal is the traditional method that needs water seal under the reactor. Dry ash discharge is suitable for silica rich ash collection. Gas leakage problem is a challenge in the later technology.

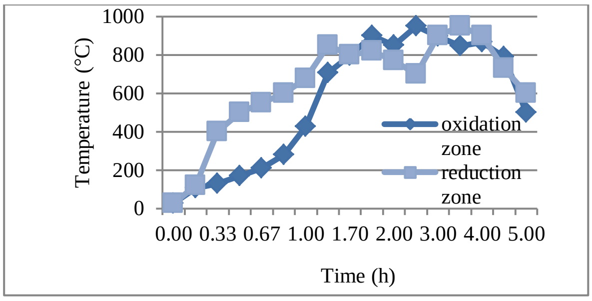

Fig 2 Temperature Profile Inside The Gasifier At Run 4

The reactor temperature is one of the key factors that have an influence on producing cleaner gas. Temperature profile of run 4 shows that instability nature of temperature inside the reactor. At the startup time, ignition of the fuel was made with diesel supply to the fuel. Stable gasification is achieved at about 30 min for briquette rice husk. Briquette needs more time to gasify the product compared to normal rice husk. Operation time of complete run is 5 hour average. Average fuel consumption of briquette is 1.7kg /h. Combustible gases are obtained for about 4 hour of 5 hour operation time. Reaction rate of the reactor is directly proportional to the air inlet that is controlled by suction blower. At higher suction of blower, the producer gas were unstable. So proper control of suction blower was required to maintain stable combustible gas production.

To improve the stability of the gasification process, temperature distribution should be stable. But in this operation, we found that zone temperature was changing with time. This is because of the ash agglomeration and bridging nature inside the reactor. Rotating the grate at high temperature and dense briquette makes the deformation of grate handle. This problem deters ease of operation and causes gasification disorder. So the current briquette gasification is not suitable to use this type of grate for long time operation.

It was found that the composition of the producer gas strongly depended on the temperature in the combustion and gasification zone. The temperature of the gasifier had to be maintained within the optimum range 700–950°C. At the lower temperature the efficiency of gasification is lower, and the tar content of the gas is excessive.

The 0.5 kg/h ash removal system is required for this system (1.7kg/h) to maintain the stable temperature distribution of combustion and reduction zones inside the reactor.

B. Cyclone

The cyclone is use to remove ash and dust from the producer gas using centrifugal force and the different density between the particle and gases. Water seal is used beneath the blower to collect particles. Only small amount of ash and fine particles were collected during the eleven experimental run. Many small scale Myanmar gasifiers do not use cyclone. So it is recommended that cyclone could be removed from this briquette gasifier system as dense briquette ashes do not follow the produced gas.

Fig 3 Cyclone

C. Water Scrubber And Recycle Water Tank

Inside the water scrubber, spray nozzle and PVC pipes are used to maximize the contact between gas and water. Water inlet and outlet were provided to circulate cooling water continuously in the scrubber.

Water scrubbing is an efficient method to cool producer gas and condense heavy tars component from raw producer gas. From the experiment, it was observed that without using scrubber the filters became hot and the producer gases were difficult to burn. So water scrubber is important to obtain combustible producer gas.

Fig 4 Water Scrubber

Water recycle system is used in all experiment. Many problems related with Myanmar gasifier come from waste water disposal units. Most of the gasifiers in rural area do not use waste disposal system. So current environmental issue of gasifier is the waste discharge system. The research shows that if the recycle units were used effectively, it can minimize the environmental concern.

Double cloth filters can help the improvement of recycle water quality and usage time. At the same time, regular replacement of fresh water is required for stable system efficiency.

Another option is waste water discharge treatment system. The waste should be discharged as per authorized rule and regulation.

Fig 5 Water Recycle Tank

Air will be polluted with poisonous gases such as carbon monoxide and carbon dioxide if there are gas leakage problem in system and improper shutdown of the engine. It might be a thread to operator.

D. Filters And Gas Holder

Cool gas was piped through cast iron pipe to the dry filter packed with china clay and foam. Suction blower was inserted between the two filters to regulate the gas flow to the flare. When using the engine, it can be shutdown.

