LONG-TERM REGULATION OF THE ENERGY EFFICIENCY AND GREENHOUSE GAS EMISSION FOR THE SMALL POWER PRODUCER THERMAL POWER PLANTS

JAKRIT UPAKOOL

A Thesis Submitted to the Graduate School of Naresuan University
in Partial Fulfillment of the Requirements
for the Doctor of Philosophy in (Renewable Energy)
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Thesis entitled "Long-Term Regulation of the Energy Efficiency and Greenhouse Gas Emission for the Small Power Producer Thermal Power Plants"

By JAKRIT UPAKOOL

has been approved by the Graduate School as partial fulfillment of the requirements for the Doctor of Philosophy in Renewable Energy of Naresuan University

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ABSTRACT

Thermal power plants are mostly powered by fossil fuels, making them a major source of carbon dioxide (CO_2) and other greenhouse gases (GHG) emissions resulting to global warming. Global warming causes climate change. Climate change results to many adverse environmental impacts that negatively impact the health and well-being of humans. This paper is a study to develop a mechanism or model for assessing, promoting and monitoring improvement of energy efficiency of small thermal power plants in Thailand implemented by Small Power Producers (SPP) to reduce their GHG emissions. The model can also assist power plants make adjustments to improve performance, including use of modern technologies to comply with the 2007 Energy Industry Act, and achieve the objectives of reducing adverse environmental impacts and gaining acceptance from people living around the power plants sites. As such, this model can be adopted by the Energy Regulatory Commission as a mechanism for the assessment and monitoring of energy efficiency schemes adopted by SPPs. With this model, ERC can introduce regulations to monitor and assess the operation of electricity companies for their compliance with emission standards and laws, the environmental impacts of the power plants, and the responses to the complaints of peoples living around the power plant areas, and thus assuring the environmental and health concerns of the people are properly addressed. This paper presents the parameter

and method to monitor energy efficiency and CO_2 emission of operational Thermal power plants (Steam Turbine Technology). The parameter of operation data has important to control the performance and improvement of the power plant. The method to monitor energy efficiency power plant include first law of thermodynamics theory, JIS B8222:1993: land boiler including hot water boiler method, ASME PTC-2004 steam turbine, methodological tool baseline; project and/or leakage emissions from electricity consumption and monitoring of electricity generation version 03.0.,a methodological tool, determining the baseline efficiency of thermal or electric energy generation systems version 02.0. Moreover, standard practice for determination of heat gain of loss and the surface temperatures of insulated pipe and equipment system using a computer program. (designation: C680 -89 reapproved 1995); case 2 cylindrical section, ASTM C 585 rigid and flexible, respectively. The long term regulation energy efficiency and CO_2 emission from operation thermal power plants with parameter effect on performance and CO_2 emission from operation, thermal power plants include boiler system, turbine system, condenser system, thermal power plant. This parameter of a performance monitoring system can provide plant operation information to help them identify problems, improve performance, and planning decisions about scheduling maintenance and optimizing plant operation. In addition, performance monitor can compare current performance to expected performance, and tracks for comparison over time.

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CHAPTER I

INTRODUCTION

Statement of the problems

Most countries are now giving priority to developing their energy supply, particularly electricity, from renewable energy sources. The objectives are promoting energy savings in the end-using economic sectors, reducing importation of fossil fuels, and reducing the adverse environmental effects of the use of these fuels. Energy is key input to people's life and a needed to fuel economic growth and development. Besides, an industrial country using fossil fuel in the process of industry sector, and transport sector, but the industrial country to develop energy-saving technology and innovative technology for a decrease to using fossil fuel because of fossil fuel high prices and impact to environmental For industrializing countries, there is higher energy demand for the industries and transport sectors and as such, there is a greater importance to reduce use of fossil fuels because of the economic cost and adverse environmental impacts are higher. Thus, in such countries, there is more interest for energy-saving and efficient technologies and, promoting wider use of renewable energy.

Thailand is one such country, and thus, its Ministry of Energy has adopted the 20-year "Thailand Power Development Plan (PDP) 2018" that considered the concerns mentioned above. Firstly, the "PDP 2018" has an 'energy security" objective, which has the following targets; meet all electricity and other energy requirement for economic development, decrease oil and other energy importations, and promote fuel diversification for electricity generation. Secondly is the "economic objective" that aims to support and promote widespread use of technologies that will lower the cost of power generation and electricity supply. To achieve this, the government will regulate the cost of electricity generation and supply, promote efficiency of power plants to reduce cost of electricity production, and support the deployment of cheaper renewable energy systems. Finally is the "environmental objective' of reducing the emission of carbon dioxide and other greenhouse gases from the energy sector. To help the power sector achieve this, renewable energy-based micro grids will be promoted for adoption in communities and in special economic zones. The micro-grids will aim for the efficient generation, transmission and distribution of renewable energy-generated electricity.

The Energy Regulatory Commission (ERC) of Thailand has the mandate over the energy industries of the country, especially the power plants, under the Energy Industry Act of 2007. The Act has the following objectives:

1. promote adequate and secure energy service provision, while ensuring fairness to both energy consumers and licensees,

2. promote the efficiency in energy industry operation and ensure fairness to both licensees and energy consumers,

3. promote economical and efficient use of energy and resources in energy industry operation, with due consideration of the environmental impact and the balance of natural resources, and

4. promote the use of renewable energy, which has minimal impact on the environment in the electricity industry operation.

Furthermore, the ERC is also responsible for receiving complaints of people and communities, whose lives and environment are affected by power plants construction and operations. Most of these complaints are about local air pollution (sulfur dioxide, nitrogen oxides and PM2.5 particulates emissions which do not meet emission standards), and water pollution generated during the power plant operations. Complains also include the non-compliance of the power plants of conditions set earlier in the granting of their licences to operate.

There is a need to improve energy regulation to better implement PDP 2018 in order to increase efficiency of power generation, and to improve power plant operations to reduce or eliminate, not only local air and water pollution (that will avoid complaints and resistance from local communities), but also reduce emissions of carbon dioxide and other GHG emissions that contribute to climate change.

Therefore, this researcher intent to do a research on the topic of "Long-Term Regulations of Energy Efficiency and Greenhouse Gas (GHG) Emissions for the Small Power Producer Thermal Power Plants".

Objectives of Research

1. To determine baseline of greenhouse gas emissions per unit electricity generation (tCO_2/kWh) from Small Power Producer (SPP) thermal power plants.

2. To analyze and compare the efficiency of and the greenhouse gas emissions from SPP thermal power plants.

3. To design how to regulate the efficiency of electricity generation of and to reduce the greenhouse gas emissions from SPP thermal power plants.

Scope of the Research

The study will be on the "Long Term Regulations of the Energy Efficiency and Green House Gas (GHG) Emission for the Small Power Producer (SPP) Thermal Power Plants" that can be used to provide license to these power plants.

The ERC database contains a list of 48 of thermal power plants, categorized as (small power producers or SPPs (more than 10 MW but less than 90 MW) with a total installation capacity of 2,386.35 MW.

If all types of SPPs are included, both thermal and other types using other renewable energy sources such as hydro, solar and wind; the total installed capacity of SPPs is 12,054.11 MW (see Table 1-2 and figure 1.) (1).

This research will have the following specific objectives:

1. Assessment of the greenhouse gas emissions per unit of electricity generation (tCO_2/kWh) from the SPP thermal power plants

2. Comparison of the actual energy efficiency of electricity generation with the designed efficiency of the SPP thermal power plants

3. Assessment of energy efficiency of electricity generation from SPP thermal power plants

4. To study the operation of SPP thermal power plants at normal load and full load conditions.

Table 1 Power Producers (SPP) in Thailand

Type of Fuel	Installation Capacity (MW)	Amount of Plant
Coal	851.00	7
Natural Gas	8,373.72	66
Wind	973.00	14
Hydro Power	22.00	1
Waste	200.95	5
Solar PV	588.64	7
Biomass	1,034.40	34
Bunker Oil	10.40	1
Total	**12,054.11**	**135**

Table 2 Type of Small Power Producer Technology in Thailand

Type of Technology	Installation Capacity (MW)
Thermal	2536.35
Solar PV	588.642
Combine Cycle	7688.717
Gas Turbine	235
Engine Diesel	10.40
Hydro Power	22
Wind	973.00
Total	**12,054.11**

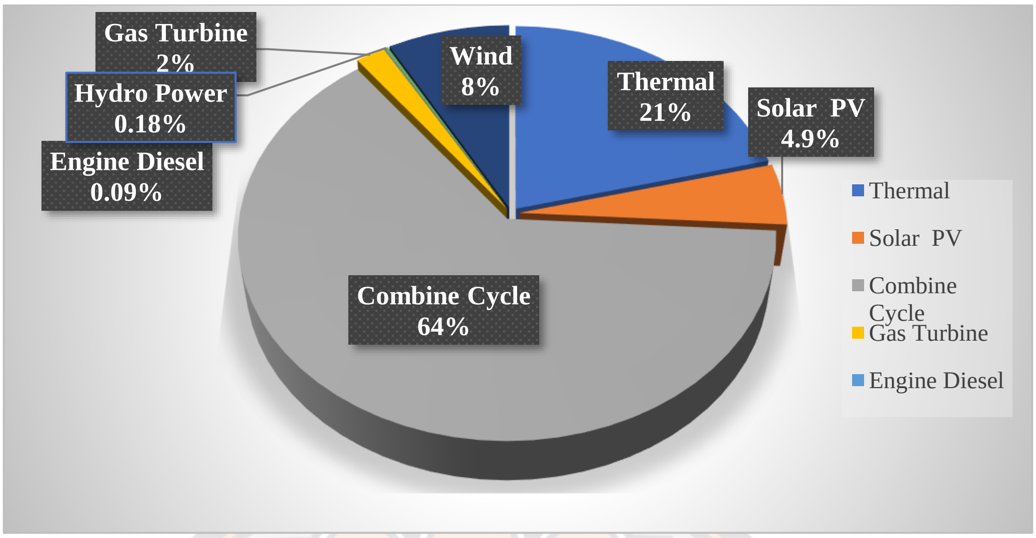


Figure 1 Types of Small Power Producer Technologies in Thailand (in %)

Expected Benefits of Research

Methodology for the introduction of laws and regulations for the operation of thermal power plants, particularly Small Power Producers (SPP) thermal power plants using steam turbine technology. SPP are those between 10 to 90 MW capacity and not more than five years in operation. The methodology will target to:

1. improve and increase the efficiency of thermal power plants.
2. reduce emissions of greenhouse gases (GHG), particularly CO_2 emissions.
3. reduce local air, land and water pollution that affect people living around power plant areas, thereby reducing complaints from these people.

CHAPTER II

BACKGROUND & RATIONALE FOR RESEARCH

Comparison of Policies and Regulations to Monitor Performance and CO_2 Emissions of Thermal Power Plants

This research began with a study of policies and regulations to monitor and evaluate the performance and CO_2 emissions of thermal power plants. The study included work being done under the U.S. Environmental Protection Agency, Japan Electricity Power, and Thailand Ministry of Energy. The study focused on the methodologies used for controlling performance of and reducing CO_2 emission from thermal power plants.

The specific policies and methods for the three countries, to control electricity generation from the thermal power plants, and to reduce CO_2 emissions that will allow compliance with their commitments under the Paris agreement, are shown on Table 3.

Implementation of Power Plant Sector Regulations in Thailand

Thailand Energy Industry Act 2007 Section 7 defines the objectives of this Act as follows:

1. promote adequate and secure energy service provision, while ensuring fairness to both energy consumers and licensees,

2. promote economic and efficient use of energy and resources in energy industry operation, with due consideration of environmental impact and the balance of natural resources, and

3. promote the use of renewable energy which has minimal impact on the environment in the electricity industry operation.

Section 11, states the authority and duties of the commission or the ERC as follows:

1. regulate energy industry operation to ensure compliance with objectives of this act under the policy framework of the government,

2. issue an announcement determining types of licenses for energy industry operation, and propose an issuance of a royal decree to determine the categories, capacities, and characteristics of the energy industry which are exempt from license requirement,

3. impose measures to ensure security and reliability of electricity system,

4. inspect the energy industry operation of the licensees to ensure efficiency and transparency, and

5. promote economical and efficient use of energy, renewable energy, and energy that has minimal impact on the environment, with due consideration of efficiency of electricity industry operation and balance of natural resources.

The ERC is also mandated to introduce laws to regulate the implementation of power plant projects such as the "Code of Practice (CoP) Guidelines power plants of not more than 10 MW that are using the following energy source: biomass, biogas, solar farm, solar rooftop, community garbage, and industrial waste.

Installations with capacity of more than 10 MW must the follow Environmental Impact Assessment law (EIA) of Office of Natural Resources Policy and Planning and the environment (2).

The implementation of the regulations for thermal power plants are the duties of the ERC (MOU), the Department of Industrial Works or DIW (*Industrial Ministry*), and the Natural Resources and Environmental Policy and Planning Office (ONEP). All new thermal power plants projects must follow the relevant energy, industrial and environmental laws and regulations implemented by ERC, DIW and ONEP, respectively. For example, biomass-fueled thermal power plants with targeted installed capacity of 10 MW or less must prepare a proposal and relevant reports to all the above-mentioned offices to obtain a license and allow project implementation.

The specific license to be obtained and the reports to be submitted by a power plant project developer/implementer to each of these agencies is shown on Table 4.

Table 3 Policy and Method to Control Performance and CO_2 Emission of Thermal Power Plants (3, 4, 5)

U.S. Environmental Protection Agency	**Japan Electricity Power**	**Ministry of Energy in Thailand**
Policy Mandatory heat rate reduction for all coal power plants in the United States, the proposed policy would improve the efficiency all power plants, and reduce CO_2 emission.	Policy The fifth basic energy plan to focus in further growth of the Japanese economy, improvement of the standard of living, and global development through energy supply that is stable, sustainable long term, independent with under the Paris agreement as a growth strategy	Policy Thailand power development plan in 2018 (2018-2037) base of security, economy, and ecology for reduce CO_2 emission with under the Paris agreement as growth strategy.
Implementation - Define categorized by unit size of uniform regardless of the initial heat rate. • Unit less than or equal to 200 MW must reduce heat rate by 810 Btu/kWh. • Unit less than or equal to 500 MW must reduce heat rate by 745 Btu/kWh. • Unit greater 500 MW must reduce heat rate by 740 Btu/kWh. Therefore, implemented across the can reduce heat rate about 15 % (reduce spanning from	Implementation - CO_2 emission and global waring counter measure implemented by the electricity power industry. • Japan electricity utilities are participating in the Japan business federation aforementioned commitment to low carbon society and promoting measure on both the supply and demand side of the electric power sector. The commitment to low carbon society in the electricity industry at CO_2	Implementation - Target reduction CO_2 emission about 20 – 35 % with Paris commitments climate change of PDP 2018 v.1 include • Reduction CO_2 emission from electricity sector at 56 $MtCO_2$ in 2037. • Intensity CO_2 from electricity sector 0.339 $kgCO_2$/kWh in 2027, and 0.271 $kgCO_2$/kWh in 2037. • Increase proportion renewable energy includes biomass biogas solar farm, and solar

U.S. Environmental Protection Agency	Japan Electricity Power	Ministry of Energy in Thailand
335 Btu/kWh to 1,265 Btu/kWh) of the total heat rate to generate electricity in 2016. Generation under the policy scenario to 1,536 Terawatt-hours (TWh), and amount in 2016. - CO_2 emission reduction by 2016- 2030 under the policy scenario about 1,284 $MtCO_2$. - Addition, many state support a more flexible approach and implemented similar carbon, reduce polices, such as renewable portfolio standards, end-use efficiency program, and greenhouse gas trading markets.	emission factor in fiscal 2030 of approximately 0.37 $kgCO_2$/kWh (equivalent to reduction of 35 % from the fiscal 2013 level). • Efficient and stable use of fossil fuel: Promotion of effective use of high-efficiency thermal power generation. • Promotion of energy and environmental innovation strategies, and international energy cooperation which collaboration with the US., Russia, and Asian countries; Contribution to significant CO_2 emission reduction in the world.	floating to electricity generation at 16,243 MW. • Support and develop smart grid technology, smart city, smart system, smart leaning, and battery energy storage at substation high volt.

Table 4 Government Offices Issuing Licenses and Approving Reports for Thermal Power Plant Project Proposals (2)

Department of Industrial Works	**Energy Regulatory Office**	**Natural Resources and Environmental Policy and Planning Office**
License of factory	The license of generation electricity	Report on Environment Impact Assessment: EIA consideration of electricity generation license (make to report every six months)
Report on Environment and Safety Assessment: ESA consideration to industry license	Report of Code of practice: CoP consideration of electricity generation license (make to report every one year)	Report on Environmental Health Impact Assessment: EHIA consideration of electricity generation license (make to report every one year)
Installation capacity < 10 MW	**Installation capacity < 10 MW** - Biomass Fuel - Biogas Fuel - Industry Waste - Waste of Community **Installation capacity >10 MW** - Industry Waste - Waste of Community	**Environmental Health Impact Assessment: EIA** Installation capacity > 10 MW **Environmental Health Impact Assessment: EHIA** Installation capacity > 100 MW - Coal Fuel Installation capacity > 150 MW - Biomass Fuel Installation capacity > 3,000 MW - Natural gas Fuel

Emission Standards for Thermal Power Plants (6)

The Pollution Control Department (PCD) implement the law relating to compliance to emission standards to control air pollution from both old and new thermal power plants for the following air pollutants: sulfur dioxide (SO_2), nitrous oxides (NOx), and particulate matters (PM), see Table 5-6.

Table 5 Emission Standard Control for Old Thermal Power Plants

Type of Emissions	Type of fuel Standard emission		
	Coal	Oil	Natural gas
Sulfur dioxide (ppm)			
- **Installation capacity > 500 MW**	320	320	20
- **Installation capacity 300 – 500 MW**	450	450	20
- **Installation capacity < 300 MW**	640	640	20
Oxide of nitrogen (ppm)	350	180	120
Total Suspended Particulate (mmg/m^3)	120	120	60

Table 6 Emission Standard Control for New Thermal Power Plants

Type of fuel	Sulfur dioxide (ppm)	Oxide of nitrogen (ppm)	Total Suspended Particulate (mmg/m3)
Coal			
- **Installation capacity <50 MW**	< 80	< 360	< 200
- **Installation capacity >50 MW**	< 80	< 180	< 200
Oil	< 120	< 260	< 180
Natural Gas	< 60	< 20	< 120
Biomass	< 120	< 60	< 200

Description of Thermal Power Plants (7)

In thermal power plants, heat energy is generated from the combustion of solid fuel (such as, coal, natural gas, and biomass) which is then used to convert water into high pressure and temperature steam. This steam is used to rotate the turbine blade that rotate the turbine shaft connected to the generator. The generator converts the kinetic energy of the turbine impeller into electric energy. The operation of a thermal power plant to generate electricity consists of the following:

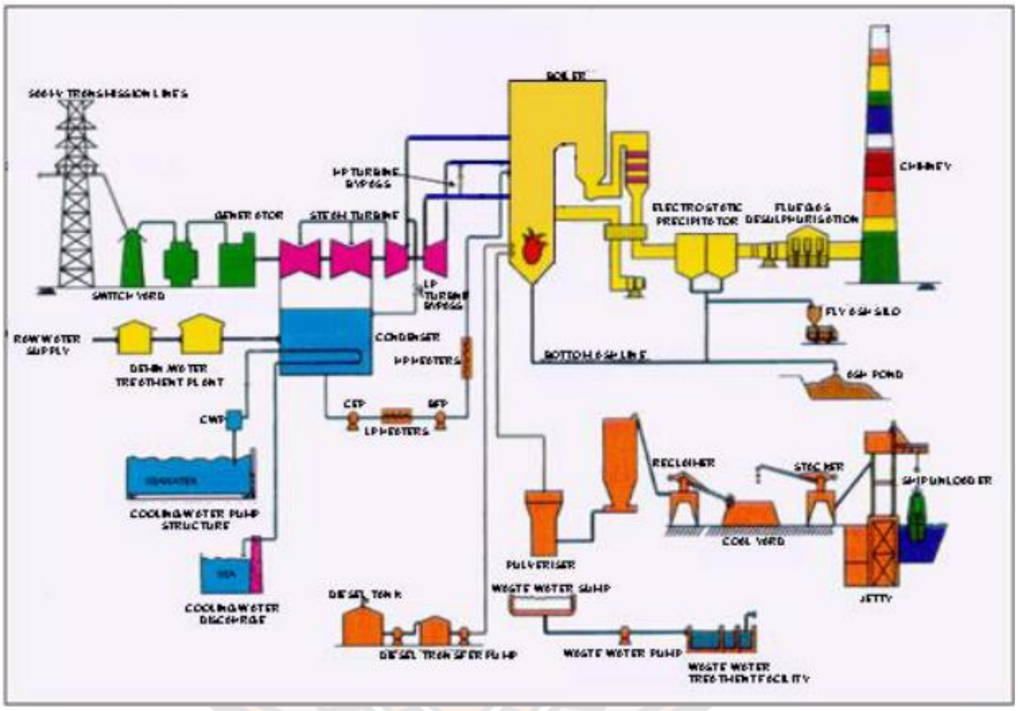


Figure 2 Process of Thermal Power Plants (8)

1. Fuel storage and handling: An essential part of any power plant is the safe storage of an appropriate amount fuel so that the plant can run smoothly not only on normal days but even there are disruption of supply from fuel sources. A fuel storage facility should be designed to store adequate amount of fuel, even in cases of supply disruption.

2. Water treatment: The water used to produce the steam to rotate the turbine comes into direct contact with the boiler, boiler tubes, boiler accessories, and turbine

blades. Most water are taken from rivers, which contains much dirt, suspended particulate matter (SPM), dissolved minerals, and dissolved gases (which is mostly air). Untreated water fed to the boiler will reduce the life and efficiency of the equipment by corroding the surfaces and scaling the equipment. This may lead to overheating of pressure parts and explosions. Water also contains dissolved oxygen, and this leads to corrosion and fouling of boiler tubes and surfaces when oxygen comes in contact in them. Removing of dissolved oxygen from water is done by adding oxygen scavengers and by using a deaerator tank. Deaerator tank can act as a feed water tank that can store the feed water. The solubility of air in water decreases when heating the feed water in a deaerator tank, thereby removing the dissolved air (and oxygen) from the water.

3. Boiler operation: The boiler is a pressure vessel which is used to generate high-pressure steam at a saturated temperature. Generally, drum water tube boilers are used. Water tube boiler consists of a furnace enclosed by the water tubes lashings. The crushed fuel from the crushers is fed into the boiler furnace over the grate. The hot air from the forced draft (FD) fan is mixed with the crushed fuel causing combustion of fuel. Combustion of fuel generates a lot of radiation heat which is transferred to water in the membrane tubes. Flue gases generated during combustion travel at high velocity across the convection bank of tubes, thereby heating water through convection heat transfer. Hot water is sent to a boiler drum at high pressure through the feed water pump.

4. Turbine: The turbine is a mechanical device that converts the kinetic and pressure energy of steam into useful work. From the super heater, steam go to the turbine where it expands and loses its kinetic and pressure energy and rotates the turbine blade which in turn rotates the turbine shaft connected to its blades. The shaft then rotates the generator which converts this kinetic energy into electrical energy.

Green House Gas Emission Assessment (9)

Greenhouse gases (GHG) that result to global warming and climate change include Carbon dioxide (CO_2), Methane (CH_4), and Nitrogen oxides (N_2O). They are mostly emitted during the burning of fossil fuels in thermal power generation plants. Biomass fuels also generate GHG, but this is mainly carbon dioxide.

This research applied the methodological tools available from the for estimating baseline emissions, the project and/or leakage emissions from electricity consumption and monitoring of electricity generation version 03.0 from CDM Methodologies (see - https://cdm.unfccc.int/methodologies/PAmethodologies/tools). The assessment of baseline CO_2 emissions and CO_2 emissions during project operation can determined from the equations shown on Table 7.

Table 7 Equation to Assessment CO_2 Emission of Power Plant

Method	Technology	Tool	Measure	Equation
Methodological tool baseline; project and/or leakage emissions from electricity consumption and monitoring of electricity generation version 03.0.	- Boiler travel gate - Truck of fuel - Generator system	- Supervisory Control and Data Acquisition: SCADA - Data sheet record - electricity generation - fuel consumption - distance truck	- CO_2 emission of project	**<u>Determine electricity generation.</u>** Equation 1 Annual CH_4 released = HHVof bagasse used by project x CH_4 emission factor for bagasse x GWP of CH_4 when; Annual CH_4 released = emission CH_4 from combustion of fuel; tCO_{2e}/yr HHV= High heating value of bagasse; kJ/kg CH_4= emission factor fuel; tCH_4/kJ GWP of CH_4 = Global warming potential of CH_4; tCO_{2e}/tCH_4 Annual CO_2 = Amount of fuel used x HHX of fuel x Emission factor **<u>Determine distance transport of fuel.</u>** Equation 2 Distance travelled = Total bagasse consumed by project x Truck capacity x Return trip distance to supply side when; Total fuel consumed by project; ton/yr Truck capacity; ton Return trip distance to supply site; km **<u>Determine Emission from transport of fuel.</u>** Equation 3 Annual emission = Emission factor x Distance travelled when; Emission factor = from fuel consumption in transport of fuel; $tCO_{/2e}/km$ Distance travelled; km/yr **<u>Determine emission of start-up</u>**. Equation 4 Annual CH_4 released = HHV of fuel using to startup x emission factor fuel x GWP of CH_4

Method	Technology	Tool	Measure	Equation
				when; Annual CH_4 released = emission CH_4 from combustion of fuel; tCO_{2e}/yr HHV = high heating value of fuel using to startup; kJ/kg GWP of CH_4 = Global warming potential of CH4; tCO_2/tCH_4 Emission factor fuel = emission of fuel using to start up; tCH_4/kJ **Determine amount CO_2 emission of electricity exported by project.** Equation 5 CO_2emission = Amount electricity exported x CO_2 emission factor when; CO_2 emission = amount CO_2 emission of electricity exported ; tCO_2/yr Amount electricity exported ; MWh CO_2 emission factor ; tCO2/MWh **Determine baseline CO_2 emission of project** Equation 6 Baseline CO_2 Emission = Emission from grid electricity - Emission from fueled electricity generation - Emission from transportation of fuel - Emission from start-up; tCO_2/yr
Methodological tool; Determining the baseline efficiency of thermal or electric energy generation systems version 02.0.	-Boiler travel gate - Generator system -Back pressure turbine -Extraction condensing turbine	- Supervisory Control and Data Acquisition: SCADA -3E Plus Soft ware - SSTM software Data sheet record - electricity generation - fuel consumption	- Compare Design value of equipment such as - Boiler system - Generator system - Steam turbine	**Design Value of main equipment** - Boiler system - Generator system - Back pressure turbine - Extraction condensing turbine

Assessment of Energy Efficiency of Thermal Power Plant

Improving energy efficiency or heat rate of power plants are important not only in improving operation of thermal power plants but also in reducing the GHG emissions from their operations. Government regulatory agencies should also focus on increasing the efficiency of thermal power plant operations. While is design electricity generation process of thermal power plants to apply first law of thermodynamics theory such mass balance, and conservation of energy principle to heat and thermodynamic processes (internal energy, heat, and system work). The design of thermal power plants is based on the principles of the laws of thermodynamics. Although all forms of energy are interconvertible, and all can be used to do work, it is not always possible to convert the entire available energy into work. There will always be energy losses in the form of heat. The amount of heat losses is an indication of the heat rate or efficiency of the energy conversion process. The higher the heat losses, the lower the efficiency.

In the calculation of the boiler efficiency (η_{Bolier}) the usable energy output is divided by the energy input. There are two main methods for calculating thermal efficiency, the Direct Method and the Indirect Method (based on standards for boiler testing at site using indirect method namely JIS B8222: 1993; land boiler including hot water boiler. Therefore, calculator to The calculations for the energy efficiency of thermal power plants can be determined using the equations in Table 8.

Table 8 Efficiency Assessment of Power Plant and Component

Power plant system and components	Method	Technology	Tool	Measure	Equation
Performance of power plant	First law of thermodynamics theory such mass balance, and conservation of energy principle to heat and thermodynamic processes (internal energy, heat, and system work) (10, 11, 12, 13)	- Boiler travel gate - Extraction condensing turbine - Back pressure turbine - Generator system	-Supervisory Control and Data Acquisition: SCADA - 3E Plus Soft ware - SSTM software	Overall performance power plant.	**<u>Performance of power plant</u>** $\eta_{overall} = \eta_{boiler} * \eta_T * \eta_G$ Equation 7 **when;** $\eta_{overall}$ = Overall energy efficiency of power plant; % η_{boiler} = Efficiency of boiler system; % $\eta_{Turbine}$ = Efficiency of turbine; % $\eta_{Gernerator}$ = Efficiency of generator; % (the ratio generator output and generator output plus generator loss.) **<u>Heat Rate of power plant</u>** $\text{Heat Rate} = \frac{F}{E}$ Equation 8 **when;** F = Heat energy input supplied by fuel to the power plant for period; kJ/kg E = Energy output from the power plant in a period; kWh

Power plant system and components	Method	Technology	Tool	Measure	Equation
Boiler system & Steam turbine	JIS B8222: 1993; Land Boiler including hot water boiler method.	- Boiler travel gate	- Flue gas analysis	CO_2, CO, SO_2, NO_x and O_2 exhaust gas	**Indirect method** Equation 9 **Heat loss =** $\mathbf{L_h = L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_{pipe}}$ **when;** L_1 = Fuel gas loss of boiler system; kJ/kg L_2= Soot blow loss of boiler system; kJ/kg L_3= Incomplete combustion loss of boiler system; kJ/kg L_4= Unburned loss of boiler system; kJ/kg L_5= Radiation loss boiler system; kJ/kg L_6= Blowdown loss boiler system; kJ/kg L_{pipe} = Pipe loss; kJ/kg **Flue gas loss ,** $\mathbf{L_1 = Gx\ C_p x(T_g - T_a)}$ Equation 10 **when;** G = Flue gas of mass flow rate; m^3/kg C_p = Specific heat of flue gas exhaust; kJ/m^3 °K T_g = Temperature of flue gas exhaust; °K T_a = Temperature of environment; °K $\mathbf{G = G_o + G_w + [A_o x(m - 1)] + G_{w1}}$ Equation 11

Power plant system and components	Method	Technology	Tool	Measure	Equation
					when; G_o = Amount of theoretical flue gas; m^3/kg G_w = Amount of steam generation by burn and heat derived from moisture in fuel; m^3/kg A_o = Amount of theoretical of air; m^3/kg m = Ration of excess air; % G_{w1} = Amount of steam due to hygroscopic moisture in combustion air; m^3/kg $\mathbf{G_o = \frac{1}{100}\left[8.89 \times C_1 + 21.1\left(h - \frac{O}{8}\right) + 3.3 \times S + 0.8 \times N\right]}$ Equation 12 **when;** C_1 = Carbon in combustion; % h = hydrogen in fuel; % O = oxygen in fuel; % S = Sulfur in fuel; % N = Nitrogen in fuel; % $\mathbf{A_O = \frac{1}{100}\left[8.89 \times C_1\ 26.7\left(h - \frac{O}{8}\right) + 3.3 \times S\right]}$ Equation 13

Power plant system and components	Method	Technology	Tool	Measure	Equation
					when; C_1 = Carbon in combustion; % h = Hydrogen in fuel; % O = Oxygen in fuel; % S = Sulfur in fuel; % $\mathbf{m} = \frac{21}{21-79\left[\frac{(O_2)-0.5(CO)}{(N_2)}\right]}$ Equation 14 **when;** O_2 = Oxygen in flue gas; % CO = Carbon in flue gas; % N_2 = Nitrogen in flue gas; % $\mathbf{G_w = \frac{1}{100}[1.24(9h + \omega)]}$ Equation 15 **when;** h = Hydrogen in fuel; % ω = Moisture in fuel % $\mathbf{G_{w1} = 1.61zmA_o}$ Equation 16 **when;** A_o = Amount of theoretical of air; m^3/kg m = Ration of excess air; % *z* = Absolute humidity of air to combustion; %

Power plant system and components	Method	Technology	Tool	Measure	Equation
					$\mathbf{L_2 = W_b(h_g - h_{fw})}$ Equation 17 **when;** W_b = Amount of steam using to soot blow ; kg/hr h_g = Enthalpy of steam using to soot blow ; kJ/kg h_{fw} = Enthalpy of feed water ; kJ/kg $\mathbf{L_3 = 26.1[G_o + (m - 1)A_0] \times CO}$ Equation 18 **when;** CO = Carbon in flue gas; % G_o = Amount of theoretical flue gas; m^3/kg m = Ration of excess air; % $\mathbf{L_4 = 339xC_2}$ Equation 19 **when;** C_2 = Compare carbon surplus and carbon in fuel $\mathbf{L_5 = \frac{3,600 \times Q_W}{\dot{m}_f}}$ Equation 20

Power plant system and components	Method	Technology	Tool	Measure	Equation
					when; Q_w = Amount of heat loss at wall boiler or surface pipe; kW $\dot{m}_f$ = Amount of fuel using; kg/hr $\mathbf{L_6 = \dot{m}_{bd} \frac{(h_{bd}-h_{FW})}{\dot{m}_f}}$ Equation 21 **when;** $\dot{m}_{bd}$ = flow rate of blowdown; kg/hr h_{bd} = Enthalpy of blowdown rate; kJ/kg h_{FW} = Enthalpy of feed water; kJ/kg **<u>Efficiency of boiler system</u>** $\boldsymbol{\eta = \left(1 - \frac{L_h}{H_h+Q}\right) x\ 100\%}$ Equation 22 **when;** η = Efficiency of boiler system; % L_h = Total heat loss of boiler system; kJ/kg H_h = Heat loss of flue gas reference high heating value per kg; kJ/kg Q = Heat supplement in boiler system; kJ/kg

Power plant system and components	Method	Technology	Tool	Measure	Equation
					<u>Flue saving</u> $\mathbf{FS} = \frac{\eta_{new}-\eta_{old}}{\eta_{new}}\ \boldsymbol{x}\ \dot{\boldsymbol{m}}_{\boldsymbol{f}}$ Equation 23 **when;** FS = Fuel saving; ton/hr $\dot{m}_f$ = Fuel using; ton/hr η_{new} = Efficiency of after improvement; % η_{old} = Efficiency of before improvement; % **<u>CO_2 reduction emissions</u>** $\mathbf{CO_2\ Emission = EF\ x\ FS}$ Equation 24 **when;** EF = Emission factor; $kgCO_2$/ton (*ref ; CO_2 emission EPA for wood and wood residuals = 1,640 $kgCO_2$/ton*) FS = Fuel saving; kg/hr

Standard Efficiency of Thermal Power Plants (14)

1. **Coal-Fired Power Plants**

Coal-based power accounts for almost 41 % of the world's electricity generation. Coal-fired power plants operate on the modified Rankine thermodynamic cycle. The efficiency is dictated by the parameters of this thermodynamic cycle. The overall coal plant efficiency ranges from 32 % to 42 %. It is mainly dictated by the Superheat and Reheat steam temperatures and Superheat pressures. Most of the large-scale power plants operate at steam pressures of 170 bar and 570 °C Superheat, and 570 °C reheat temperatures. The efficiencies of these plants range from 35 % to 38 %. Supercritical power plants operating at 220 bar and 600/600 °C can achieve efficiencies of 42 %. Ultra-supercritical pressure power plants at 300 bar and 600/600 °C can achieve efficiencies in the range of 45% to 48 % efficiency.

2. **Natural Gas-Fired Power Plants**

Natural Gas fired (including LNG fired) power plants account for almost 20 % of the world's electricity generation. These power plants use Gas Turbines or Gas Turbine based combined cycles. Gas turbines in the simple cycle mode, only Gas turbines running, have an efficiency of 32 % to 38 %. The most important parameter that dictates the efficiency is the maximum gas temperature possible. The latest Gas Turbines with technological advances in materials and aerodynamics has efficiencies up to 38 %. In the combined cycle mode, the new "H class" Gas turbines with a triple pressure HRSG and steam turbine can run at 60 % efficiency at ISO conditions. This is by far the highest efficiency in the thermal power field.

3. **Biomass Power Plants**

Biomass fuels, harvested from the nation's lands and forests, has the potential to provide an important source of renewable, sustainable energy for the country. To develop this critical energy sector successfully, however, public policy can play a critical role in addressing issues of scale, efficiency, biomass supply, environmental impacts, local economics, harvesting capability, and investment and financing. Using biomass for energy in ways that sustain the health of the nation's lands and forests and with the operation of biomass power plants using heat or heat-led combined heat and power (CHP), results to biomass energy use of approximately 75-80 percent efficient, while the generation of electricity is only 20-25 percent efficient.

There have researchers assessing energy efficiency of thermal power plants mostly to compare the energy efficiency of thermal power plants before and after commercial operations (M.N. Eke, D.C. onyejekwe, O.C. Iloeje, C.I.Ezekwe, and P.U. Akpan). These were studies of the energy efficiency of thermal power plants (mostly in the SPPs range) that compared between the design values and the operation values of energy efficiency.

Related Research

S.M. Shafie., H.H. Masjuki., T.M.I Mahlia. (15) did a life cycle assessment of electricity generation from rice husk and straw in Malaysia. The results showed that in Malaysia, use of such biomass fuels can reduce greenhouse gas emission by about 1.79 kg CO_{2-eq}/kWh and 1.05 kg CO_{2-eq}/kWh compared with using coal and natural gas, respectively. Malaysia is now developing and deploying technologies to collect agricultural wastes to be used as fuel for electricity generation. The environmental benefits include reducing global warming and the potential for soil acidification.

Deshwar AG, Vembu S, Yung CK, Jang GH, Stein L, Morris Q. (16) did an energy and exergy analyses of biomass cogeneration systems. Three configurations were considered: back pressure steam turbine cogeneration system, condensing steam turbine cogeneration system, and double back pressure steam turbine cogeneration system. The results showed, the effect of fuel type on energy and exergy efficiency of the fuel characteristics. The fuel calorific value can improve system performance. In simple back pressure steam turbine generation, the increase in pressure on the work output and process heat due to increase enthalpy of the steam, with temperature increases of 20 °C, enhanced the overall performance. The investigation pointed out that improving and developing natural gas cogeneration system can be a good choice for the future. Their GHG emissions are reduced significantly compared to conventional coal fired power generation.

Atilgan B, Azapagic A. (17) studied the life cycle assessment of electricity generation in Turkey and did a Cradle-to-Grave environmental assessment. Therefore, to study thermal power plants of lignite coal fuel amounts 16 plants and thermal power plants of natural gas fuel amount of 187 plants The study covered 16 coal thermal power plants and 187 natural gas thermal power plants. Environmental impact assessments, following. ISO 14040, 14044 and Gabi were conducted, covering impacts on greenhouse gas emissions, the ozone layer, and the acidification potential and their effects on human health, and on natural resources. The results of the research showed the need the government supporting the development of renewable energy resources, and reduction of the generation of electricity from coal.

Thanarak P, Maneechot P, Wansungnern W, Prasit, B, Phetsuwan, S. (18) conducted an assessments of carbon dioxides emissions from a 10- kW napier grass-fueled biomass power plant using (gasification technology for a community. The assessment of carbon dioxide emissions was done for the following steps: firstly, soil preparation, and the, cultivation, and harvest of napier grass; secondly, transport of napier grass, and use in the power plant The assessment used the LCA method and followed ISO 14040 used for assessment of emissions. The results showed, carbon dioxides emissions of 0.32 kgCO2eq/kWh, while carbon dioxide absorption of s - 0.19 kgCO2eq/kWh. Therefore, the net result showed that there was more carbon dioxides emissions. This was because the farmers used chemical fertilizers. The recommendation was for famers to, use organic fertilizers which may result to greater carbon dioxide absorption and net negative emissions.

Chompu, R. (19) analyzed the energy efficiency, exergy efficiency, and the cost-effectiveness of a 27-MW co-generation power plant installation capacity based on the principles of the first law and the second law of thermodynamics. Three processes were studied: steam generation only, steam and electricity generation, and electricity generation only). The results showed the following: “, steam generation only” has a higher energy efficiency of about 71.76 %, exergy efficiency about 28.08 %, and cost of steam generation of about 1,175.66 Baht/ton-steam. Also, the assessment of the co-generation power plant showed that the energy efficiency can be increased by improving fuel consumption and project investment cost.

Anjali, T. H., G., Kalivarathan (20) study shows that currently, most of the electricity produced throughout the world is from steam power plants. Therefore, it is critical to ensure that the plants are working with maximum efficiency. Thermodynamic analysis of the thermal power plant has been undertaken to enhance the efficiency and reliability of steam power plants. Most of the power plants are designed using energetic performance criteria based on the first law of thermodynamics only. The real useful of energy loss cannot be justified by the first law of thermodynamics, because it does not differentiate between the quality and quantity of energy.

Their work dealt with the comparison of energy and exergy analysis of coal-fueled thermal power plants stimulated. They showed that generally, even a small improvement in any part of the plant resulted in a significant improvement in plant efficiency. Factors affecting the efficiency of a thermal power plant were identified and analyzed for improving the working of the thermal power plant. Their study showed the use energy analysis and exergy analysis, based on the first law of thermodynamics and second law of thermodynamics respectively, identifying the locations and magnitudes of losses, in order to maximize the performance of a 15 MW thermal power plant in a paper mill. Their study evaluated the boiler, turbine and condenser efficiencies, showing that in order to improve the efficiency and performance of a plant, it was necessary to check and estimate the efficiencies separately and periodically regularly.

Hamdan M, Maály, RM. (21). study the correlation between the amount of emitted pollutants with the amount of electricity generation. The pollutants considered were carbon dioxide, carbon monoxide, sulfur oxides, and nitrogen oxides. Actual data were obtained for the four-year old Aqaba Thermal Power Station, with. calculation of emissions and efficiency of the power plant dones every month. The results showed that the correlation obtained can be used to estimate the amount of future emissions and can be used to establish a regulatory framework for reducing pollution from power plants.

Mahlia TM, Lim JY, Aditya L, Riayatsyah TM, Abas AP. (22). studied methods for reduction of, GHG emissions from thermal power plants and to implement power plant efficiency standards for power generation. Their study showed that one of the most effective ways of tackling efficiency issues is through the implementation of efficiency standards. Therefore, the government should defined a mandatory or voluntary regulatory instrument, to control greenhouse emissions from power plants. This study use a method for calculating greenhouse intensity value and with its corresponding allowable ranges, and this method was used in a case study for a 10-year-old base-load multi-fuel-fired power plant in Malaysia.

Feng TT, Gong XL, Guo YH, Yang YS, Dong J. (23) studied the regulatory mechanism designed to reduce GHG emissions in the electric power industry in China. The also looked at the policies and control methods to repair the environment used in foreign countries like Australia, Japan and South Korea. China has just integrated a new policy and method for regulating the operation of the electric power industry. Thus, China has improved policies for controlling the power plants sector such as in policy coordination mechanism, policy design, policy adaptation, rewards and penalties, system of the regulatory bodies and their functions, independent institutions. It has built, regulatory capacity and develop professionals, define a framework of laws and regulations, adopted a strategic and systematic legal system, and support for the operability of laws and regulations. It created operating mechanisms such as the GHG emissions indicator system; a monitoring, reporting and verification (MRV) systems; a monitoring and evaluation mechanism; and a carbon trading mechanism. The, existing problems in China with regards to the regulation of the power industry and the design of regulatory scheme were a addressed by the above-mentioned supporting measures, which were viewed from four perspectives, namely: policy, legal system, institutions and operations. This is for the purpose of establishing a complete and effective collaboration mechanisms, scientific-based decision-making, and effective public participation, which further guarantee the effectiveness of the regulatory scheme.

Conceptual Framework

Life cycle assessment of electricity generation from power plants can be done to conduct energy efficiency analysis and environmental impact assessment which can used in 20-year Thailand Power Development Plan (PDP) 2018. This can support the objectives of the PDP 2018 to support green technologies for electricity generation, increase the share of renewable energy use in the country, and reduce importation of fossil fuels. This can also be used to formulate and introduce policies and regulations for the power plant sector to follow the laws and regulations on emission control standards (of the Natural Resources and Environmental Policy and Planning Office); such as those for particulate matter (PM 2.5), sulfur dioxides, and nitrogen oxides, thereby reducing emissions from the power plant sector.

The methodology used for the assessment of energy and exergy efficiency of thermal power plants can be used by the ERC to regulate power plants sector for them to meet the standards, reduce their emissions, and mitigate their adverse environments impacts.

Environmental issues are important to people living around power plant project areas. People are concerned with the environmental effects of power plant operations such as air pollution, wastewater discharges, and health impacts like respiratory disease, and dermatitis.

Therefore, this study aims to design a regulatory framework methodology for monitoring and control of energy efficiency and greenhouse gas (GHG) emissions from thermal power plants. This can guide the government sector in developing power plants under PDP 2018.

CHAPTER III

RESEARCH METHOD

To design the long-term regulation of the e energy efficiency and greenhouse gas (GHG) emission from small power producer thermal power plants with apply, Methodological tool baseline; project and/or leakage emissions from electricity consumption and monitoring of electricity generation version 03.0 and firstly law of thermodynamic theory (assessment energy efficiency of thermal power plants) For the design of regulations for energy efficiency, this research use the application of the first law of thermodynamics in the assessment of energy efficiency of thermal power plants. For regulations on emissions from SPP thermal power plants, this research applied the CDM methodological tool (Version 03.0) for the assessment of baseline emissions and for monitoring project and/or leakage emissions in electricity consumption. The research method developed by this study is shown on Figure 3 below.

Research Methodology

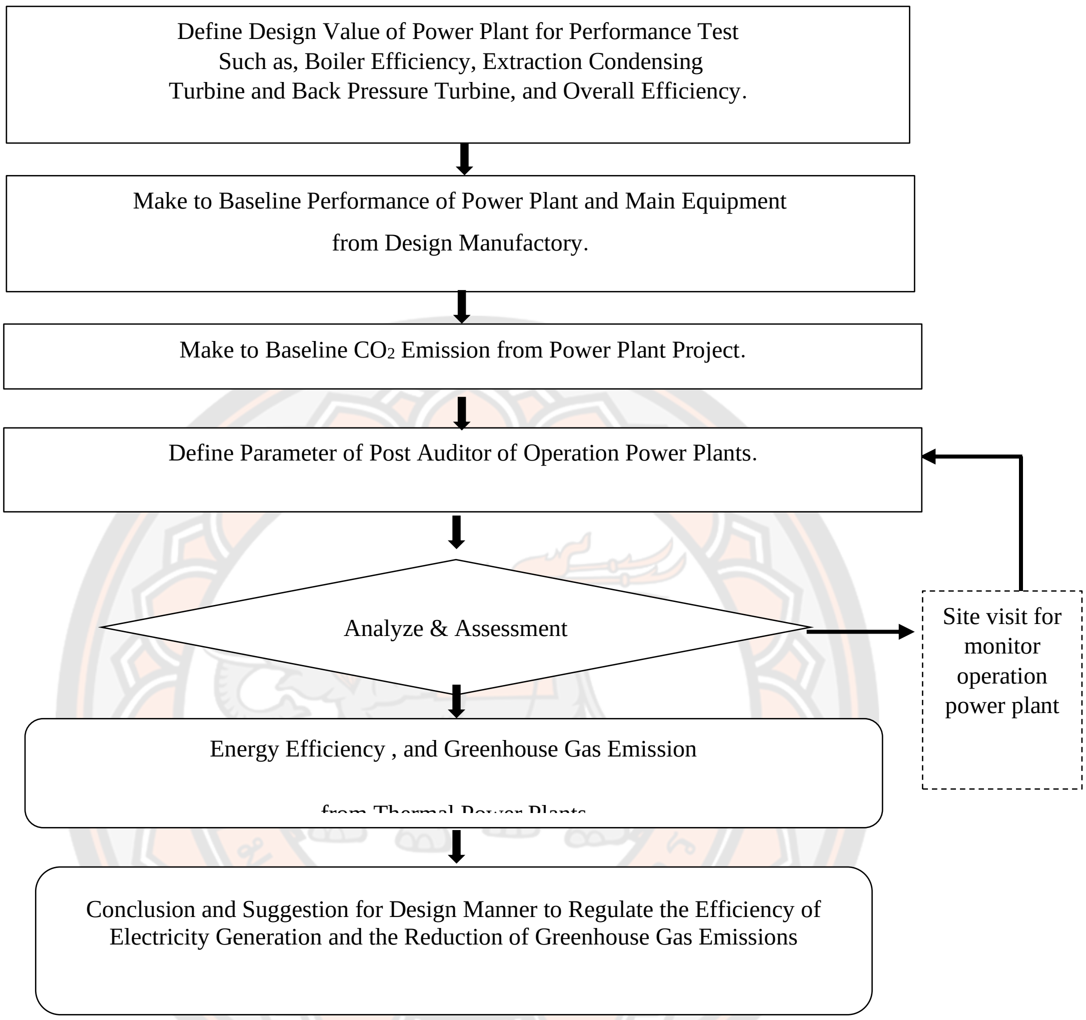


Figure 3 Research Methodology

Monitor and Regulate the Performance and CO_2 Emission of Thermal Power Plant

Thermal power plants such as steam power plants, combined-cycle thermal power plants and gas turbines, which are fossil-fueled power plants, are the major source for generating electricity in the world today. About 98% of CO_2 emissions that results to global warming come from the operation of these fossil-fueled thermal power plants. Increasing the energy efficiency of thermal power plants not only improve and reduce the cost of operations; it also results to less negative environmental impacts by lowering CO_2 emissions, and avoiding local air pollution (such as smoke and particulate matters). Several countries have existing policies, laws and regulations to encourage and monitor how thermal power plants implement energy efficiency programs (see Table 9).