Fig 6 Two Filters And Gas Holder

China clay ring and foam were used to condense and retain dust, tar and water in the packed bed filters. Traditionally, Myanmar gasifiers use rice husk and sawdust as filter materials depending on the local resources. The tar and dust are retained in the filter during the run. Tar condensation occurs at low temperature and adequate residence time. Moreover, most of filter materials are adsorbents that can adsorb heavy and light tars. Heavy and light tars from the producer gas were separated in these filters. Tars are collected by water seal under the filters. So, regular replacements of these materials are required to every gasifier for efficient tar separation and stable long time operation.

Gas holder is used to collect product gas for sufficient distribution to the load. Collection of reserve gas is required in the gas holder to support the load requirement. Many Myanmar gasifiers do not use gas holders. Consequently, when adequate amount of gas cannot be supplied to the engine, it might lead to problems related with engine stability.

E. Gasifier System

Overall gasifier system is shown in Fig 7.

It was found that every processes (eg. reactor, scrubber, filter) were important in successful gasification system. Reactor size is the most important factor for thermal and electrical loads. Design configuration of reactor and cleaning system dominate the quality of producer gas. Overload might cause system failure and poor gas quality.

Tar problem is related with poor system and insufficient maintenance in traditional Myanmar gasifiers. Many gasifiers lack regular replacement filter materials. It leads to problems for long time operation.

Fig 7 Gasification Experiment

In the rural electrification plants, energy demand rise dramatically. This causes overload in the rural electrification power plants. It leads to system instability and failure. This causes tar problems in engine.

F. Biomass Consumption

Three types of biomass (rice husk,50:50 briquette, briquette only) were used in the experiments especially 50:50 rice husk and briquette. Rice husk has 1cm length in 0.4cm diameter. It has smaller size and no need to reduce size. So Rice husk gasification is trouble free in this system.

This study tries to examine the possibility of rice husk briquette in the gasification process. Briquette density is ten times greater than rice husk. It is difficult to achieve combustible gas at only briquette. It is because of the compact and high density of the briquette.

It was found that the gasification was difficult using only the briquette. Average briquette size is 4×4 cm^2. Gasification rate of briquette is slow compared to rice husk only. After mixing with rice husk (50%mass), it was obtained the reliable gasification process. Average fuel consumption is 1.6~1.8 kg/h for complete 5 h operation.

G. Gas Composition

Gas sample are collected in sample bag at the exit of cleaning units. The producer gas compositions are measured with GC-TCD using molecular sieve 5A column and Argon carrier gas. Helium carrier gas has same thermal conductivity with hydrogen. So, it is difficult to separate hydrogen by using helium carrier gas. So argon carrier gas is used in all experiments within the same condition in the gas analysis.

Molecular sieve 5A column can separate hydrogen, oxygen, nitrogen, methane and carbon monoxide. Normalization method was used to calculate the composition of the producer gas.

Gas production rate strongly depend on the suction blower. The blower had a larger capacity than the production rate of reactor. It had to control the blower at inlet valve for successful combustible gas production. The air flow to the reactor was controlled by controlling the blower performance. Average combustible gas composition is 50% hydrogen, 5%

carbon monoxide and 1% methane by using the normalization method. Component identification is made with retention time comparison with other GC-TCD method with same operation conditions, column and carrier gas (Argon).

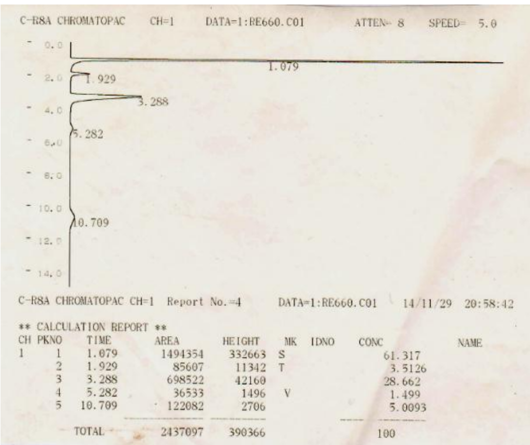

Fig 8 Chromatogram Of Run 4

H. *Lower Heating Value Of Producer Gas*

LHV of the producer gas were calculated using the equation (2) by elimination of water content in the products. There is a considerable range of variation of the gas heating value in the range 5.2–7.1MJ/Nm^3 even under conditions of the same load and feedstock. Average heating value is 6.3 MJ/Nm^3 from all experiment data.