Table 9 Monitor Performance and CO_2 Emission of Thermal Power Plants

Ministry of Resource Planning and Environment in Malaysia (24)	Department of Energy & Climate Change in United Kingdom (25, 26)	Energy Regulatory Commission in Thailand (2)
This monitor the performance apply guideline ISO 14001 certified coal power plants operation in Malaysia base on data current operational and environment which include • The plants operation records; log sheet for maintenance works; manufacturer information; environmental database as its environmental monitor reports. • Environmental Parameters to monitor include air quality (TSP: Total Suspended Particulate, Particulate Matter to 10 μm: PM_{10}, Nitrogen Oxides: NO_2 and Sulfur Oxides: SO_2) with compare emissions standard base on technology to electricity generation in the county. • Performance Parameters to monitor which base on the operating performance consist; Thermal Efficiency, Equivalent Availability Factor (EAF); Equivalent Unplanned Outage Factor (EUOF), and Equivalent Planned Unplanned	Department of Energy, & Climate Change define guide to monitor emission and performance of thermal power plants (Combine Heat and Power or Co-generation) for development data and best practice to operation power plants. Therefore, regulation emission from operation power plants installation capacity more than 50 MW, and not more than 50 MW. • CO_2/kWh, • SO_2/kWh, • NOx, • PM, type of fuel using and technology to combustion in boiler and electricity generation. Besides, Department of Energy, & Climate Change introduce guide of parameter to monitor performance of operation Combine Heat and Power or Co-generation and development data to work shop and knowledge management to operation and maintenance power plants, with parameter to monitor include;	

Ministry of Resource Planning and Environment in Malaysia (24)	Department of Energy & Climate Change in United Kingdom (25, 26)	Energy Regulatory Commission in Thailand (2)
Outage Factor (EUOF) were identified performance parameter accordance with performance standards developed by the Institute of Electrical and Electronics Engineers (IEEE) To further improve the emission of air pollution, the power plants may consider to adopt of available clean coal technology program and improvement on the plants operational performance to reduce concentration of air pollutants. In addition, the government focus on institutional power with tax incentives to support Improvement low performance of plants on long term financial, and introduce of energy efficiency standard focused on improving efficiency of thermal power plants and complement this effort.	• Heat and power output. • Fuel consumption. • Water consumption • Ambient air conditions • Gas pressure and temperature • Exhaust and cooling system condition • Exhaust gas constituents • Site energy and utility consumption • Electricity import and export metering • Prediction of site energy load patterns. In the further, Department of Energy, & Climate Change to support electricity companies installation automatic measurement tool record data operation or Supervisory Control and Data Acquisition System: SCADA for monitor and record parameter operation power plants.	ERC to define mechanisms to monitor performance operation and pollution of thermal power plants license include electricity generation license, electricity distribution system license, and electricity distribution license wherewith base on environmental protection, stability and reliability to electricity supply, and service standard. This plants operation records; log book operation monthly, manufacturer information design, environmental reports, and CEM_s: Continuous emission monitoring. • Electricity generation license follow CoP monitor, EIA monitor, condition of license, and stability and reliability to electricity supply (include GWEAF: Generating Weighted Equivalent Availability Factor)

Ministry of Resource Planning and Environment in Malaysia (24)	Department of Energy & Climate Change in United Kingdom (25, 26)	Energy Regulatory Commission in Thailand (2)
		• Electricity distribution system license follow service standard of law such as SAIFI: System Average Interruption Frequency Index, and SAIDI: System Average Interruption Duration Index. • Electricity distribution license follow service standard and service mind of law such as electricity bill, repair electricity problems, and one stop service. This organizational structure organizational structure for monitoring the operations of thermal power plants is focused on protecting the environment and saving natural resources. Thus, the researcher see a need to reform the monitoring system to also support the assessment of energy efficiency of the operation of the power plants.

Authority of Government Office to Monitor Operation Thermal Power Plants in Thailand

Today, new thermal power plant projects operated by the private sector need to follow the environmental and industrial laws implemented by three government agencies namely; ERC, the Department of Industrial Works (DIW) and the Office of Natural Resources and Environmental Policy and Planning (ONEP).

For example, a 10MW biomass power project proposal will need to submit reports to these three government offices to obtain license for project implementation, including an EIA (Environmental Impact Assessment) Report. The process for obtaining the license to implement the power project proposal, and the monitoring of the power plant project, following the required environmental laws are shown in Figures 4 and 5 below.

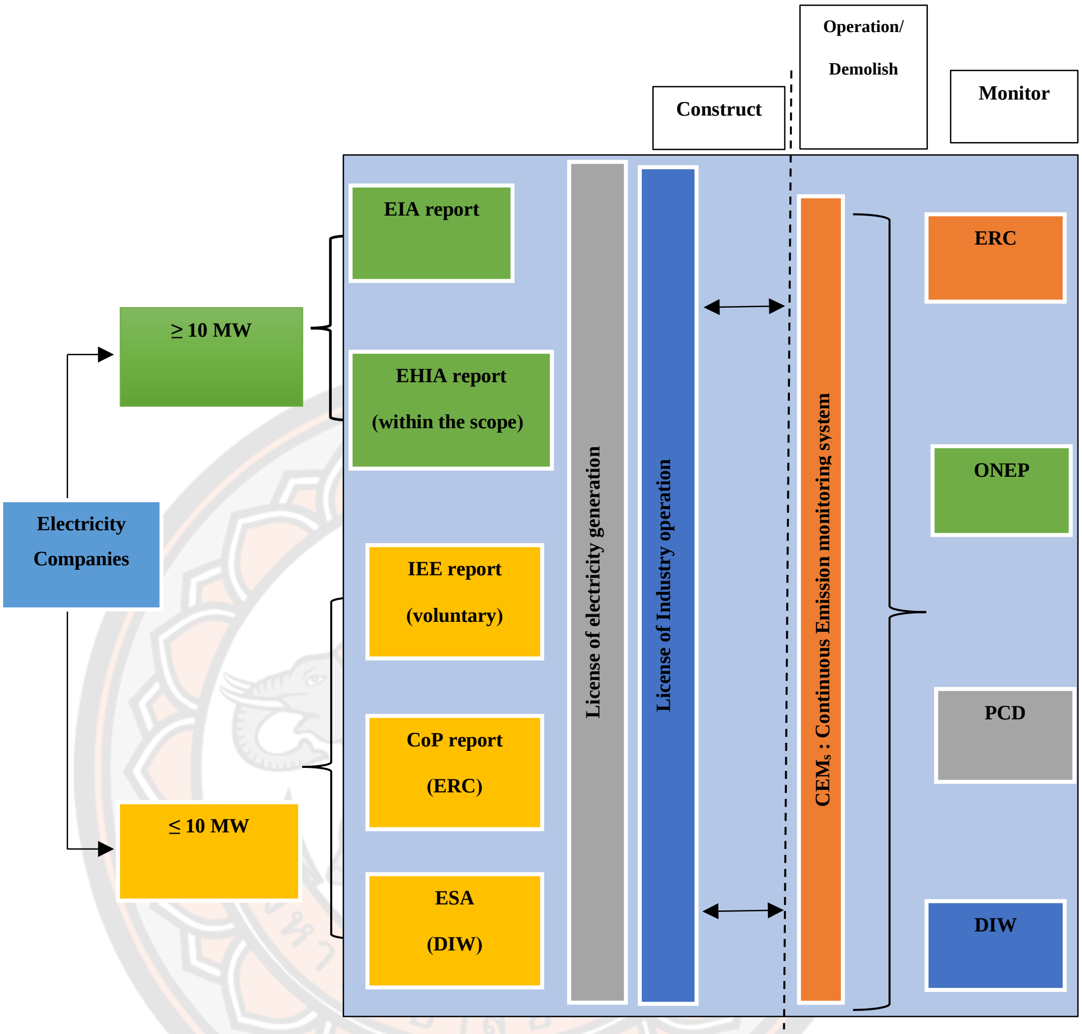


Figure 4 Government Monitoring System for Power Plant Start-up and Operation (2)

Figure 4 above and Figure 5 below show the organizational structure and mandates of the three government agencies previously mentioned; ERC, DIW and ONEP; and how they collaborate and integrate their work to assure that power plants meet the emission control standards and adhere to environmental laws. These laws and regulations to monitor and control operations of and pollution from thermal power plants include

1. EIA,
2. CoP (Code of Practice),
3. ESA (Environmental and Safety Assessment),
4. "License of Electricity Generation" (for power plant capacities of 1 to 10 MW), and
5. "License of Industry Works" (for power plant capacities 5 to 10MW).

The EIA, ESA and CoP reports define provisions for the protection of the environment, the reduction of environmental impacts, and to ensure safety conditions during the whole project cycle (i.e.; preparation, implementation, operation and demolition). Such provisions include:

1. air pollution control system,
2. the wastewater treatment system,
3. waste plan management,
4. location of project, transport system around power plant area
5. water balance of the power plant project,
6. test reports on chemical composition of fuel, air quality, underground water quality,
7. heat balance of the power plant project

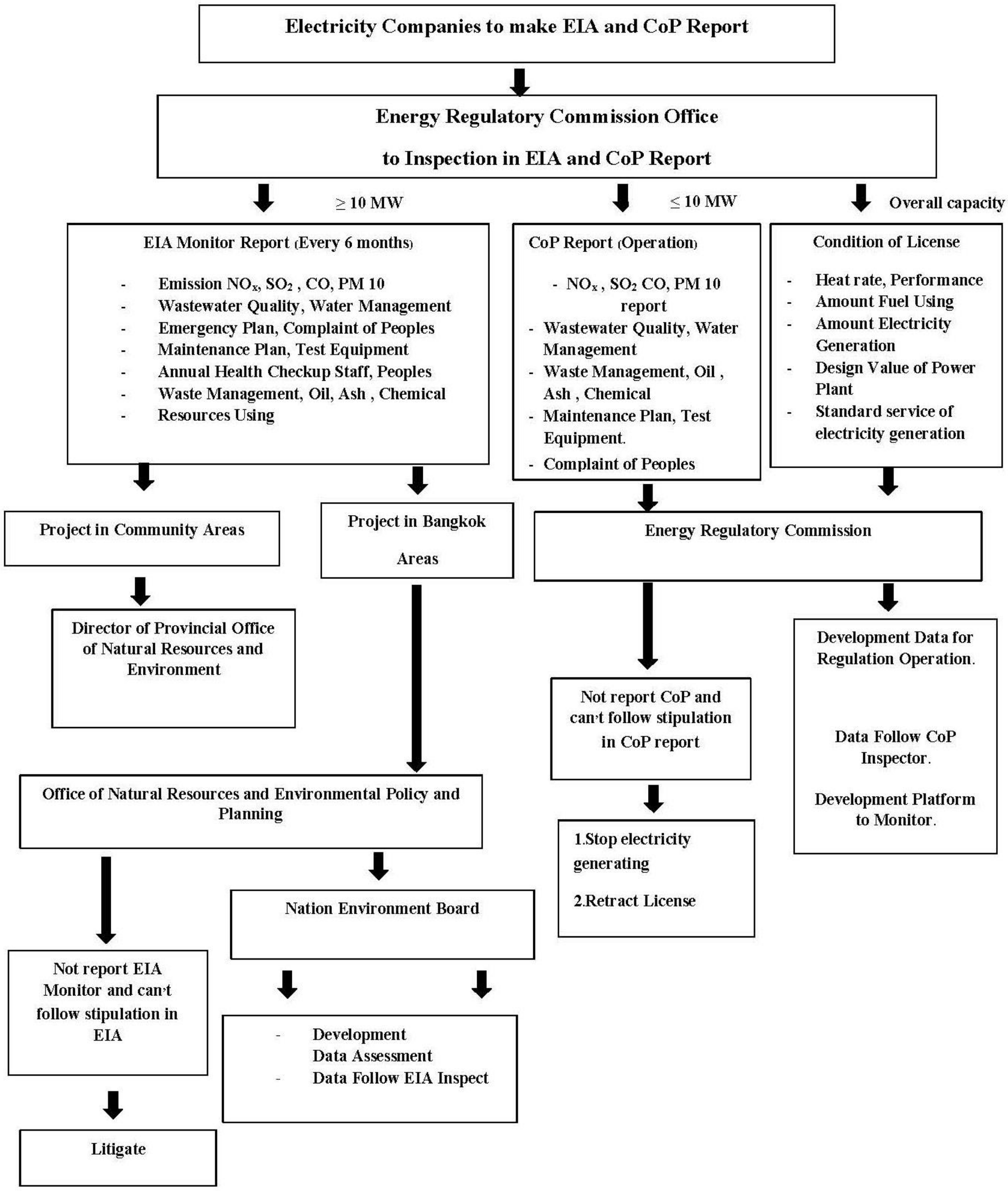


Figure 5 Process to Monitor Operation Thermal Power Plants (6)

The government offices – ERC, DIW, & ONEP – define the laws and regulations for enforcing the regular submission of reports such as the EIA), CoP (every six months) and the "Condition of License Report" (every year). Monitoring and enforcement are done by inspectors from the offices. If a company can not submit the reports on time, the company can be stopped from generating electricity, its license retracted or the company is litigated

Survey Data Operation of Thermal Power Plants

The existing thermal power plants (Extraction Condensing and Back Pressure Turbine Technology) covered by the case study include;

1. 50 MW (bagasse fuel),
2. 22 MW (rice husk fuel),
3. 24 MW (coal fuel), and
4. 27 MW (natural gas),

with the cases study aiming to determine the parameters to use and method to apply to monitor performance and CO_2 emissions from these thermal power plants.

Solid fuels (like coal and biomass) from a storage yard are continuously transferred to a storage yard from which the fuel is brought by a belt conveyor to the furnace chamber of a boiler. The fuel is burned in the chamber and the resulting thermal energy is used to boil water to generate steam. The steam goes to the extraction condensing turbine and the back pressure turbine, which both drive the generator to generate electricity. The steam, which has passed through the back pressure turbine is supplied for process heating in the factory. The condensates from both turbines are collected and transported by a boiler feed pump back to be used as feed water for the boiler to regenerate steam. Meanwhile, the cooling water used for condensing steam, passes through a cooling tower, which transfer the heat into the atmosphere. The cooling water is reused. This cooling water system is a closed-circuit system. The heat balance of this process is shown on Figure 5. The data on the operation of the normal load thermal power plant are shown on Tables 9 to- 26. The and methods used to assess the overall performance of the power plant, and estimate its CO_2 emissions are shown on Figures 6 to-10.

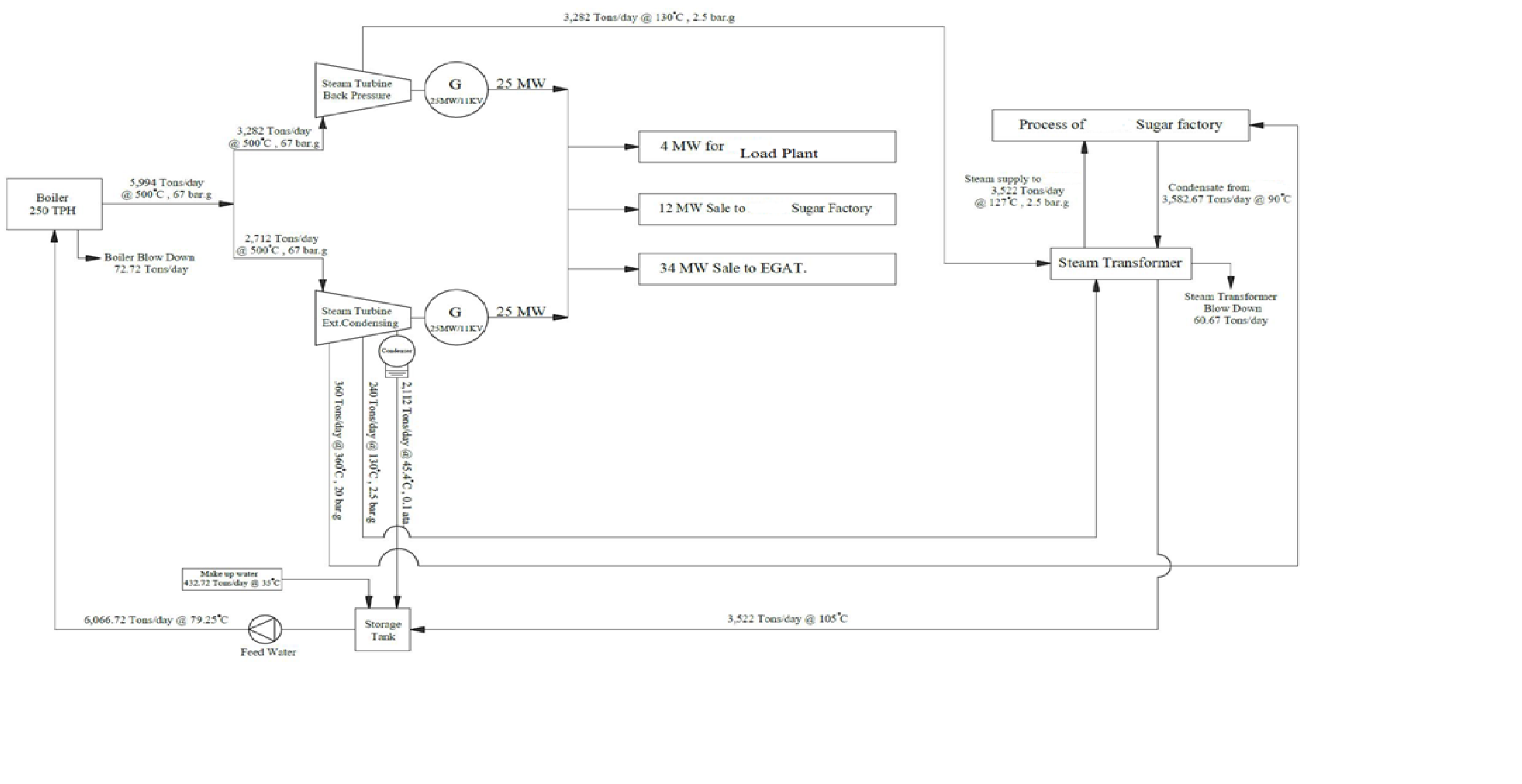


Figure 6 Process Diagram and Heat Balance of Bagasse Fuel (27)

Table 10 Assessment Overall Performance and CO_2 Emission of Bagasse Fuel Power Plant

1. Equation Boiler Efficiency	$$\eta_{boiler} = \frac{\dot{m}_s(h_s - h_f)}{\dot{m}_f x\ HHV}$$		
Description	**Parameter**	**Unit**	**Data**
High heating value of fuel	HHV	kJ/kg	6,447.67
Mass steam flow rate	$\dot{m}_s$	tons/hr	218
Mass fuel feed	$\dot{m}_f$	ton/hr	121
Enthalpy of steam generation	h_s	kJ/kg	3,379.7
Enthalpy of water feed	h_f	kJ/kg	1,159.8
Boiler Efficiency	η_{boiler}	**%**	**<u>62.02</u>**
2. Equation Steam-Generator Efficiency	$$\eta_{Steam-Generator} = \frac{\text{Electricity Power Output}}{\text{Energy Input to Steam Turbine}}$$		
Description	**Parameter**	**Unit**	**Data**
	Block # 1		
Energy Input to Steam Turbine	E_{in}	kW	19,862.2
Electricity Power Output	E_{out}	kW	18,869.1
Steam-Generator Efficiency	$\eta_{Steam-Generator}$		**<u>95</u>**

Block # 2			
Energy Input to Steam Turbine	E_{in}	kW	19,862.2
Electricity Power Output	E_{out}	kW	18,300.0
Steam-Generator Efficiency	$\boldsymbol{\eta_{Steam-Generator}}$	**%**	**<u>92.13</u>**
3. Equation Isentropic Turbine Efficiency	$\eta_{Ext\ or\ Bp} = \frac{\text{Energy actual}}{\text{Energy ideal}}$		
Extraction Condensing Turbine			
Description	**Parameter**	**Unit**	**Data**
Energy actual	E_{actual}	kW	21,180.2
Energy ideal	E_{ideal}	kW	24,944.8
Isentropic Turbine Efficiency	$\boldsymbol{\eta_{Ext}}$	**%**	**<u>84.90</u>**
Back Pressure Turbine			
Description	**Parameter**	**Unit**	**Data**
Energy actual	E_{actual}	kW	20,942.8
Energy ideal	E_{ideal}	kW	26,360.8
Isentropic Turbine Efficiency	$\boldsymbol{\eta_{BP}}$	**%**	**<u>79.44</u>**
4. Equation Overall Performance Power Plant	$\eta_{th} = \eta_{boiler} x\, \eta_{Isentropic\ efficiency} x \eta_{generator}$		
Description	**Parameter**	**Unit**	**Data**
Block # 1			
Boiler Efficiency	η_{boiler}	%	62.02

Steam -Generator Efficiency	$\eta_{Steam-Generator}$	%	95
Extraction Condensing Turbine	η_{Ext}	%	84.9
Overall Performance Power Plant	$\boldsymbol{\eta_{th}}$	**%**	**50.02**
Block # 2			
Boiler Efficiency	η_{boiler}	%	62.02
Steam -Generator Efficiency	$\eta_{Steam-Generator}$	%	92.13
Back Pressure Turbine	η_{BP}	%	79.44
Overall Performance Power Plant	$\boldsymbol{\eta_{th}}$	**%**	**45.39**
5.Equation CO_2 Emission from Electricity Generation	Annual CH_4 released = HHVof b*iomass* used by project x CH_4 emission factor for bagasse x GWP of CH_4		
Description	**Parameter**	**Unit**	**Data**
Total Fuel Using	$m_{total\ fuel}$	Ton/year	23,243.68
HHV of biomass used by project	HHV	TJ	149.85
emission factor for biomass	CH_4 factor	tCH_4/TJ	0.03
Global warming potential of CH_4	GWP of CH_4	tCO_{2e}/tCH_4	21
Total Electricity Generation	$E_{generation}$	kWh/year	46,657,150,000
CO_2 Emission from Project	CO_2 Emission	tCO_{2e}/year	94.40
CO_2 Emission per Unit Generation Electricity	**CO_2 Emission**	gCO_{2e}/kWh	**2.02**

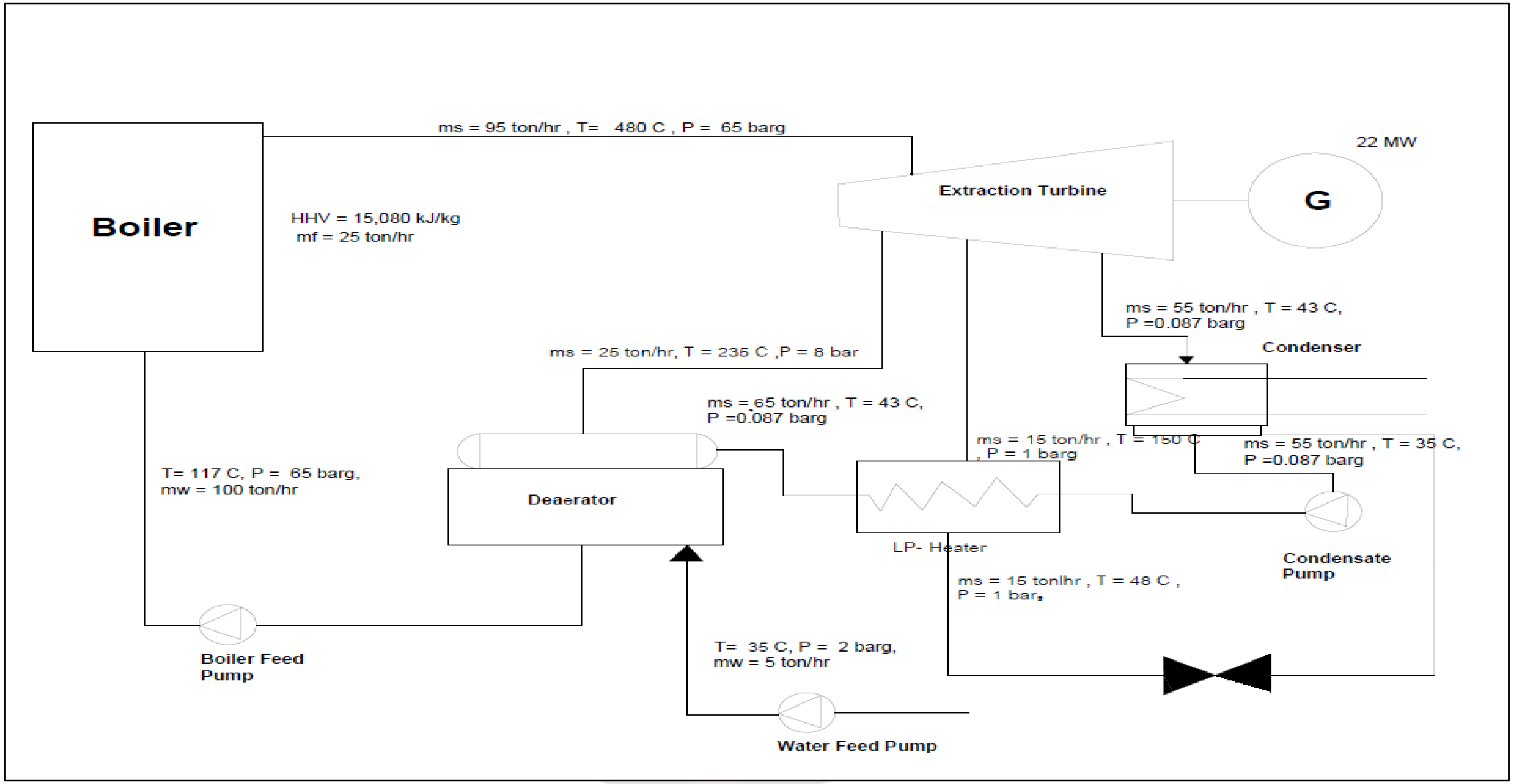


Figure 7 Process Diagram and Heat Balance of Rice Husk Fuel (28)

Table 11 Assessment Overall Performance and CO_2 Emission of Rice Husk Fuel Power Plant

1. Equation Boiler Efficiency	$\eta_{boiler} = \frac{\dot{m}_s(h_s - h_f)}{\dot{m}_f \times HHV}$		
Description	**Parameter**	**Unit**	**Data**
High heating value of fuel	HHV	kJ/kg	15,080
Mass steam flow rate	$\dot{m}_s$	tons/hr	95
Mass fuel feed	$\dot{m}_f$	ton/hr	25
Enthalpy of steam generation	h_s	kJ/kg	3,360
Enthalpy of water feed	h_f	kJ/kg	729.50
Boiler Efficiency	η_{boiler}	**%**	**66.28**
2. Equation Steam - Generator Efficiency	$\eta_{Steam-Generator} = \frac{\text{Electricity Power Output}}{\text{Energy Input to Steam Turbine}}$		
Description	**Parameter**	**Unit**	**Data**
Heat Input to Steam Turbine	E_{input}	kW	18,581.7
Electricity Power Output	E_{out}	kW	17,709.10
Steam-Generator Efficiency	$\eta_{Steam-Generator}$	**%**	**95.30**
3. Equation Isentropic Turbine Efficiency	$\eta_{Isentropic\ efficiency} = \frac{\text{Energy actual}}{\text{Energy ideal}}$		

Description	Parameter	Unit	Data
Extraction Condensing Turbine			
Energy actual	E_{actual}	kW	17,709.1
Energy ideal	E_{ideal}	kW	20,717.1
Isentropic Turbine Efficiency	$\boldsymbol{\eta_{Ext}}$	**%**	**<u>85.48</u>**
4. Equation Overall Performance Power Plant	$\eta_{th} = \eta_{boiler} x\ \eta_{Isentropic\ efficiency} x \eta_{generator}$		
Description	**Parameter**	**Unit**	**Data**
Boiler Efficiency	η_{boiler}	%	66.28
Generator Efficiency	$\eta_{Generator}$	%	95.30
Isentropic Turbine Efficiency	$\eta_{Isentropic\ efficiency}$	%	85.48
Overall Performance Power Plant	$\boldsymbol{\eta_{th}}$	**%**	**<u>53.99</u>**
5. Equation CO_2 Emission from Electricity Generation	Annual CH_4 released = HHVof b*iomass* used by project x CH_4 emission factor for bagasse x GWP of CH_4		
Description	**Parameter**	**Unit**	**Data**
Total Fuel Using	$m_{total\ fuel}$	Ton/year	144,632
HHV of biomass used by project	HHV	TJ	2,181.05
CH_4 emission factor for biomass	CH_4 factor	tCH_4/TJ	0.03
Global warming potential of CH_4	GWP of CH_4	tCO_{2e}/tCH_4	21
Total Electricity Generation	$E_{generation}$	kWh/year	147,056,366.40
CO_2 Emission from Project	CO_2 Emission	tCO_{2e}/year	1,374.34
CO_2 Emission per Unit Generation Electricity	CO_2 Emission	gCO_{2e}/kWh	**<u>9.34</u>**

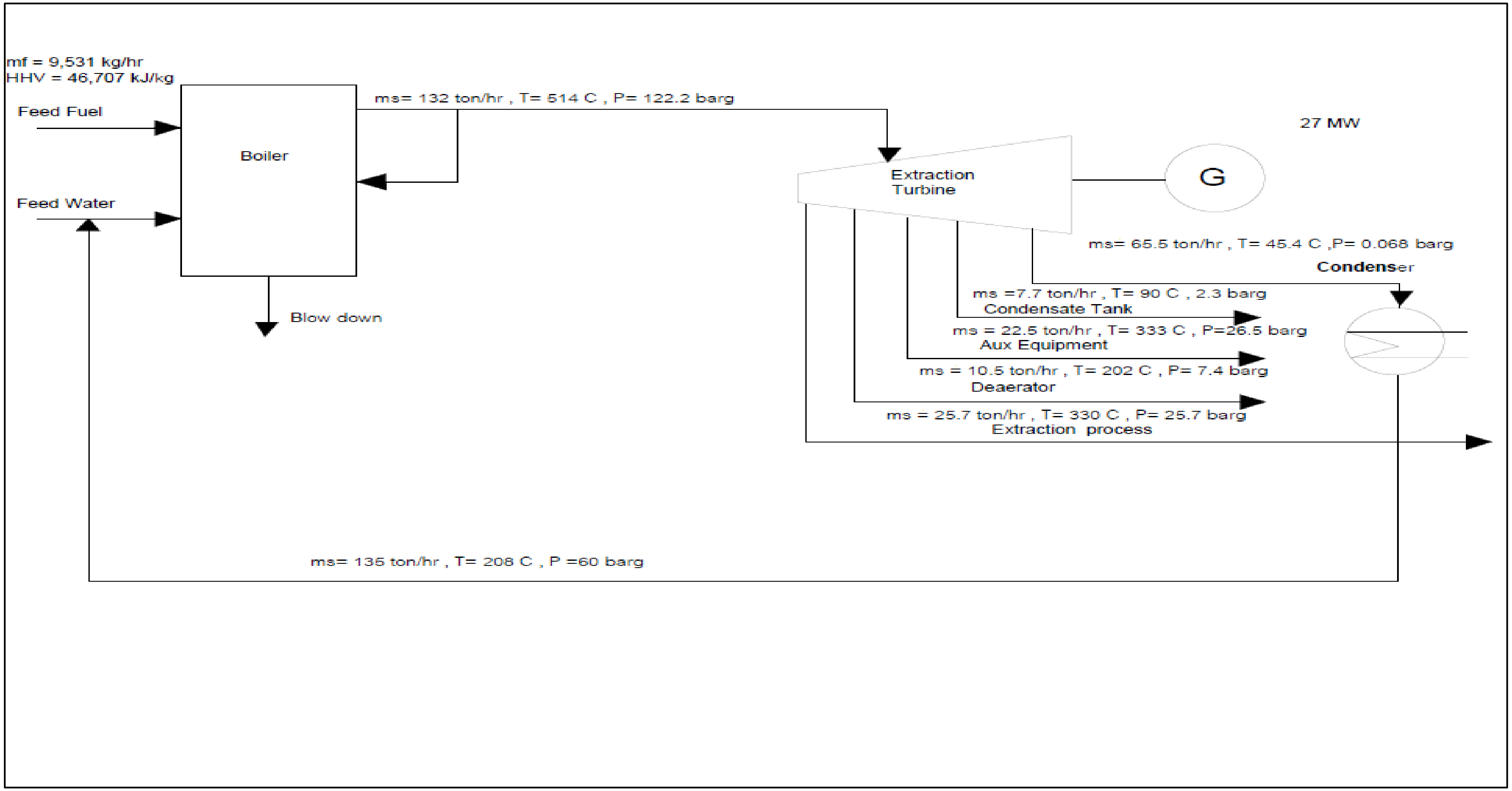


Figure 8 Process Diagram and Heat Balance of Natural Gas Fuel (29)

Table 12 Assessment Overall Performance and CO_2 Emission of Natural Gas Power Plant

1. Equation Boiler Efficiency	$\eta_{boiler} = \frac{\dot{m}_s(h_s - h_f)}{\dot{m}_f x\ HHV}$		
Description	**Parameter**	**Unit**	**Data**
High heating value of fuel	HHV	kJ/kg	46,707
Mass steam flow rate	$\dot{m}_s$	tons/hr	132,000
Mass fuel feed	$\dot{m}_f$	ton/hr	9,531
Enthalpy of steam generation	h_s	kJ/kg	3,395.50
Enthalpy of water feed	h_f	kJ/kg	892.5
Boiler Efficiency	$\boldsymbol{\eta_{boiler}}$	**%**	**<u>66.60</u>**
2. Equation Steam - Generator Efficiency	$\eta_{Steam-Generator} = \frac{\text{Electricity Power Output}}{\text{Energy Input to Steam Turbine}}$		
Description	**Parameter**	**Unit**	**Data**
Energy Input to Steam Turbine	E_{input}	kW	27,000
Electricity Power Output	E_{out}	kW	26,200
Steam-Generator Efficiency	$\boldsymbol{\eta_{Steam-Generator}}$	**%**	**<u>97</u>**
3. Equation Isentropic Turbine Efficiency	$\eta_{Isentropic\ efficiency} = \frac{\text{Energy actual}}{\text{Energy ideal}}$		

Description	Parameter	Unit	Data
Extraction Condensing Turbine			
Energy actual	E_{actual}	kW	21,420.80
Energy ideal	E_{ideal}	kW	26,934.70
Isentropic Turbine Efficiency	$\boldsymbol{\eta_{Ext}}$	**%**	**79.53**
4. Equation Overall Performance Power Plant	$\eta_{th} = \eta_{boiler} x\ \eta_{Isentropic\ efficiency} x \eta_{generator}$		
Description	**Parameter**	**Unit**	**Data**
Boiler Efficiency	η_{boiler}	%	66.60
Generator Efficiency	$\eta_{Generator}$	%	97
Isentropic Turbine Efficiency	$\eta_{Isentropic\ efficiency}$	%	79.53
Overall Performance Power Plant	$\boldsymbol{\eta_{th}}$	**%**	**50.93**
5. Equation Heat Rate to Generation Electricity		$\textbf{Heat Rate} = \frac{\mathbf{F}}{\mathbf{E}}$	
Description	**Parameter**	**Unit**	**Data**
Heat Input to Generation Electricity	F	kJ/h	445,164,417.00
Amount of Electricity Generation	E	kW	26,200
Heat Rate to Using Electricity Generation	**Heat Rate**	kJ/kWh	**16,991.01**
6. Equation CO_2 Emission from Electricity Generation	CO_2 Emission = Fuel Consumption x Emission Factor		
Description	**Parameter**	**Unit**	**Data**
Total Amount of Fuel Combustion	Fuel Consumption	TJ/year	3,630.21
Emission Factor of Natural Gas	Emission Factor	tCO_2/TJ	17.20
CO_2 Emission from Project	CO_2 Emission	$tCO_2/year$	62,439.55
CO_2 Emission per Unit Generation Electricity	**CO_2 Emission**	gCO_2/kWh	**291.99**

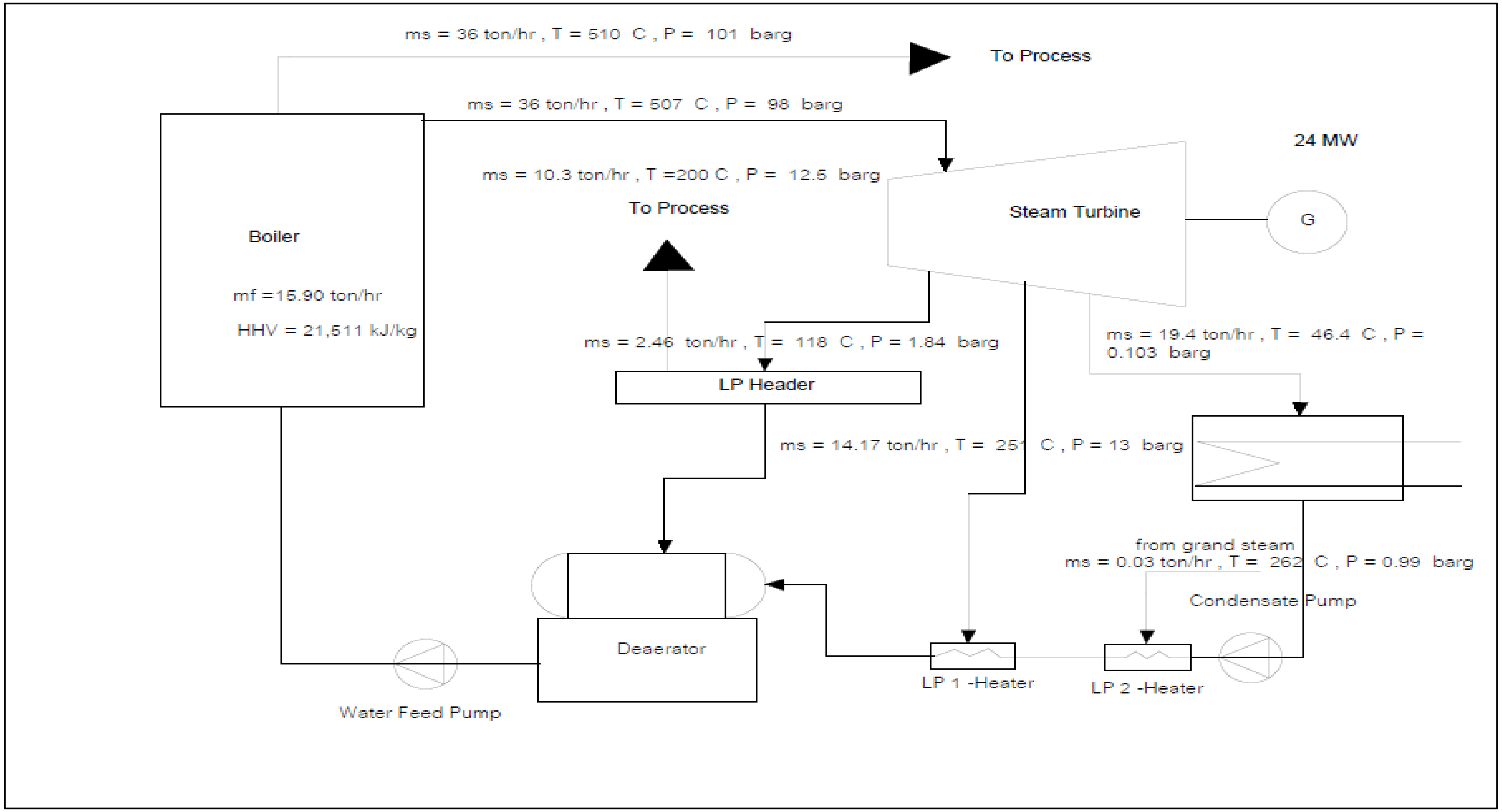


Figure 9 Process Diagram and Heat Balance of Coal Fuel (30)

Table 13 Assessment Overall Performance and CO_2 Emission of Coal Power Plant

1. Equation Boiler Efficiency	$\eta_{boiler} = \frac{\dot{m}_s(h_s - h_f)}{\dot{m}_f x\ HHV}$		
Description	**Parameter**	**Unit**	**Data**
High heating value of fuel	HHV	kJ/kg	21,511.78
Mass steam flow rate	$\dot{m}_s$	tons/hr	130,000
Mass fuel feed	$\dot{m}_f$	ton/hr	19.50
Enthalpy of steam generation	h_s	kJ/kg	3394.3
Enthalpy of water feed	h_f	kJ/kg	719.3
Boiler Efficiency	η_{boiler}	**%**	**<u>82.90</u>**
2. Equation Steam - Generator Efficiency	$\eta_{Steam-Generator} = \frac{\text{Electricity Power Output}}{\text{Energy Input to Steam Turbine}}$		
Description	**Parameter**	**Unit**	**Data**
Energy Input to Steam Turbine	E_{input}	kW	29,030.5
Electricity Power Output	E_{out}	kW	23,0000
Steam-Generator Efficiency	$\eta_{Steam-Generator}$	**%**	**<u>79.22</u>**
3. Equation Isentropic Turbine Efficiency	$\eta_{Isentropic\ efficiency} = \frac{\text{Energy actual}}{\text{Energy ideal}}$		

Description	Parameter	Unit	Data
Extraction Condensing Turbine			
Energy actual	E_{actual}	kW	6,750.50
Energy ideal	E_{ideal}	kW	7,910.2
Isentropic Turbine Efficiency	$\boldsymbol{\eta_{Ext}}$	**%**	**85.34**
4. Equation Overall Performance Power Plant	$\eta_{th} = \eta_{boiler} x\ \eta_{Isentropic\ efficiency} x \eta_{generator}$		
Description	**Parameter**	**Unit**	**Data**
Boiler Efficiency	η_{boiler}	%	82.90
Generator Efficiency	$\eta_{Generator}$	%	79.22
Isentropic Turbine Efficiency	$\eta_{Isentropic\ efficiency}$	%	85.34
Overall Performance Power Plant	$\boldsymbol{\eta_{th}}$	**%**	**56.05**
5. Equation Heat Rate to Generation Electricity		$\textbf{Heat Rate} = \frac{\mathbf{F}}{\mathbf{E}}$	
Description	**Parameter**	**Unit**	**Data**
Heat Input to Generation Electricity	F	kJ	419,479,710.00
Amount of Electricity Generation	E	kWh	23,000
Heat Rate to Using Electricity Generation	**Heat Rate**	kJ/kWh	**19,500.00**
6. Equation CO_2 Emission from Electricity Generation	CO_2 Emission = Fuel Consumption x Emission Factor		
Description	**Parameter**	**Unit**	**Data**
Total Amount of Fuel Combustion	Fuel Consumption	TJ/year	3,524.07
Emission Factor of Coal	Emission Factor	tCO_2/TJ	26.20
CO_2 Emission from Project	CO_2 Emission	tCO_2/year	92,330.72
CO_2 Emission per Unit Generation Electricity	**CO_2 Emission**	gCO_2/kWh	**477.84**

Method to Assessment Overall Energy Efficiency of Thermal Power Plant

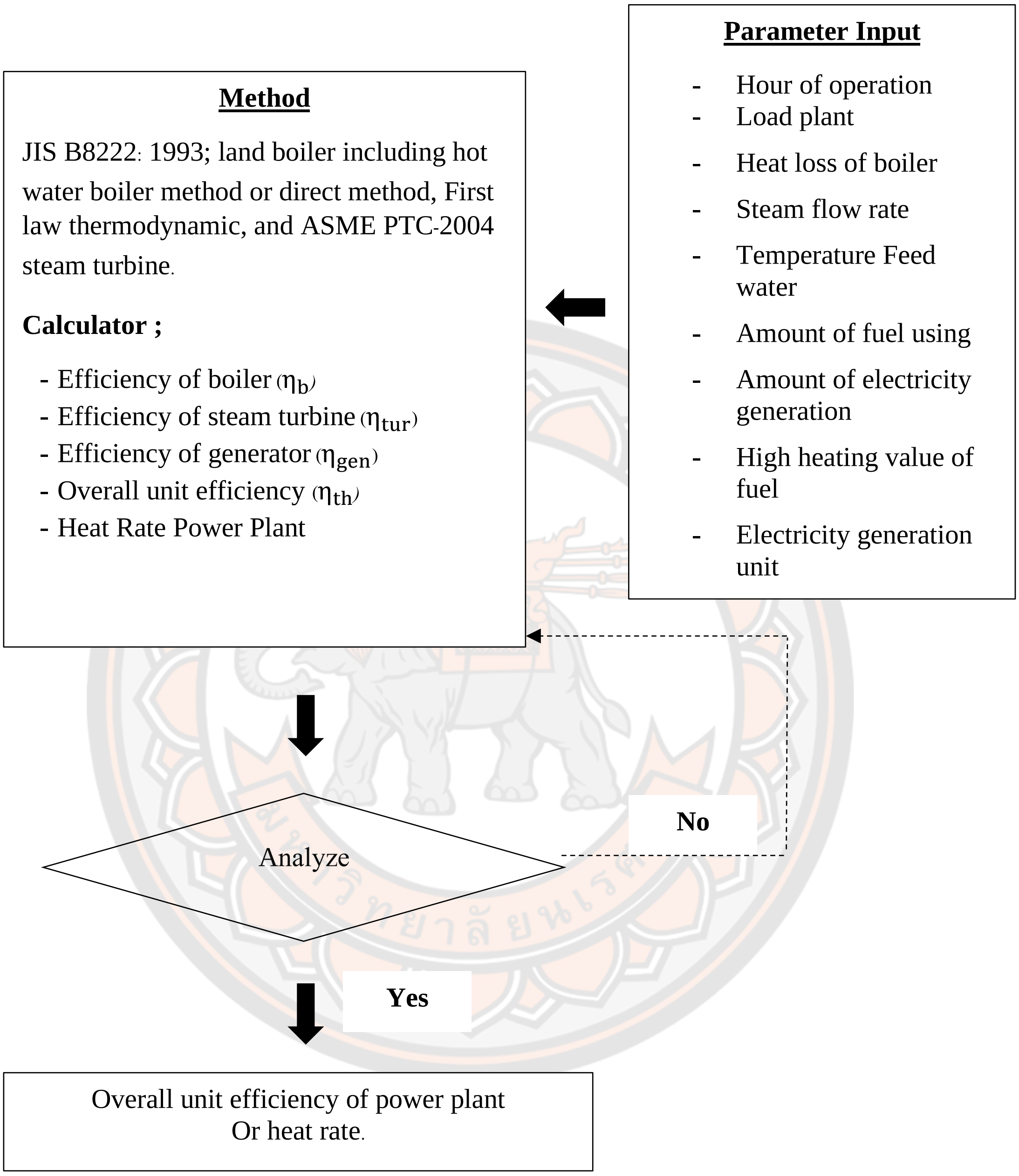


Figure 10 Process of Determine Overall Unit Efficiency or Heat Rate of Thermal Power Plant