These variations are due to changes instability inside the reactor. So we must consider the abnormal performance of the gasifier before confirming the highest load of sets; otherwise, if the workload is too high, the change of gas heating value will easily lead to shutdown of engines. Overload could make the producer gas incombustible.

TABLE I
LOWER HEATING VALUE CALCULATION FOR SELECTED RUNS

Run		LHV_i	x_i	x_iLHV_i
4	H2	9.88	0.613	6.06
	CO	11.57	0.050	0.58
	CH4	32.79	0.015	0.49
	LHV			7.13
7	H2	9.88	0.573	5.66
	CO	11.57	0.029	0.33
	CH4	32.79	0.016	0.52
	LHV			6.52
9	H2	9.88	0.547	5.40
	CO	11.57	0.030	0.35
	CH4	32.79	0.016	0.54
	LHV			6.29
11	H2	9.88	0.470	4.64
	CO	11.57	0.030	0.35
	CH4	32.79	0.006	0.21
	LHV			5.20

I. *Specific Gasification Rate*

Specific gasification rate (SGR) was calculated using the weight of dry rice husk gasified for a run, net operating period and the cross sectional area of the reactor using equation 4. From the experimental results (fig 9), SGRs were directly proportional with load of suction blower. At 54 kg/m^{2}h, the gases produced were leading to incombustible one. Because of overload, the gases were unstable. So maximum acceptable SGR for this system is 54 kg/m^{2}h. This result show that gasification process strongly depends on the reactor diameter, fuel consumption and load. Synchronization is required within gasification rate and load. Engine will be shutdown if synchronization is lost.

J. *Specific gas production rate*

Anemometer is used in the gasifier to calculate producer gas flow rate at the end of the system. The gas flow rate was calculated using temperature and pressure correction by using ideal gas law. Average gas flow rate is 1.34 Nm^3/h from the selected run.

Specific gas production rate is the rate of producer gas generation per unit cross-sectional area of the gasifier. It limits the gasifier performance and acceptable load. Average SGPR for this system is 42.77 Nm^3/m^{2}h.

K. *Energy efficiency(η)*

Energy efficiency data of the gasifier system are described in Fig 9. Average energy efficiency is 37% (±4) by neglecting utilities (pump and blower).

L. *Performance of the system*

The experiment data of the system is shown in Fig 9.

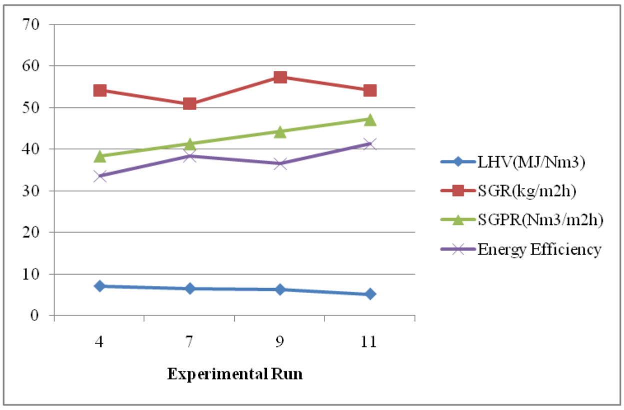

Fig 9 Experimental Results Of Selected Runs

LHV of the producer were in the range from 5.2 to 7.1 MJ/Nm^3. As all the sampled gases had heating values greater than 4.2 MJ/Nm^3 (engine requirement), the quality of producer was satisfactory for engine use. Although finding problems related with ash removal, the system could produce the combustible gas and its heating values were greater than 4.2.So it is recommended that rice husk briquette (50:50) can be used in gasification processes.

SGRs were from 51 to 57 kg/m^{2}h. Average was 54 kg/m^{2}h. By using the data obtained from the pilot plant, it is possible to calculate reactor size for required fuel consumption.

SPGRs were in the range from 38 to 47 Nm^3/m^{2}h. Average value was 43. The maximum acceptable load can be calculated for this system by using SPGR data.

Energy efficiencies were varying 34 to 41% respectively. Average was 37%. If energy values of ash and tar can be added to the system, its efficiency will increase significantly.