Method to Assessment of Boiler Efficiency

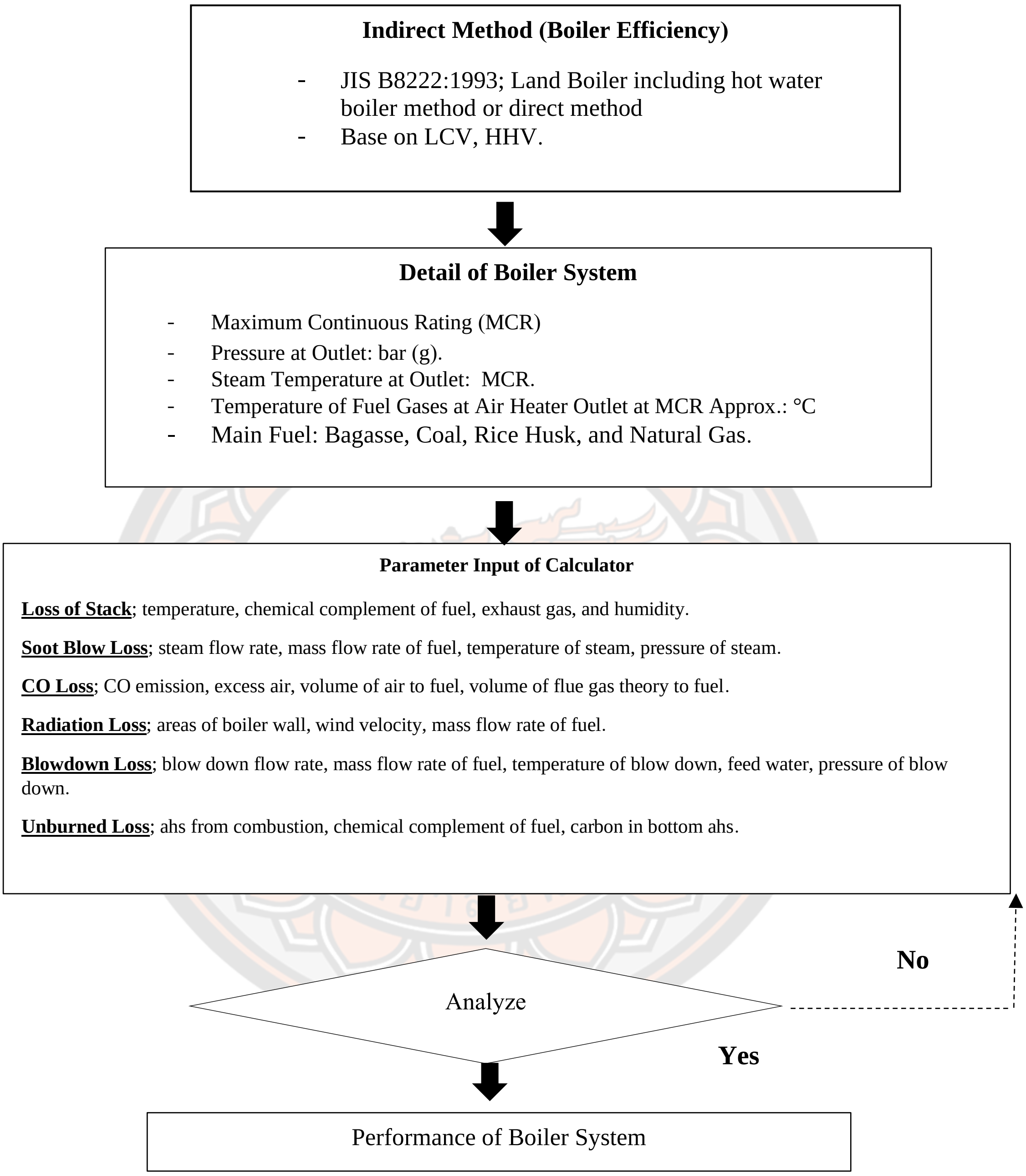


Figure 11 Process Determine Performance of Boiler System

Method to Assessment Performance Steam Turbine

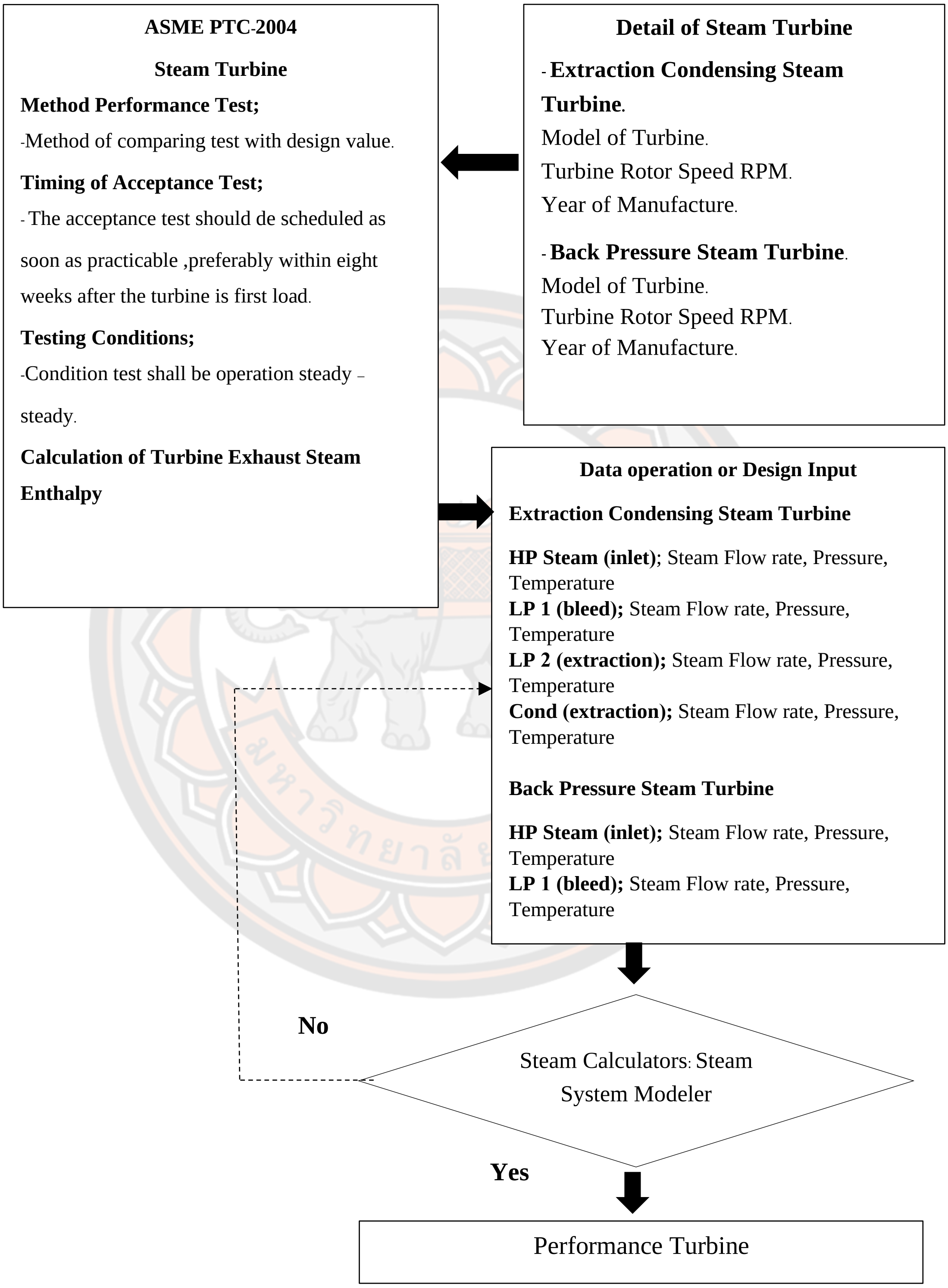


Figure 12 Process of Determine Performance Turbine

Method to Assessment Heat loss of Surface Boiler, and Steam Piping

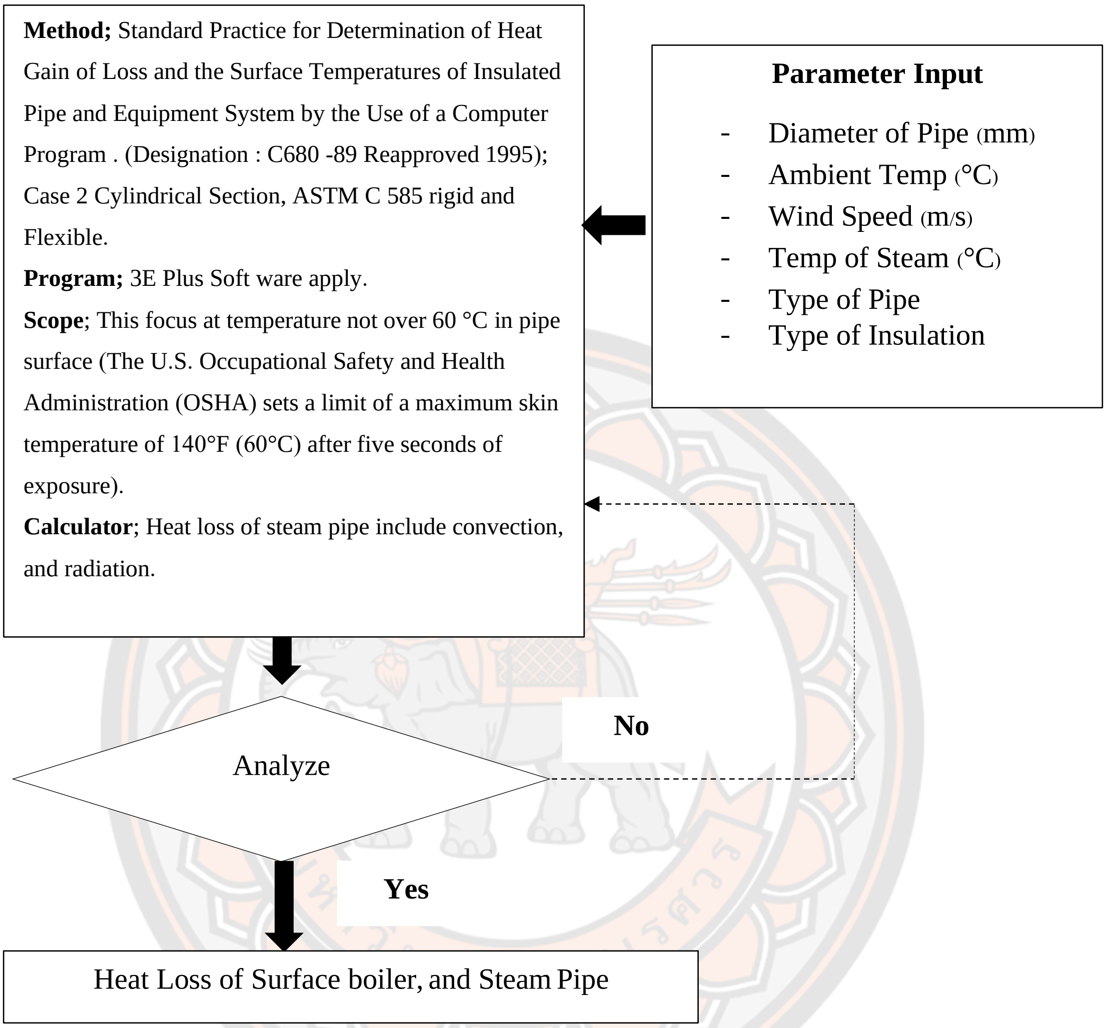


Figure 13 Process of Determine Heat Loss Steam Pipe and Surface Boiler

Method to Assessment CO_2 Emission of Thermal Power Plant

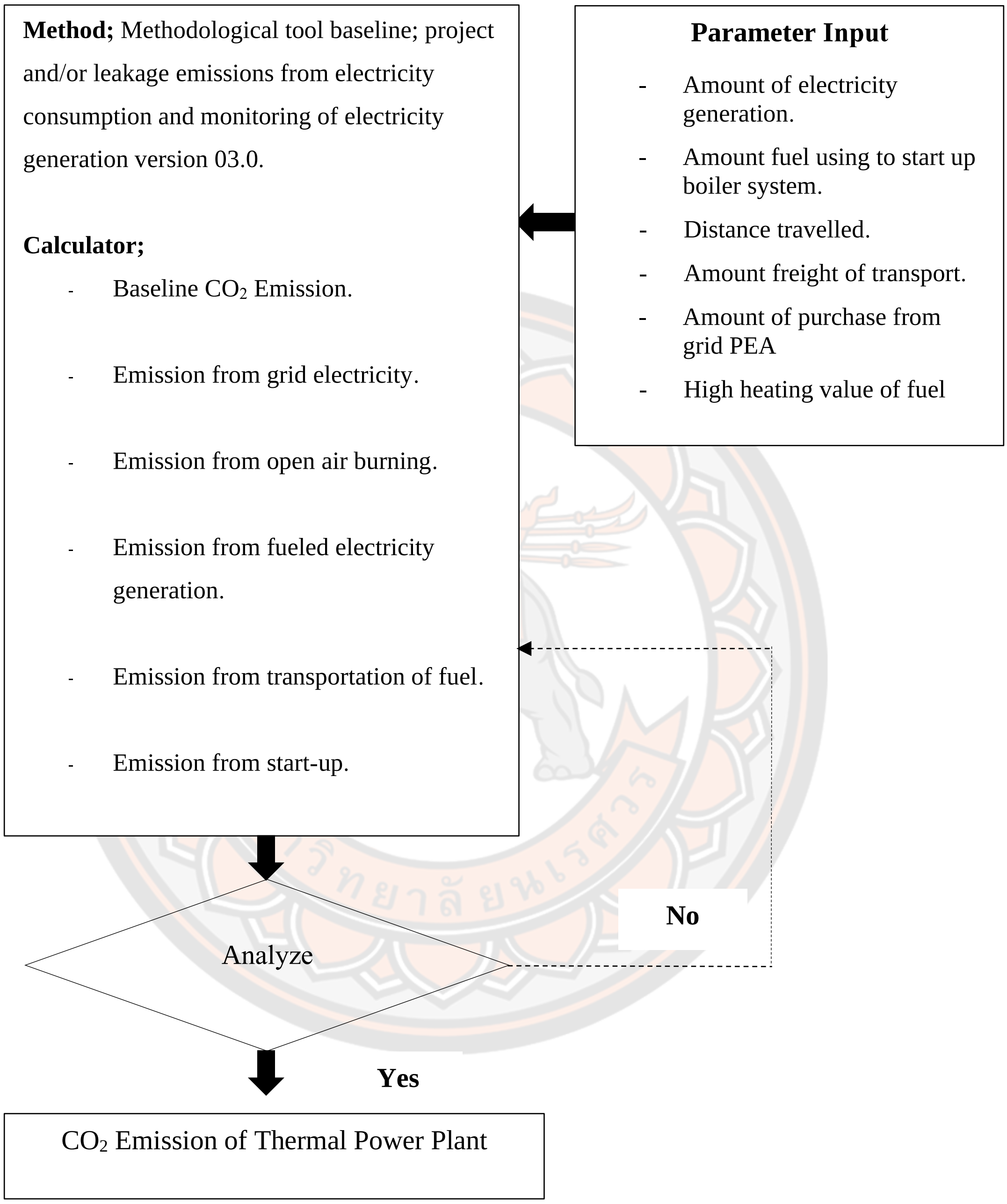


Figure 14 Process of Determine CO_2 Emission of Thermal Power Plant

Site Visit for Assessment Energy Efficiency and CO_2 Emission of Thermal Power Plant Installation Capacity 50 MW

A site visit was conducted to monitor the efficiency and conduct a post audit of a 50-MW biomass cogeneration plant, and to compare the test values with the design value during an 8-hour operation (7.00 AM – 4.00 PM). A normal load test (with boiler steam generation of 218 ton/hr, main steam temperature of 485 °C, pressure of main steam at 69 bar, and temperature of furnace 828 °C). The electricity generation capacity is 43.50 MW of which 25 MW is supplied to EGAT, 4 MW the load of the plant, and 16 MW supplied to the factory. The steam generation of the back pressure turbine supplied for process heating in the sugarcane factory is about 39.37 ton/hr at temperature 136 °C. The extraction condensing turbine sent to the condenser system about 63.7 ton/hr at temperature 132 °C. The condensate water is returned to the storage tank for feed water to boiler system. Table 6 shows the data records for the average values. The duration of the test for the exhaust flue gas location inlet air preheater and outlet air preheater to determine the combustion efficiency of the boiler system was 2 hour with data recorded every 10 minutes. Samples of the bagasse fuel was sent to a laboratory (King Mongkut's University of Technology-Thonburi laboratory) to determine the chemical composition of the bagasse fuel by conducting a proximate analysis, an ultimate analysis, and a determination of its high heating value (based on the American Society for Testing Materials or ASTM, 1997).

As a result, the monitor energy efficiency biomass cogeneration power plant installation 50 MW can in conclusion as following;

1. **Boiler System Testing**.

The testing applied the JIS B8222: 1993 methodology: “Land Boiler including hot water boiler” method with a testing time duration of: 2 hours (for solid fuel). The results of the boiler efficiency tests are shown on Tables 14 to 22.

Table 14 Detail Test of Boiler System

Data test	February 21, 2020
Test duration	8 hours (7.00 A.M.-4.00 P.M.)
Ambient Temperature & %RH	34 °C, 70 %RH
Boiler capacity	• Steam generation 250 ton/hr • Pressure 68 bar, 500 °C • FW 105 °C
Load factor	• 87.2% @average • Steam flow rate 218 ton/hr • Pressure 65 bar, 485 °C
Fuel	• Bagasse @ 56 % moisture • HHV 6,447.67 kJ/kg
Excess air ration	• 2.55 @ Exhaust gas (O_2 11.85%)
Exhaust gas	• Fuel Temp., 130.8 °C • Oxygen in Flue Gas, 11.85 % • CO in Flue Gas, 1,805 ppm • No_x in Fuel Gas, 85 ppm • SO_2 in Fuel Gas, 23 ppm

Table 15 Result of Performance Boiler System

Description	Parameter	Unit	Data	Note
$\eta_{indirect} = (1 - \frac{L_{stack} + L_{soot\ blow} + L_{CO\ loss} + L_{radiation\ loss} + L_{blow\ down\ loss} + L_{unburned\ loss} + L_{Steam\ pipe\ loss}}{HHV + HG})$				
High Heating Value	HHV	kJ/kg	**6,447.67**	Result Test form Lab
Stack Gas Loss	L_1	kJ/kg	**2,262.06**	Calculator
Carbon Loss	L_2	kJ/kg	**82.20**	Calculator
Soot Blown Loss	L_3	kJ/kg	**-**	Calculator
Unburned Loss	L_4	kJ/kg	**113.83**	Calculator
Radiation Loss	L_5	kJ/kg	**32.38**	Calculator
Blow Down Loss	L_6	kJ/kg	**28.24**	Calculator
Main Steam Pipe Loss	L_7	kJ/kg	**0.83**	Calculator
Another of Heat Input	HG	kJ/kg	**-**	Calculator
Performance of Boiler	$\eta_{indirect}$	*%*	**60.92**	**Calculator**

Table 16 Parameter of Calculation Stack Gas Loss (L_1)

Description	Parameter	Unit	Data
	$L_1 = G \times C_g x(t_g - t_o)$ $L_{1h} = L_1 + 25(9h + \omega)$		
Temperature of flue gas	t_g	°C	**131.65**
Temperature of surrounding	t_o	°C	**43.95**
Specific heat capacity in flue gas	C_g	kJ/kg °C	**1.38**
Flue gas of mass flow rate	G	m^3/kg	**5.59**
Hydrogen	h	%	**1.862**
Moisture in fuel	ω	%	**56**
Stack Gas Loss	L_1	**kJ/kg**	**2,262.06**

Table 17 Parameter of Calculator Carbon Loss (L_2)

Description	Parameter	Unit	Data
$L_2 = 126.1(G_o + (m-1)\ A_o)CO$			
Amount of theoretical flue gas	G_o	m^3/kg	**1.74**
Amount of theoretical of air	A_o	m^3/kg	**1.82**
Ration of excess air	m	%	**2.54**
Carbon in flue gas	CO	%	**0.14**
Carbon Loss	L_2	**kJ/kg**	**82.20**

Table 18 Parameter for Calculator and Result Unburned Loss (L_4)

Description	Parameter	Unit	Data
$L_4 = 339xC_2$			
Ahs in fuel	a	%	**6.887**
Carbon surplus in ahs	u	%	**4.54**
Ratio carbon surplus and carbon in fuel	C_2	%	**0.335**
Unburned loss	L_4	**kJ/kg**	**113.83**

Table 19 Parameter for Calculator Radiation Loss (L_5)

Location	Areas of surface wall m^2	Variable insulation Thickness	Average temp. of surface wall (°C)	Average wind speed (m/s)	$Q_{total\ losses}$ (W/m^2)
$L_5 = \frac{3,600 \text{ x } Q_w}{\dot{m}_f}$					
Top Side	192	Bare	121	3.6	**1,231.00**
Front Side	348	Bare	90.75	3.6	**740.20**
Left Side	192	Bare	110.25	3.6	**1,048.00**
Right Side	192	Bare	97	3.6	**835.80**
Black Side	348	Bare	86	3.6	**669.50**
Total heat loss wall of boiler ; kW					**1,088.62**
Amount fuel using; ton/hr					**121**
Radiation loss; L_5					**32.38**

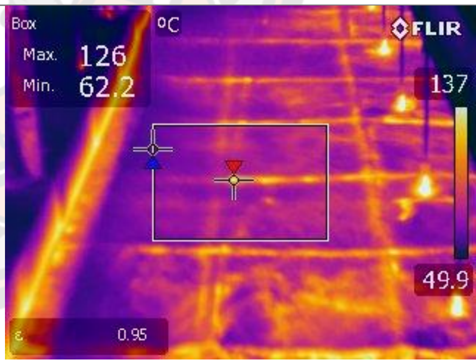
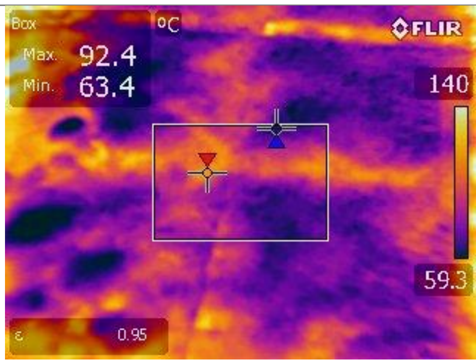
Table 20 Parameter for Calculator Blow Down Loss (L_6)

Description	Parameter	Unit	Data
$$L_6 = \dot{m}_{bd}\frac{(h_{bd} - h_{FW})}{\dot{m}_f}$$			
Flow rate of blowdown	$\dot{m}_{bd}$	kg/hr	**3,409**
Enthalpy of blowdown rate	h_{bd}	kJ/kg	**1,485.10**
Enthalpy of feed water	h_{FW}	kJ/kg	**482.6**
Amount fuel using	$\dot{m}_f$	kg/hr	**121,000**
Blow down loss	L_6	kJ/kg	**28.24**

Table 21 Parameter for Calculator Radiation Loss of Main Steam Pipe

Location	Type of Pipe	Type of Insulation	Temp. of Surface Of Pipe (°C)	NPS Pipe Size (mm)	Wind Speed (m/s)	$Q_{total\ losses}$ (W/m)
		$L_{main\ steam\ pipe} = \frac{3,600 \times Q_w}{\dot{m}_f}$				
Main Steam Stop Valve	Stainless Steel	Bare	302	25	3.6	**1.45**
Main Steam Pipe Line	Stainless Steel	Bare	417	150	3.6	**8.49**
Connecting pipe Steam inlet Extraction Condensing Turbine	Stainless Steel	Bare	446	250	0	**6.27**
Main Steam inlet to Extraction Condensing Turbine	Stainless Steel	Bare	470	250	0	**7.06**
Main Steam inlet to Back Pressure Turbine	Stainless Steel	Bare	94	250	0	**0.311**
Connecting pipe Steam inlet Back Pressure Turbine	Stainless Steel	Bare	333	250	0	**4.36**
Total heat loss surface of steam pipe ; kW						**27.95**
Amount fuel using ; ton/hr						**121**
Radiation loss ; $L_{main\ steam\ pipe}$						**0.83**

Table 22 Thermal Scan Heat Radiation of Surface Wall and Steam Pipe

Location	Type of Equipment	Temp. of Surface °C
Main Steam Pipe Line	Steam Pipe	
Main Steam inlet to Extraction Condensing Turbine	Steam Pipe	
Top Side	Wall of Boiler	
Black Side	Wall of Boiler	

Result Experimental Data of Boiler System

The data from Table 5 were used to make a Sankey diagram to show the heat balance for the boiler system (see Figure 15). The heat input was 6,447.67 KJ/kg. The heat used for electricity generation was 3,928.13 kJ/kg. The heat losses were as follows:

1. Stack gas loss 2,262.06 kJ/kg or 35.08 %
2. Carbon loss 82.2 kJ/kg or 1.27 %
3. Unburn loss 113.83 kJ/kg or 1.77 %
4. Radiation loss 32.38 kJ/kg or 0.55 %
5. Blow down loss 28.24 kJ/kg or 0.44 %
6. Loss of steam pipe 0.83 kJ/kg or 0.01 %

The efficiency of the old biomass-fired boiler was 80% (on dry biomass basis), while that of the new biomass-fired boiler was 85%. Testing results was about 60.92% which was not in the range of boiler standards. The stack gas loss was more than in any other component of the boiler system and the burning operation did not have proper control of the proportion between the air and bagasse fuel resulting to gas loss, and loss from unburnt carbon in the furnace. The excess air for combustion, which should have been 3-5%, was probably more than this optimal amount. The fuel moisture content also affects the performance of the boiler, and the moisture of the bagasse may have been higher.

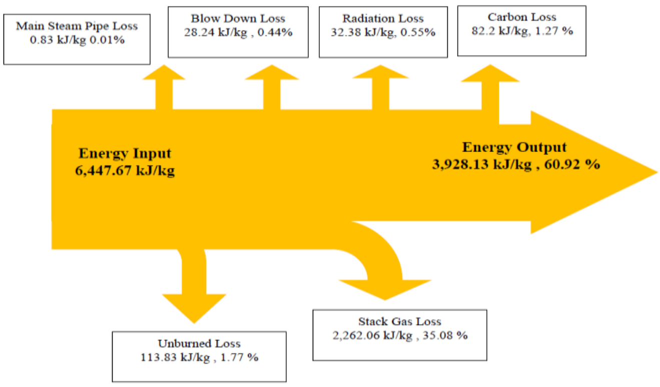


Figure 15 Sankey Diagram Heat Balance of Boiler System

2. **Steam Turbine Testing**.

   Black pressure steam turbine.

Table 23 Detail of Black Pressure Steam Turbine

Turbine type	Black Pressure
Data test	February 21, 2020
Test duration	8 hours (7.00 A.M.-4.00 P.M.)
Turbine capacity	• Steam flow rate 150 ton/hr • Pressure 65 bar , 480 °C
Turbine black	• Pressure 2.5 bar (a)
Load factor	• Normal load • Steam flow rate 122.5 ton/hr • Pressure 63 bar , 470 °C • 20.10 MW
Turbine generator	• 25 MW
Efficiency of turbine generator	• 95 %

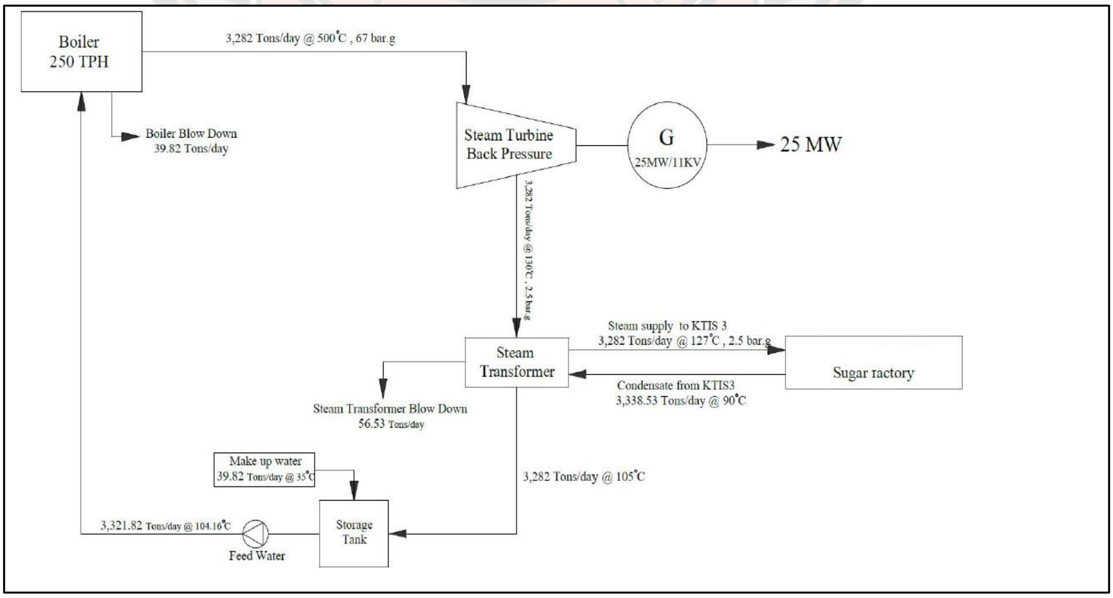


Figure 16 Diagram of Back Pressure Steam Turbine

Table 24 Parameter for Calculator Back Pressure Steam Turbine

Parameter	Unit	Data of Operation
	HP Steam	
Steam Consumption	tons/hr	**122**
Enthalpy of steam	kJ/kg	**3,361.4**
	Extraction 1: Exhaust	
Energy out	kW	**20,935.6**
Isentropic Efficiency	%	**79.4**
Generator Efficiency	%	**92.13**
Power out (Actual)	kW	**19,288.0**
Energy out (Ideal)	kW	**26,360.8**
Isentropic Efficiency	**%**	**79.4**
Gross power	**MW**	**19.29**
Steam rate	**ton-s/MWh**	**6.38**

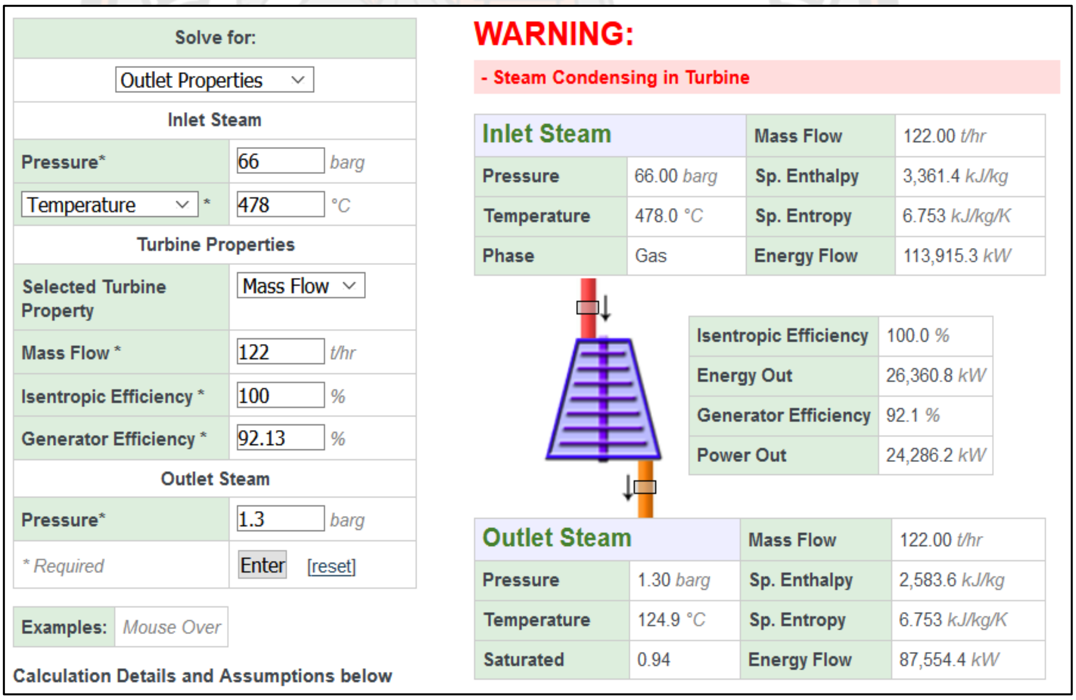


Figure 17 Calculator Isentropic Efficiency Back Pressure Steam Turbine

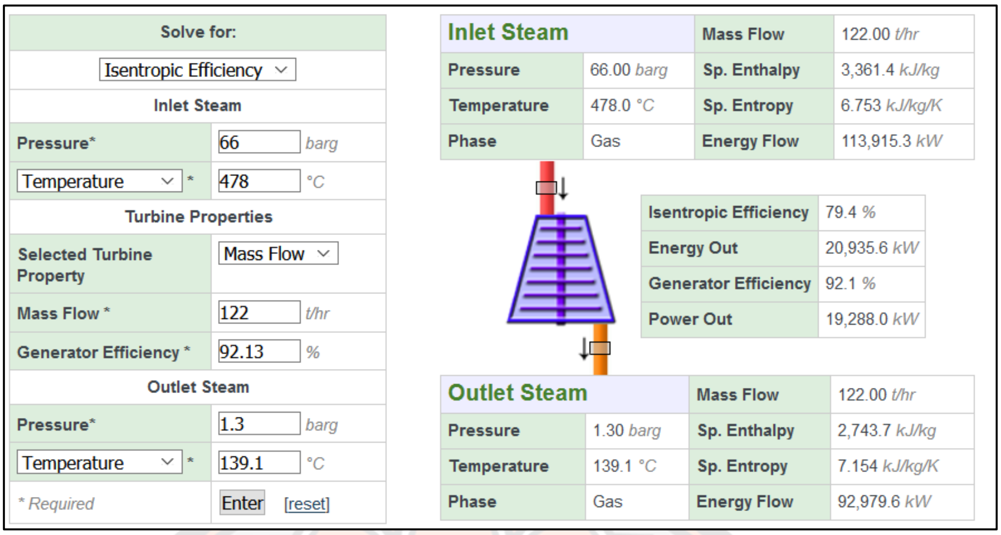


Figure 18 Calculator Actual Efficiency Back Pressure Steam Turbine

Extraction condensing steam turbine.

Table 25 Detail of Extraction Condensing Steam Turbine

Turbine type	Extraction condensing
Data test	February 21, 2020
Test duration	8 hours (7.00 A.M.-4.00 P.M.)
Turbine capacity	• Steam flow rate 150 ton/hr • Pressure 65 bar, 480 °C
Extraction 1	• Steam flow rate 55 ton/hr • Pressure 20 bar, 130 °C
Extraction 2	• Steam flow rate 55 ton/hr • Pressure 2.5 bar, 130 °C
Condensing	• Steam flow rate 45 ton/hr • Pressure 0.10 ata , 32 °C
Load factor	• Normal load • Steam flow rate 113 ton/hr • Pressure 65 bar, 480 °C • 25 MW
Turbine generator	• 25 MW
Efficiency of turbine generator	• 95 %

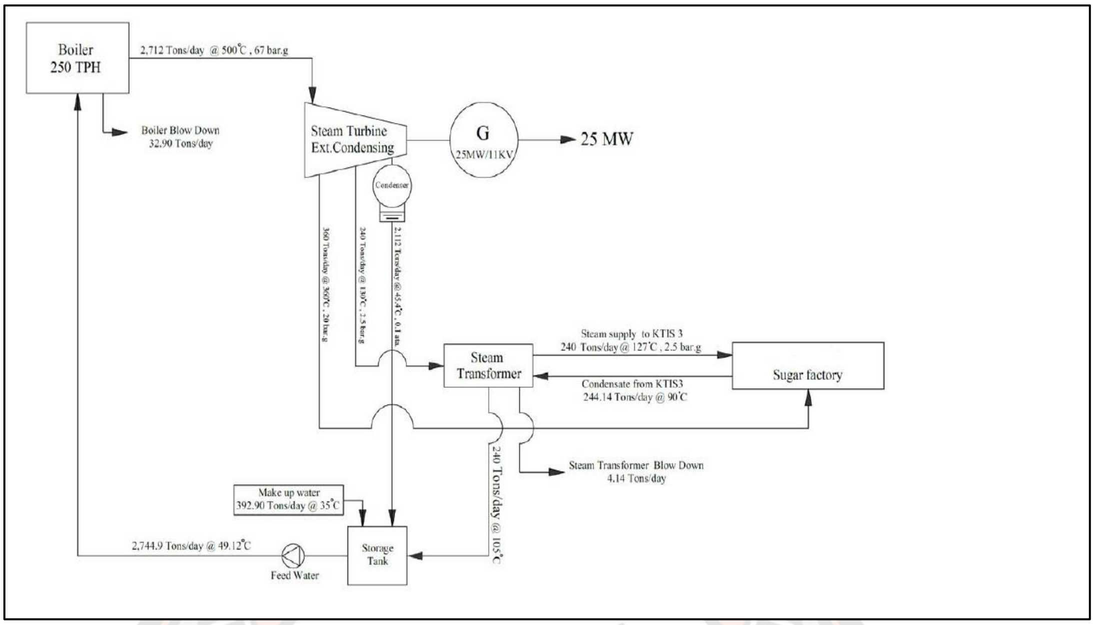


Figure 19 Diagram of Extraction Condensing Steam Turbine

Table 26 Parameter for Calculator Extraction Condensing Steam Turbine

Parameter	Unit	Data of Operation
HP Steam		
Steam Consumption	tons/hr	**113.2**
Enthalpy of steam	kJ/kg	**3,367.0**
	Extraction 1: LP	
Energy out	kW	0
Isentropic Efficiency	%	0
Generator Efficiency	%	0
Power out (Actual)	kW	0
Energy out (Ideal)	kW	0
	Extraction 2: LP	
Energy out	kW	0
Isentropic Efficiency	%	0
Generator Efficiency	%	0
Power out (Actual)	kW	0
Energy out (Ideal)	kW	0

Parameter	Unit	Data of Operation
	Exhaust Steam: Cond	
Energy out	kW	**21,180.2**
Isentropic Efficiency	%	**84.9**
Generator Efficiency	%	**95**
Power out (Actual)	kW	**20,121.2**
Energy out (Ideal)	kW	**24,944.8**
Isentropic Efficiency	**%**	**84.9**
Gross power	**MW**	**20.12**
Steam rate	**ton-s/MWh**	**5.62**

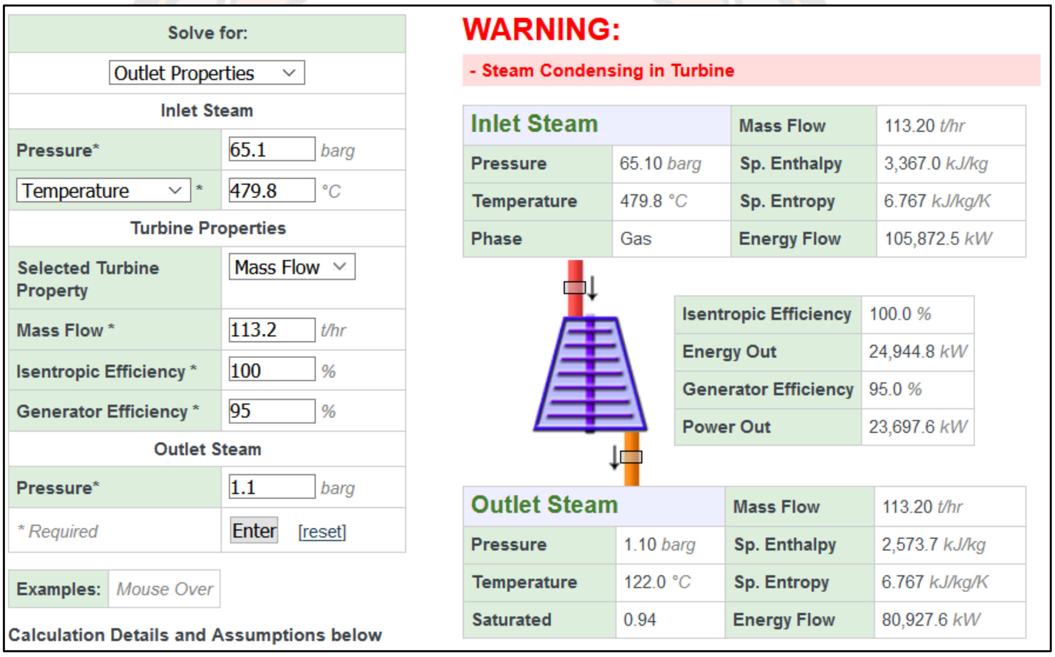


Figure 20 Calculator Isentropic Efficiency Extraction Condensing Steam Turbine

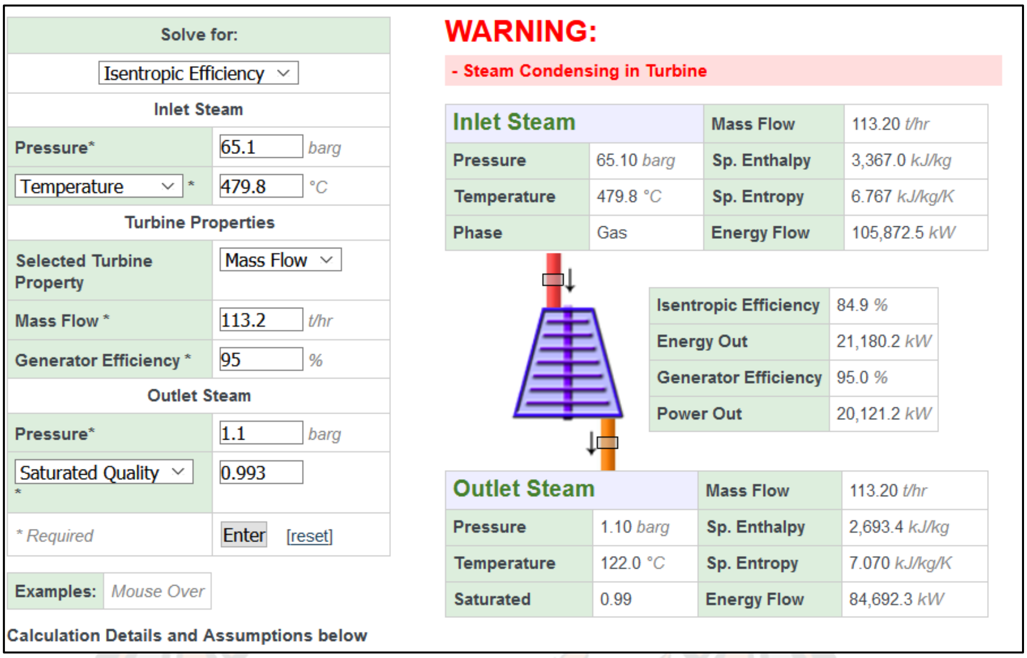


Figure 21 Calculator Actual Efficiency Extraction Condensing Steam Turbine

Result Experimental Data of Steam Turbine.

Assessments of the performance, using the “Steam System Modeler Tool” or SSMT, of the “back pressure steam turbine” and the “extraction condensing steam turbine” with data from a normal load operation of a power plant are shown of Figures 20 and 21. It shows the heat balance for the “extraction condensing steam turbine”, which supplied electricity via a 115 KV grid connection to the Electricity Generation Authority in Thailand (EGAT). The test performance for the “extraction condensing steam turbine” showed an efficiency of 84.9%, which was within the range or standard values. The energy input was 105.87 MW at an exhaust temperature of 132 °C of the turbine component, and an energy loss of 1.06 MW in the generator component. Therefore, the system generated 20.12 MW of electricity. The rejected heat from the condenser was used for heating in sugarcane processing and the feed.

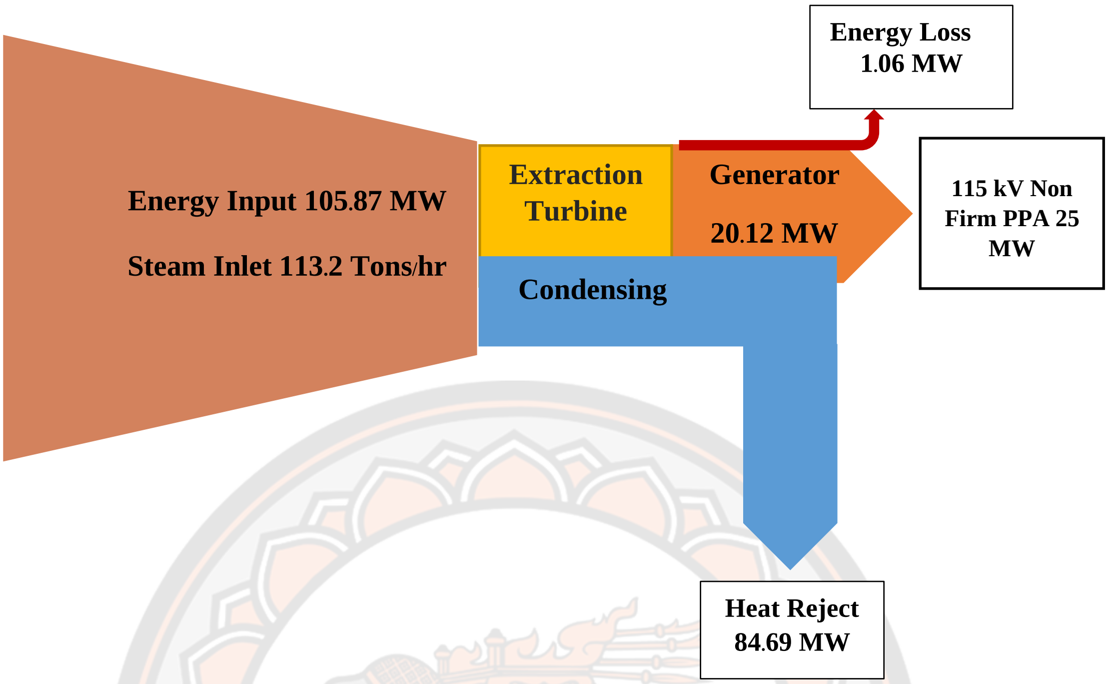


Figure 22 Sankey Diagram Heat Balance of Extraction Condensing Turbine

Another test was conducted for the back pressure steam engine with a normal load. Its net electricity generation was 19.28 MW, with 4 MW supplied to the grid by a 115 KV connection and 15.28 MW supplied to the sugarcane factory. The result showed a 79.4% efficiency. The Shankey diagram of the heat balance shows that input energy of the system was 109.89 MW, of which 92.97 MW was the energy of the process steam supplied to the sugarcane factory and 1.64 MW was the energy loss in the generator.

The back pressure steam turbine is mostly used for co-generation in the sugarcane industry as this can supply steam at temperature of about 139.1 °C and electricity of amounts between 14-16 MW.

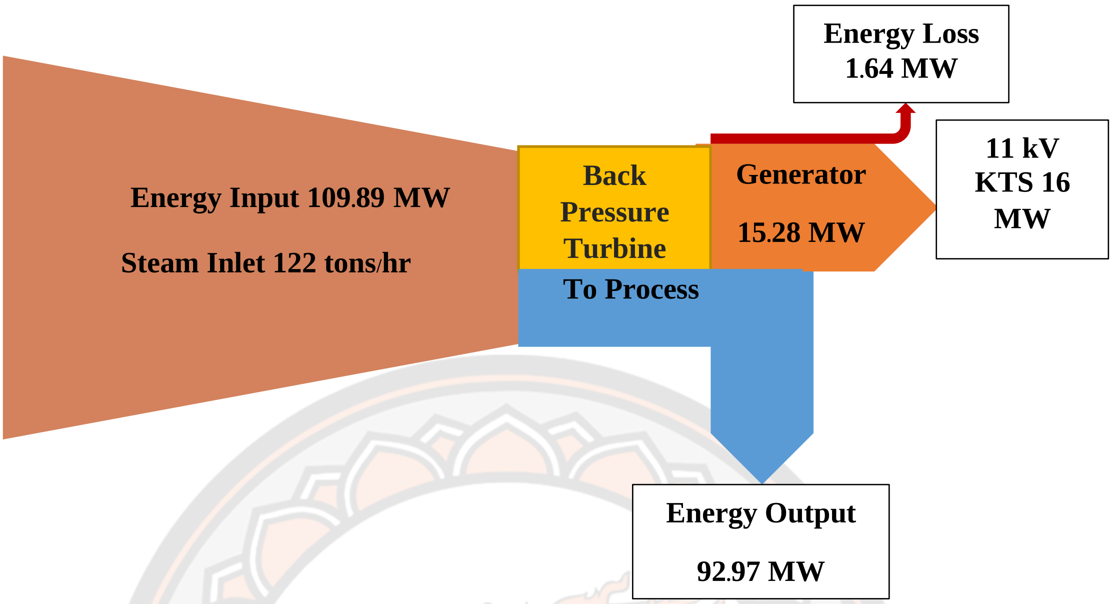


Figure 23 Sankey Diagram Heat Balance of Back Pressure Turbine

3. Overall Performance of Thermal Power Plant.

Results of 8-hour tests (using ASME PTC-2004 methodology for steam turbine tests) of the overall performance of the power plant and overall efficiency of the co-generation plant at normal load, to compare with the design values are shown on Tables 27 and 28.

Table 27 Parameter of Overall Efficiency of Thermal Power Plant

Description	Parameter	Unit	Data
Load plant	L_p	%	**80**
Heat loss of boiler	η_b	%	**60.92**
Steam flow rate	$\dot{m}_s$	ton/h	**218**
Amount of fuel using	$\dot{m}_f$	ton/h	**121**
Temperature Feed water	T_w	°C	**115**
Amount of electricity generation	P	MW	**35.4**
High heating value	HHV	kJ/kg	**6,447.67**

Table 28 Calculator Overall Efficiency of Thermal Power Plant

Description	Parameter	Unit	Data
	Block # 1		
Efficiency of boiler	η_b	%	60.92
Efficiency of Extraction Condensing Turbine	η_{Ext}	%	84.9
Efficiency of generator	η_{gen}	%	95
Overall unit efficiency	$\boldsymbol{\eta_{th}}$	**%**	**55.81**
	Block # 2		
Efficiency of boiler	η_b	%	60.92
Efficiency of Back Pressure Turbine	η_{BP}	%	79.4
Efficiency of generator	η_{gen}	%	92.1
Overall unit efficiency	$\boldsymbol{\eta_{th}}$	**%**	**50.60**

CO_2 Emission of Thermal Power Plant

Results of the assessments of CO_2 emissions from the thermal power plant from 10 December 2019 to 25 February 2020 (crushing season) and with normal load operation of the power plant are shown on Tables 29 to -35.

Table 29 Description of How the Definition of the Project Boundary Related to the Baseline Methodology is Applied to the Project Activity

	Source	Gas	Included in emission calculation
Baseline	Grid electricity generation	CO_2	Emission factor CO_2 apply from mixer electricity of grid connect in the Thailand
	Open air burning of sugarcane leaves	CH_4	CH_4 emission from burning sugarcane leaves in open air
	Bagasse Fuel electricity generation	CH_4	CH_4 emission from combustion bagasse fuel in the boiler system.
		CO_2	
		CH_4	

	Source	Gas	Included in emission calculation
Project	Transportation (Off-site)	N_2O	CO_2, CH_4, and N_2O emission from combustion diesel fuel in tractor .
	Start-up to boiler system (Sugarcane leaves)	CH_4	CH_4 emission from combustion Sugarcane leaves fuel in the boiler system to start up.