In conclusion, gas quality inversely proportional to the gas production rate. Thus overload might be a problem to the acceptable quality of producer gas. Controlling gas quantity will ensure sufficient gas quality. Similarly, energy efficiency is directly proportional to the gas flow rate. It is favorable to increase energy efficiency. So optimization of these parameters is required to enhance the gasification process for necessary gas quality.

IV. CONCLUSION

Gasifiers have taken continuously growth with its design, fuel types and performance parameters issues. The performance of gasifier is evaluated in term of different parameters. These all parameters take significant impact on the performance of gasifier.

From the tests, the best scheme of gasifier system was reactor, cyclone, water scrubber with recycle tank, two filters and gas holder for the current rural electrification plants that are suitable for environmental friendly and low cost gasifier system. This is because the system can disturb and eliminate significantly heavy tar, light tar and particulate from the producer gas.

Downdraft gasifier is the most reliable one for small scale rural electrification and rice milling industry. It is suggested that the downdraft gasifier system for rice husk can be used to other biomass, such as waste wood, pellet, MSW etc., only little change is needed. Additional modification is required for briquette gasification to achieve stable temperature distribution, zone shift between combustion and gasification and handle material fabrication on grate.

Cyclone can be ignored from the gasifier.

Water scrubber is one of the most efficient cooling and cleaning unit in the rural gasifier. Recycle water system should be used to mitigate environmental concern.

Different types and size of filter materials should be used to eliminate tar and clean the product gas for engine requirement.

Fuel consumption rate strongly influence the capacity of the gasifier. Biomass consumption (1.7kg/h) can produce thermal power 2.33kWh.

Fuel consumption, SGR, SPGR, LHV and energy efficiency data can be used for effective design estimation of large scale plants.

Modern instrumentation should be incorporated into the current pilot plant for further precise analysis.

ACKNOWLEDGEMENT

The author is very grateful to teachers and colleagues who have contributed guidance, encouragement, and assistance in this research. This work was partly supported by MTU, DRI and HEI-ICI-SUCCEED project. Thanks are also extended to Yangon Technological University for supporting test facilities.

REFERENCES

[1] Hina,B. et.al(2012)"Parametric Study of Fixed Bed Biomass Gasifier A review".*International Journal of Themal Technologies*, vol.2, No.1,ISSN 2277-4114

[2] Sharma,A.K.(2011)."Experimental investigations on a 20 kWe, solid biomass gasification system". *Biomass and Bioenergy*, 35(1),.421-428.doi:0.1016/j. biombioe.2010.08.060 http://dx.doi.org/10.1016/j.biombioe.2010.08.060

[3] Guangul, F. M., Sulaiman, S. A., & Ramli, A. (2012). Gasifier selection, design and gasification of oil palm fronds with preheated and unheated gasifying air. *Bioresour Technol*, 126, 224-232. doi: 10.1016/j.biortech.2012.09.018 http://dx.doi.org/10.1016/j.biortech.2012.09.018

[4] Dogru, M., Midilli, A., Howarth, C.R.,(2002). "Gasification of sewage sludge using a throated downdraft gasifier and uncertainty analysis". *Fuel Process. Technol*. 75, 55–82 http://dx.doi.org/10.1016/S0378-3820(01)00234-X.

[5] Phuphuakrat, T., Namioka, T., & Yoshikawa, K. (2011). "Absorptive removal of biomass tar using water and oily materials". *Bioresour Technol*, 102(2), 543-549. doi: 10.1016/j.biortech.2010.07.073 http://dx.doi.org/10.1016/j.biortech.2010.07.073

Mr. Ye Min Htut is a lecturer in Renewable Energy Training Centre in Department of Research and Innovation (DRI), Ministry of Science and Technology, Yangon, Myanmar. He is now doing his Ph.D research in the title "Parametric Study of a Downdraft Gasifier: Equilibrium Modeling and Experiments" in Mandalay Technological University. He was born in Myanaung on10.6.1980. He received his Bachelor of Chemical Engineering from Mandalay Technological University in 2003 and Master of Chemical Engineering from Yangon Technological University in 2007.

Previous publication:

"Using a Simple Modeling and Simulation Scheme for Complicated Gasification System" in IJSRP.2015.

His research interests are biomass gasification technology, renewable energy and modeling.