Table 30 CO_2 Emission Baseline of Power Plant Project

Parameter	Description	Unit	Value
$\mathbf{E_{open-air}}$	Emission reduction from open air burning for sugarcane leaves	$tCO_{2e}/year$	**5,209.35**
$\mathbf{LE_{transp,y}}$	Leakage emissions from road transportation of freight	tCO_2/year	**1,339.53**
$\mathbf{LE_{start\ up\ boiler}}$	Leakage emissions from start up boiler	$tCO_{2e}/year$	**1.06**
$\mathbf{LE_{biomass\ electricity\ generation}}$	Leakage emissions from biomass electricity generation	$tCO_{2e}/year$	**94.42**
$\mathbf{Em_{CO2,grid,y}}$	Reduce amount of CO_2 emission from electricity export	tCO_{2e}/year	**26,426.61**
$\mathbf{BE_y}$	**Reduce Baseline Emission in year**	$\mathbf{tCO_2e/year}$	**<u>30,200.95</u>**

Table 31 Quantity of Net Electricity Supplied to the Grid with Activity

Parameter	Description	Unit	Value
hours	Operating hours	hours	**933.14**
$EG_{net,y}$	Net electricity generation supplied to the grid, load plant, and sugar factory	MWh	**46,657.15**
EF_{CO2}	CO_2 emission factor of the grid	tCO_2e/MWh	**0.5664**
$\mathbf{Em_{CO2,grid,y}}$	**Reduce amount of CO_2 emission from electricity export**	$\mathbf{tCO_2}e\mathbf{/year}$	**<u>26,426.61</u>**

Table 32 Quantity of Leakage Emissions from Road Transportation of Freight

Parameter	Description	Unit	Value
D_t	Distance travelled	km/yr	**1,121,548.75**
$EF_{transportationCO_2}$	Carbon dioxide emission factor of transportation	tCO_{2e}/km	**0.0011943**
$LE_{transp,y}$	**Leakage emissions from road transportation of freight**	$tCO_2e/year$	**1,339.53**

Table 33 Quantity of CO_2 Emissions from Open-air Burning of Sugarcane Leaves

Parameter	Description	Unit	Value
CF	Carbon fraction of biomass	tC/tbiomass	**0.3713**
CR	Carbon released as CH_4 in open-air burning	%	**0.005**
MC	Mass conversion factor	tCO_{2e}/tC	**16/12**
GWP of CH_4	Potential of Goble warming	tCO_{2e}/tCH_4	**21**
Cr	Carbon released	tC/yr	**37,209.62**
$total_{sugarcane\ leaves}$	sugarcane leaves used as fuel by plant	t biomass/yr	**100,214.43**
$E_{open-air}$	**Emission from open air burning for sugarcane leaves**	$tCO_{2e}/year$	**5,209.35**

Table 34 Quantity of CO_2 Emissions from Start Up Boiler System

Parameter	Description	Unit	Value
$HHV_{sugarcane\ leaves}$	High heating value of sugarcane leaves	TJ/year	**1.68**
EF_{CH_4}	Methane emission factor for Sugarcane leaves	tCH_4/TJ	**0.03**
GWP of CH_4	Potential of Goble warming	CO_{2e}/tCH_4	**21**
$LE_{start\ up\ boiler}$	**Leakage emissions from start up boiler**	$tCO_{2e}/year$	**1.06**

Table 35 Quantity of CO_2 Emissions from Biomass Electricity Generation

Parameter	Description	Unit	Value
$\mathbf{HHV_{bagasse}}$	High heating value of bagasse	TJ/year	**149.86**
$\mathbf{EF_{CH_4}}$	Methane emission factor for Sugarcane leaves	tCH_4/TJ	**0.03**
GWP of CH_4	Potential of Goble warming	CO_{2e}/tCH_4	**21**
$\mathbf{LE_{biomass\ electricity\ generation}}$	**Leakage emissions from biomass electricity generation**	$\mathbf{tCO_{2e}/year}$	**94.42**

The assessment of the baseline and the project CO_2 emissions for the biomass thermal power plant is shown on Figure 24. The following are the results:

1. Baseline CO_2 emission of the project = 30,200.95 tCO_2e/year
2. CO_2 emission, reduce emission from electricity exports: GEG = 5,209.35 tCO_{2e}/year
3. CO_2 emission, reduce from open air burning of sugarcane leaves: OAB = 26,426.61 tCO_{2e}/year
4. CO_2 emission from road transport of freight: TFS = 1,339.53 tCO_2e/year,
5. CO_2 emission from biomass fueled electricity generation: BFEG = 94.42 tCO_2e/year,
6. CO_2 emission from start-up of boiler system: FUS = 1.06 tCO_2e/year.

The operation of this biomass-fueled co-generation power plant can result to CO_2 emission reduction of about 30,200.95 tCO_{2e}/year. Although more CO_2 may be emitted from road transportation of freight, this can be compensated by the reduction of CO_2 emissions from the avoidance of open air burning of sugarcane leaves (about 3,869.81 tCO_2e/year). Therefore, electricity company should support the collection of sugarcane leaves by farmers to be used as fuel for electricity generation. This will also help address other environmental issues such as the reduction of air pollution from smoke and particulate matter (PM 2.5) emissions.

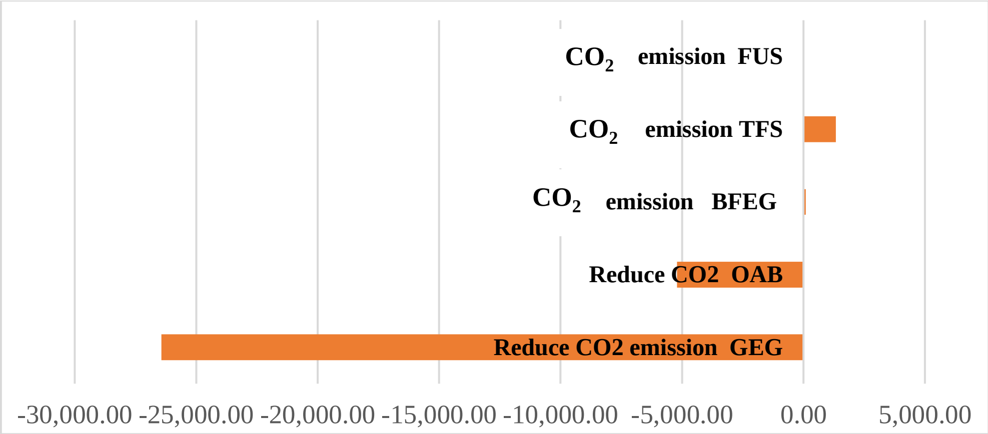


Figure 24 CO_2 Emission from Activity of Thermal Power Plant

In the Conclusion of Assessment CO_2 Emission and Energy Efficiency of Thermal Power Plants (Small Power Producer)

Greenhouse gas emissions from thermal power plants are affected by the efficiency of the electricity generation system. Lower efficiency may due to lower efficiency of any one or combinations or all of the following components of the thermal power plant:

1. Boiler system,
2. Generator system,
3. Heat loss of surface, and steam piping,
4. Steam turbine system,
5. Auxiliary of thermal power plants.

If the efficiency of the different components of the thermal power plant are properly maintained and improved, the expected efficieny of operation and the targeted reduction of GHG emissions can be both achieved. Thus, it may be good for ERC to provide reporting guidelines for the regulation of the implementation of proper maintenance of thermal power plants. This research can help define the parameters and methods that can be used for monitoring proper maintenance and the performance of the thermal power plants and the CO_2 emissions from these plants. This can improve regulations for the operations of electricity companies.

CHAPTER IV

RESULT OF RESEARCH

The following are the results of this study on the long-term monitoring of regulations for energy efficiency and GHG emissions from SPP thermal power plants This include the estimation of baseline emissions from the operations of SPP thermal power plants and terms for designing processes to regulate their energy efficiency.

CO_2 Emission and Baseline from Operation, Thermal Power Plants

The estimation of the baseline emissions of the SPP thermal power plants applied the CDM method (the 2019 fuel data was used). The assessment of emissions, in tCO_2/kWh, were done for different types of fuel: coal, natural gas, rice husk, and bagasse as shown on Figure 25 and in Table 36.

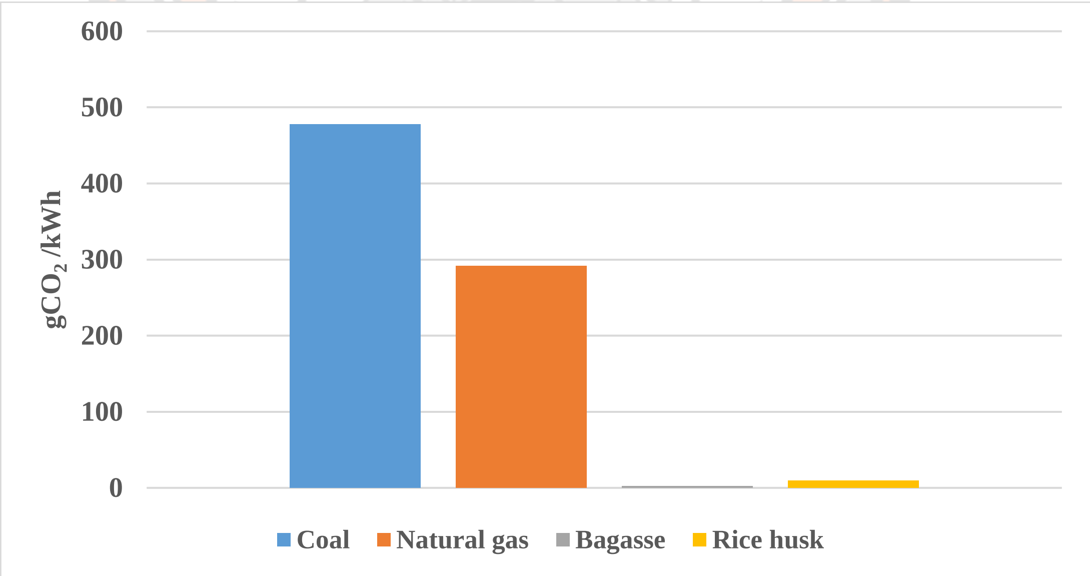


Figure 25 gCO_2/kWh to Electricity Generated of Thermal Power Plants

Figure 25 shows that. the coal power plant generate the maximum of CO_2 emission per unit of electricity generated at about 477.84 gCO_2/kWh or 92,330

tCO_2/year. This is followed by natural gas power plant with a generation of about 291.99 gCO_2/kWh or 62,439.55 tCO_2/year. Rice husk-fed, bagasse-fueled power plants have the minimum emissions of about 9.34 gCO_{2e}/kWh or 1,374.34 tCO_{2e}/year, 2.72 gCO_{2e}/kWh or 94.41 tCO_{2e}/year, respectively.

Table 36 Assessment CO_2 Emission of Operation Bagasse Fuel

Detail	Value	Unit
Reduce CO_2 emission from grid electricity generation	26,426.61	tCO_2e/year
Reduce CO_2 from open air burning for sugarcane leaves	5,209.35	tCO_2e/year
CO_2 emission from biomass fueled electricity generation	94.42	tCO_2e/year
CO_2 emission from transport of sugarcane leaves for project	1,339.53	tCO_2e/year
CO_2 emission from fuel use start up for the project	1.06	tCO_2e/year
Baseline CO_2 Emission	**30,200.95**	**tCO_2e/year**
Project CO_2 Emission	**1,435.01**	**tCO_2e/year**
CO_2 Emission Reduction	**31,635.96**	**tCO_2e/year**

In table 36 apply methodological tool baseline; project and/or leakage emissions from electricity consumption and monitoring of electricity generation for database in 2019, and normal operation The results of the application of the methodological tool for baseline assessment, the monitoring of project and/or leakage emissions from electricity consumption.

Methane emissions from the combustion of wood/wood wastes in energy industries is about 0.03 tCH_4/TJ. As such, a boiler that burns 23,243.68 tons per year of bagasse is estimated to have methane emissions of about 94.42 tCO_{2e}/year.

The transportation of biomass (sugar cane leaves) from farms to the power plant is contracted out to truckers. GHG emissions from the transport of biomass fuel is estimated based on the distance travelled, 47-ton trucks are used for transport and the average distance of the return trips is 526 km. The estimated total distance travelled is 1,121,548.75 km/year. The IPCC default factors for CO_2, CH_4, and NO_2 emissions from heavy duty vehicles are 1097 g/km, 0.06 g/km, and 0.031 g/km, respectively. Therefore, the estimated total emission for transporting sugar cane leaves is about 1,339.53 tCO_{2e}/year.

The start-up/auxiliary fuel use of sugarcane leaves for the start-up operation of the power plant is 100,214.13 tons of sugarcane leaves, which is used several times a year. The IPCC methane emission factor for wood/wood waste combustion in energy industries is 0.03 tons CH_4/TJ. Based on this IPCC value, the methane emissions from the biomass used in the start-up of the project is estimated to be about 1.1 tCO_{2e}/year.

CO_2 emissions from the generation of electricity supplied by the grid is estimated to be 26,427 tCO_{2e}/year. This is the equivalent amount of GHG emission reduction achieved in using biomass fuel. This is based on a CO_2 emission factor of 0.5664 tCO_2/MWh and estimated electricity export of 46,657.15 MWh/year.

Open air burning is the usual way to dispose of sugarcane leaves. Carbon dioxide emissions are released in the open air burning of sugarcane leaves. Estimated emission from open burning is about 5,209.35 tCO_{2e}/year. This is equivalent amount of emission reduction achieved in avoiding open burning of the biomass. The carbon fraction is 0.3713 and the amount burned is 0.005%.

Therefore, based on the calculations done above, the result of the assessment shows a baseline CO_2 emission reduction of 30,200.95 tCO_{2e}/year, and a project operational CO_2 emission reduction of 1,435.01 tCO_{2e}/year. This means that the total CO_2 emission reduction due to the operation of this SPP thermal power plant is 31,635.96 tCO_{2e}/year.

Compare Performance of Thermal Power Plant

This efficiency design values of the different equipment or component of the power plant is given as follows:

1. boiler system efficiency - 70.9 %
2. back pressure steam turbine - 85 %
3. extraction condensing steam turbine - 85 %
4. performance generator - 95 %., and
5. overall thermal power plant - 57 %.

The results of the performance showed the following efficiency for the different components:

1. boiler efficiency - 60.92 %
2. back pressure steam turbine - 79.4 %
3. extraction condensing steam turbine - 84.9 %
4. performance generator - 92-95 %, and
5. overall thermal power plant block # 1 at55.81%, and block# 2 at 50.60 %.

The results showed of 1.19% to 6.4% lower values for performance test values compared with the design values (see Figure 26). because of main lower performance co-generation power plant is boiler system not control parameter to effect of efficiency such as stack loss, unburn loss, moisture of fuel, and over air supply to combustion in boiler.

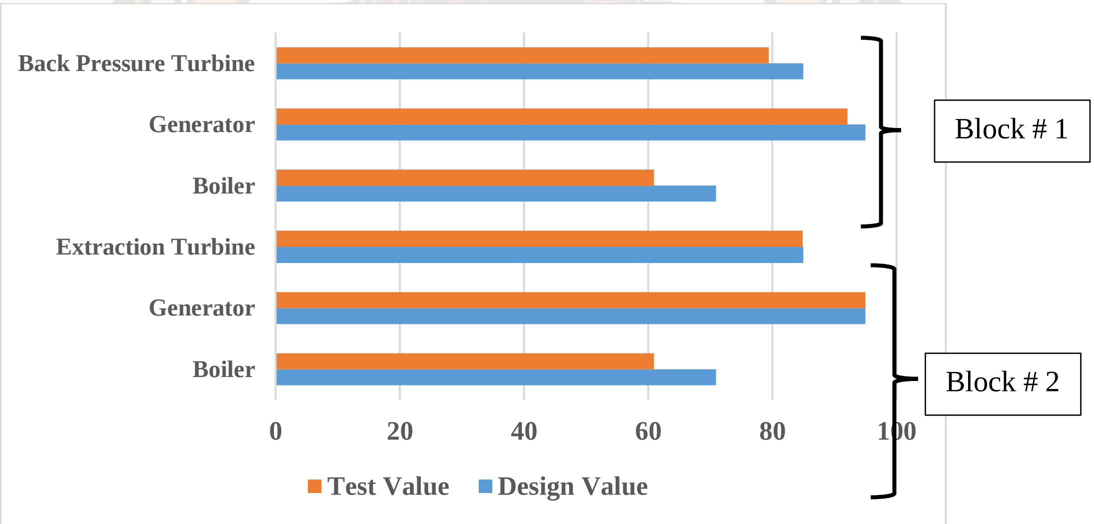


Figure 26 Compare Design Value and Test Value of Efficiency Main Equipment of CO-Generation Power Plant

Identifying Decline Key Indicator Performance for Control Thermal Power Plants Operation

The operation of a thermal power plant is a complex process involving several sub-processes, and multiple critical parameters affecting the performance of the power plant such as: heat rate factor, maintenance factor, capacity factor, load factor and operational efficiency. Thermal power plant operations focus on the heat rate of the plants to locate heat losses and develop measures to eliminate or reduce the losses and increase the efficiency of the plants. Deviations from expected or designed values of efficiency and heat losses are identified and quantified.

Deviations in the operational and maintenance costs of sub- systems, can seriously affect the overall plant economics and environmental impacts. The key operating parameters affecting the boiler and turbines, affect the heat rate. Therefore, there is a need to control the performance of the power plants to attain values nearest to the design parameters. The different parameters affecting heat rate and the effects on efficiency of the boiler and turbine, and on CO_2 emissions are shown on Figures 27-31.

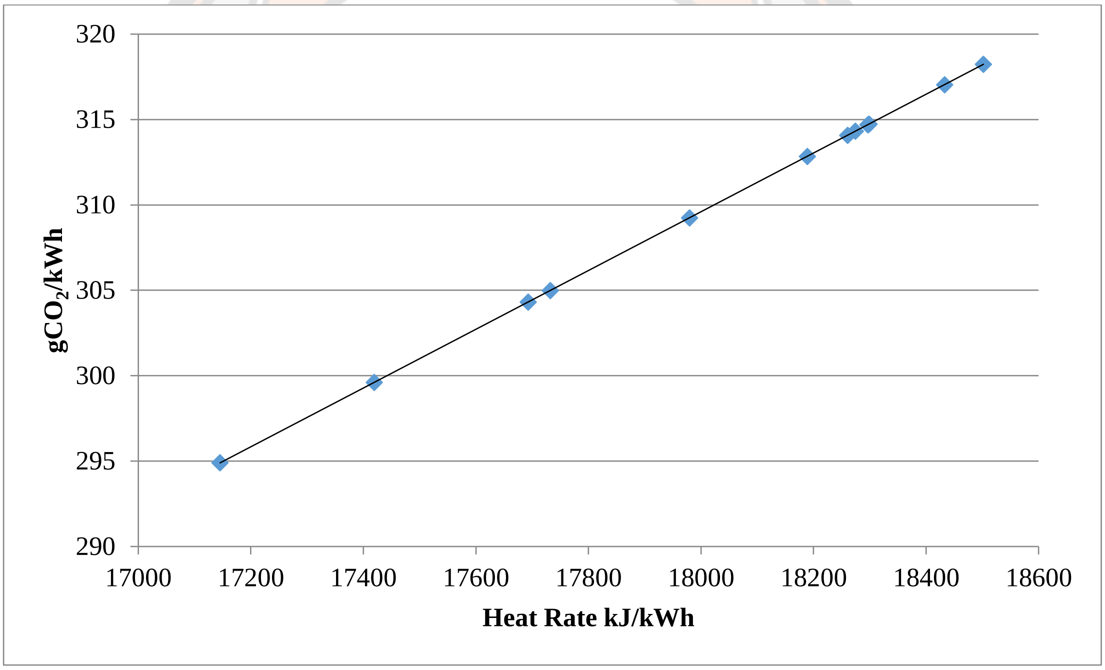


Figure 27 Correlation Heat Rate and gCO_2/kWh Emission from Operation

Figure 27 shows the correlation between efficiency or heat rate with CO_2 emissions. At a heat rate of 17,200 kJ/kWh for generating electricity, the CO_2 emission is at 295 gCO_2/kWh. The higher the heat rate, the higher the emissions. Therefore, electric companies should control the operation of the plants to attain the design values to control and reduce emissions. This can be done by following the maintenance plan provided by the manufacturer.

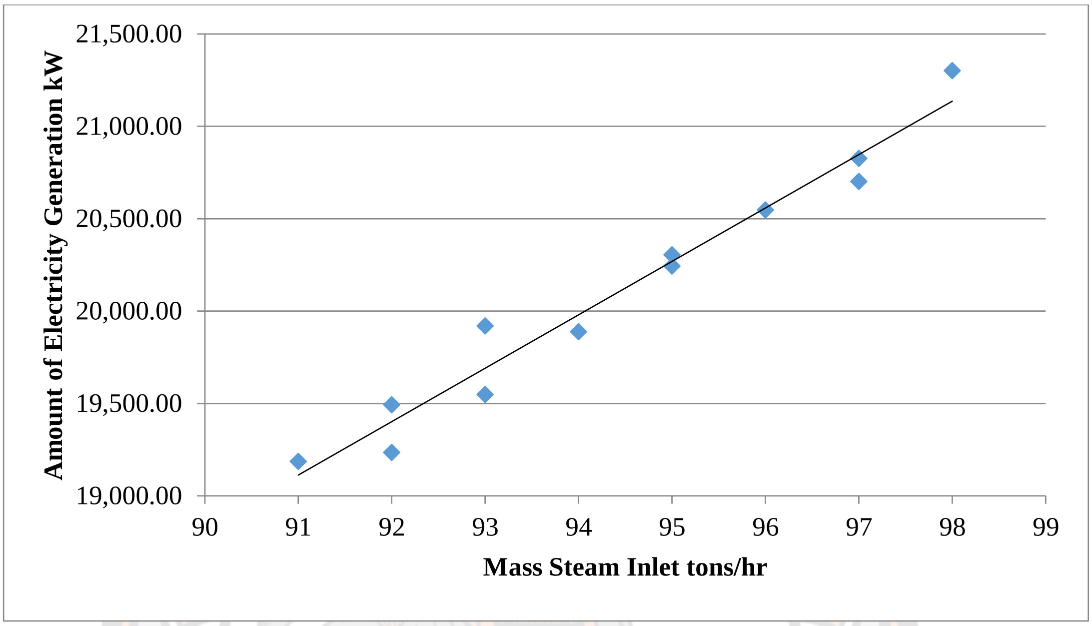


Figure 28 Correlation Mass Flow Rate and Amount of Electricity Generation

Figure 28 shows the correlation of the mass flow rate with the amount of electricity generated. The graph shows that a mass flow rate of 98 tons/hr can generate 21,000 kWh of electricity, and electricity generation increases with increases in steam mass flow rate. Electricity companies need to control the performance of the steam generator system, particularly the quality of the steam inlet turbine of the generator system to stabilized electricity generation. This can be done by preventing corrosion of the stationary and moving blades of the turbine.

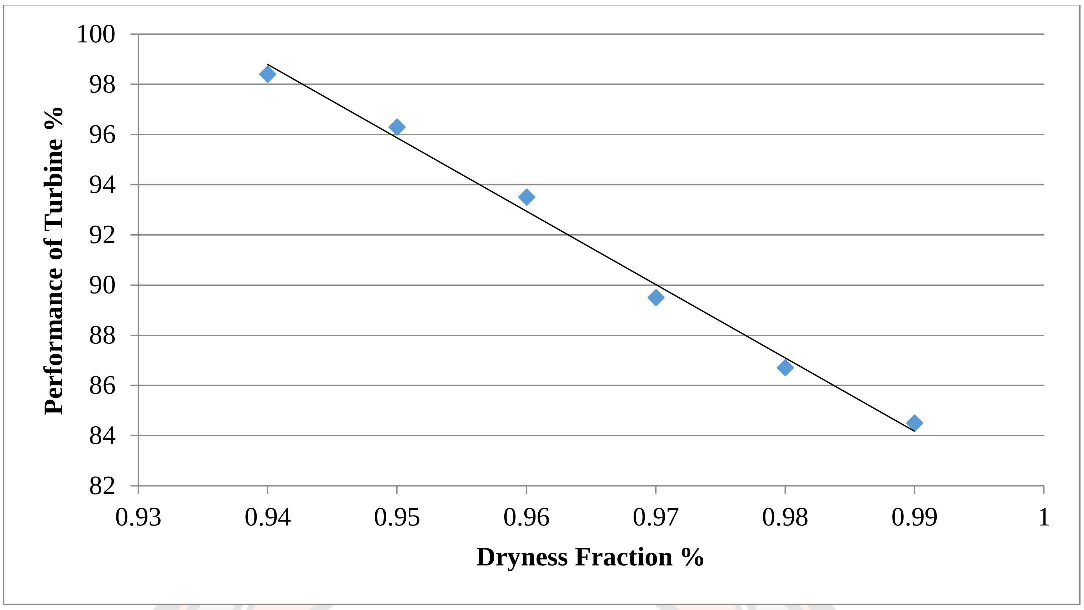


Figure 29 Correlation Dryness Fraction Steam and Efficiency Turbine

Figure 29 shows the effect of the dryness fraction of the steam on the efficiency of the turbine. The dryness fraction of the steam maintained the quality of steam generation to the standards technical design. The graph shows at a dryness fraction of the steam of 0.99%, the turbine efficiency is 98.8% and high dryness fraction values correlate with lower efficiency. Electricity companies should operate the boiler within the standard design range to maintain the performance of the turbine and the overall performance of the plant.

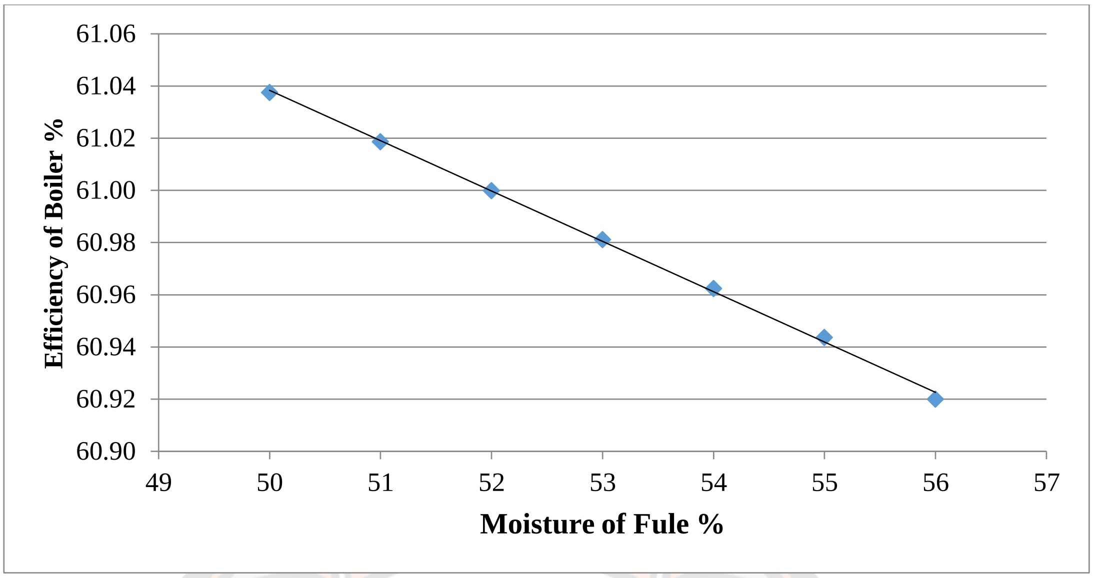


Figure 30 Correlation Moisture in Fuel and Efficiency Boiler

Figure 30 shows the effect of the fuel moisture content on the efficiency of the boiler. The fuel moisture content should be within the range of the design values, before feeding the fuel to the combustion chamber, to manage the temperature and pressure drop in the furnace. The graph shows that at a fuel moisture content of 56%, the efficiency of the boiler is 60.92%, and that the efficiency decreases with increasing fuel moisture content. Electricity companies should control the moisture content and quality of fuel to improve the performance of the boiler and the overall performance of the power plant. This will also save fuel consumption and reduce CO_2 emissions.

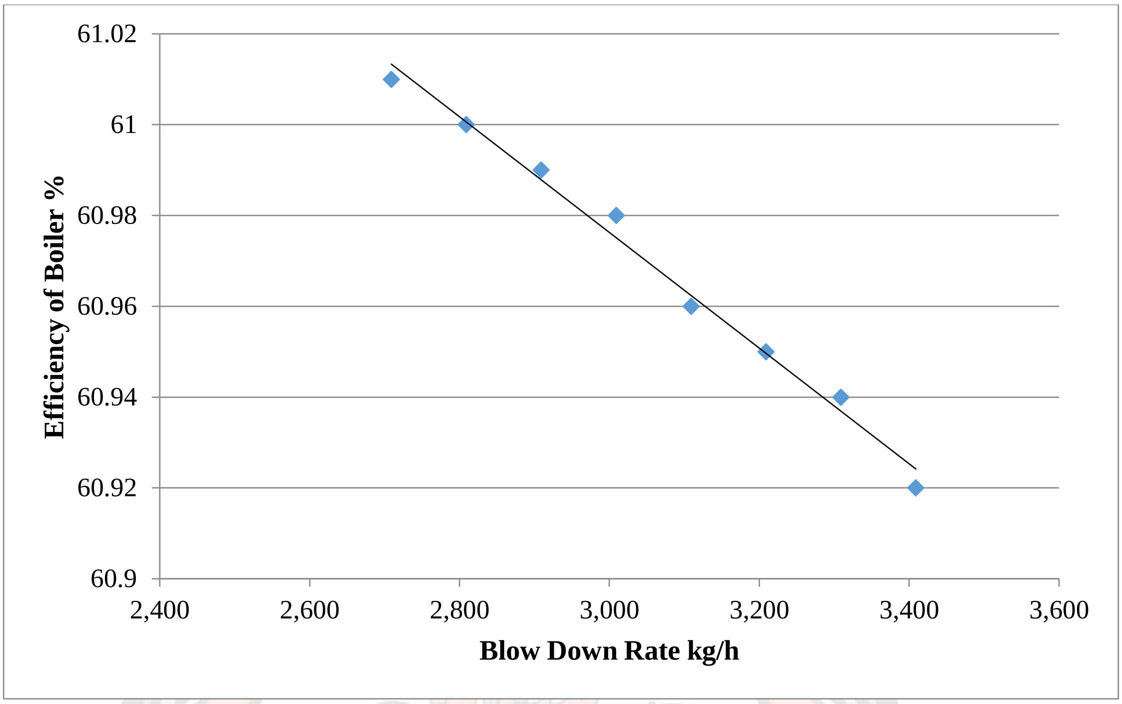


Figure 31 Correlation Blow Down Rate and Efficiency Boiler

Figure 31 shows the effect of the blow down rate on the efficiency of the boiler, and how to control the quality of the feed water to maintain technical design standards. The fluctuation of the measured parameters affects the extent of corrosion, and controlling this parameter may prevent corrosion. The graph shows that at a blow down rate of 3,409 kg/hr, the efficiency of the boiler is 60.92%. As the efficiency of the boiler decreases, the blow down rate also decreases. The feed water quality need to be monitored and controlled to prevent chemistry-related failures of boiler tubes, which are crucial for boiler performance and safety.

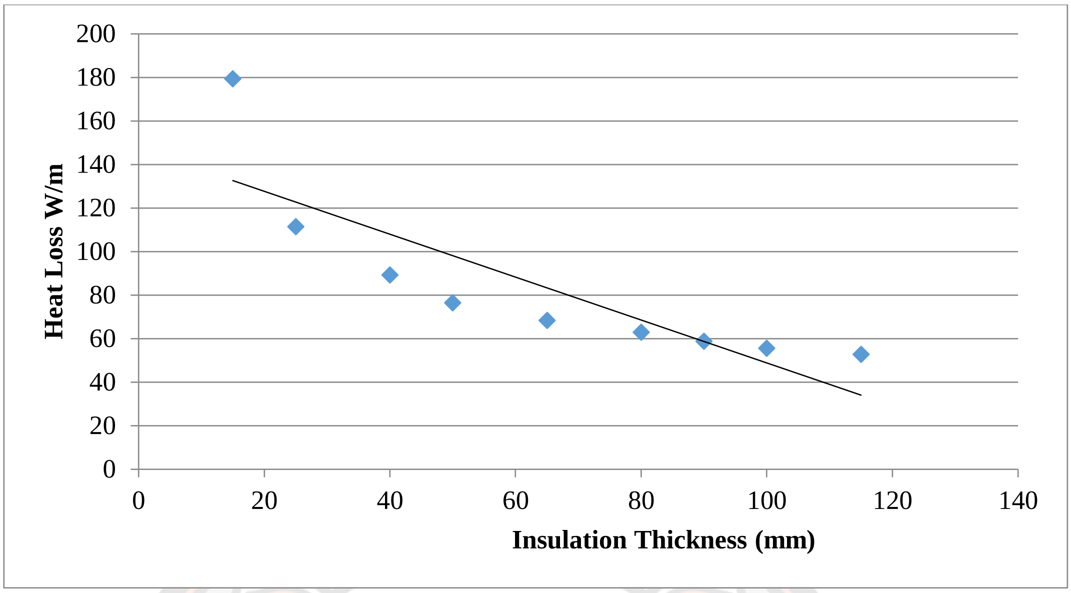


Figure 32 Correlation Insulation Thickness and Heat Loss Mineral Fiber Pipe, Type I, C547-15

Figure 32 shows the correlation between the insulation thickness and the heat loss from the steam pipe. The steam pipe is subject to the following conditions: surface temperature of 302 °C, ambient temperature of 32 °C, wind speed of 3.6 m/s, NPS pipe sizing of 25 mm, and the simulation of pipe insulation using the mineral fiber Type I, C547-15. As a result, insulation thickness of 15 mm can reduce heat loss of steam pipe about 0.793 kW, and increase performance boiler is 0.000599 %, save fuel using electricity generated about 9.53 tons/year, CO_2 emission reduction =16 tCO_2/year. An insulation thickness of 15 mm can reduce heat loss from a steam pipe by about 0.793 kW, and increase the performance of the boiler by 0.000599%, saving fuel by as much as 9.53 tons/year and reducing CO_2 emissions by 6 tCO_2/year. Choosing the suitable type of insulation, which should verified by site-inspection to check the quality of insulation and amount of heat loss is a necessary component of plant maintenance and control operations.

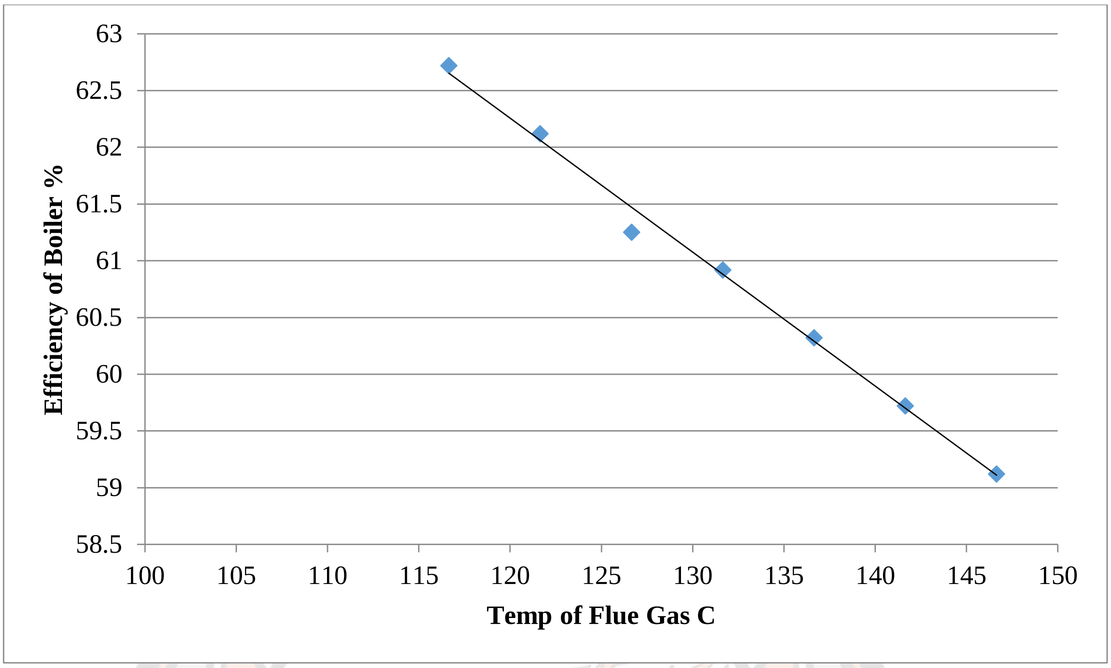


Figure 33 Correlation Temperature of Flue Gas (Stack loss) and Boiler Efficiency

Figure 33 that the correlation temperature of flue gas (Stack loss) and boiler efficiency, which a boiler efficiency depends on the temperature of flue gas. The temperature of flue gas effect on boiler efficiency such as at 145 °C of temperature of flue gas effect on boiler efficiency of 59 %, and at 119 °C of temperature of flue gas effect on boiler efficiency of 63 %. This parameter operation of boiler system important to steam generation process, operation management should control parameter, and maintain temperature of flue gas (Stack loss) and boiler efficiency can reduce CO_2 emission, saving fuel consumption, and performance stability of power plant.

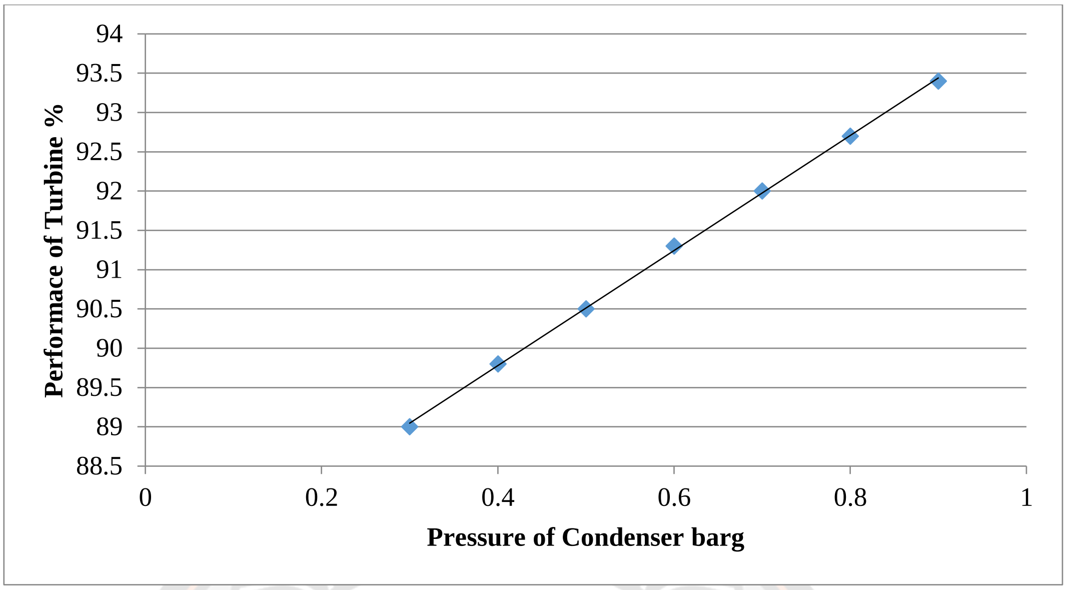


Figure 34 Correlation Condenser Pressure between Performance of Turbine

Figure 34 shows the correlation between the condenser pressure and the performance of the turbine. At a pressure of 0.9 bar, the performance of the turbine is at 93.4%, and at a pressure of 0.3% the performance is at 89%. Increasing the condenser pressure increases performance efficiency of the turbine, and this will increase overall performance efficiency of the power plant.

Parameter to Monitor Performance and CO_2 Emission of Thermal Power Plant

The overall performance of a power plant is affected by the performance of the following components: the boiler system, the turbine system, and the condenser system. The parameters affecting the performance of each of these components are shown on Table 37. In addition, performance monitor can compare current performance to expected performance, and tracks for comparison over time As such, these parameters can provide information on the plant operation, monitor its performance and can help identify problems, improve performance, and help plan and make decisions about maintenance schedule and optimization of plant operation.

Table 37 Parameter effect to performance and CO_2 emission from operation thermal power plants

Main Equipment	Parameter	Benchmark
Boiler System	• High heating value of fuel • Quality of fuel • Quality of feed water • Air supply to combustion • Soot blow • Blow down • Condition of insulator in wall boiler and main steam • Steam leaked	Efficiency, Steam Generation
Extraction Condensing Turbine	• HPS Flow • Temp inlet • Pressure inlet • Condenser pressure	Power, Efficiency
Back Pressure Turbine	• HPS Flow • Temp inlet • Pressure inlet • Temp outlet • Pressure outlet	Power, Efficiency
Condenser system	• LPST exh flow • Temp of exh • Cooling water flow	Vacuum, Efficiency
Thermal power plant	• Fuel using • High heating value of fuel • Power	Efficiency, Heat rate
CO_2 emission from operation	• Fuel using • High heating value of fuel • Power • Performance of plant	tCO_2/kWh
CO_2 emission from transport	• Distance to transport fuel • Truck capacity • Return trip distance to supply site	tCO_2/km

Main Equipment	Parameter	Benchmark
CO_2 emission from start up to boiler	• Fuel using • High heating value of fuel	tCO_2/year
CO_2 emission baseline of project	• Emission from grid electricity generation • Emission from open air burning for biomass • Emission from biomass fueled electricity generation • Emission from transport of fuel for project • Emission from fuel use start up for the project	tCO_2/year

The Design Process for Long-Term Regulation of the Energy Efficiency and Greenhouse Gas Emission for the Small Power Producer Thermal Power Plants

The study on the long-term regulation of energy efficiency and GHG emission for SPP thermal power plants, include plants that have installed extraction condensing steam turbine and back pressure steam turbine technologies. The study considered the following parameters: plant load, temperature, and steam pressure, which were also the parameters considered in developing a maintenance plan. The framework used in developing the method for the long-term regulation of energy efficiency and GHG emissions from SPP thermal power plants is shown on Figure 35. There is lack of focus on monitoring of the performance on energy efficiency and CO_2 emission in thermal power plant sector in Thailand, as adequate mechanisms to monitor the relevant parameters are absent now. For on-line monitoring of plant performance, the best practice for electricity companies is the application of SCADA (Supervisory Control and Data Acquisition) system. SCADA is used to monitor in real time the overall unit efficiency, boiler efficiency, turbine efficiency, fuel consumption and non-controllable losses in the main steam piping and regenerative cycle of the power plant. However, the net calorific value of the fuel, which is fed manually, must be measured off-line. The electricity company energy auditor, or the plant energy auditor, needs to coordinate with an external auditor to identify significant but inexpensive performance improvements to capture low hanging opportunities to save on energy losses. The efficiency audit should be carried out based on which baseline indicators for energy efficiency and CO_2 emissions will define reducing CO_2 emissions as the major performance by the plant. However, ERC should set-up the essential process mechanism for receiving and evaluating submissions of reports of energy efficiency and CO_2 emissions reductions from the plants. The process of developing a monitoring and regulatory system for thermal power plants can be initiated through a methodology assessment based on a framework for big data operation. This framework for big data operation will allow sharing of all relevant data for multiple uses. Subsequently, these data systems can be interlinked to develop a proper knowledge platform that can provide various standardized reports for management decision-making and be the server of the plant Management Information System (MIS) for both plant and corporate level management operations

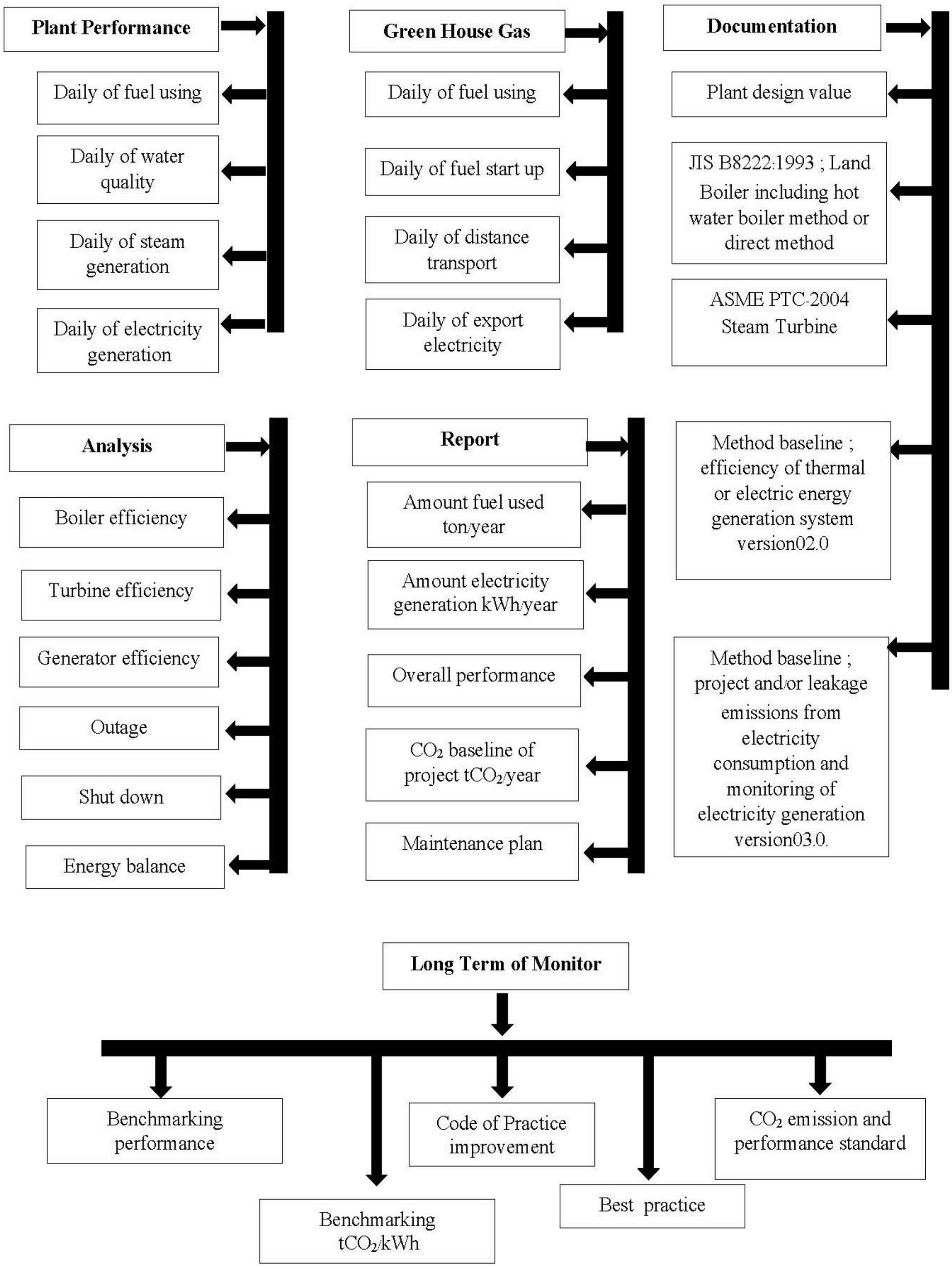


Figure 35 Framework Long-Term Regulation of the Energy Efficiency and Greenhouse Gas Emission for the Small Power Producer Thermal Power Plants

The Energy Regulatory Commission has the authority to introduce laws to monitor power plant operations, including mechanisms to regulate and monitor energy efficiency of power plants. This mechanism can also help improve performance of power plants and also reduce adverse environmental impacts, thus reducing also the complaints of people affected by these impacts such as air pollution, wastewater discharges, and water consumption poaching.

The assessment of energy efficiency should include a study of the range of values of the parameters used in the design of power plants such as the fuel high heating value, fuel moisture content, furnace temperature, the combustion burner oxygen supply, plant load, and the steam generation mass flow rate. Therefore, the study to develop a organizational structure to monitor and assess the energy efficiency of thermal power plants should be based on power plant engineering, mechanical engineering, the Energy Industry Act of 2007, and the mandate of the Energy Regulatory Commission. A proposed organizational structure to monitor and assess the energy efficiency of thermal power plants in Thailand is shown on Figure 36.

Under the proposed organizational structure to monitor and assess the energy efficiency of the operations of thermal power plants, a company proposing to implement a new power plant go through a process as follows:

1. Electricity companies proposing new projects first obtain the license for electricity generation from the ERC.

2. The company submits the designed values for the main equipment and a management plan to operate the power plant.

3. Once the plants are operational, ERC will then monitor and assess the energy efficiency of the operation of the power plants from the performance reports.

4. Electricity companies are expected to prepare and submit annual self-assessment performance reports on energy efficiency of power plants based on the comparison of the test values and design values of the power plant equipment.

It will therefore be the ERC which will monitor the performance reports of the electricity companies. The electricity companies are expected to have a maintenance plan that shows the efficient design values for the plant, and how to restore back and improve the efficiency of the plant in case efficiency goes down. It will be the ERC staff who shall act as regulators to enforce electricity companies to continually improve and increase the energy efficiency of electric power plants. Furthermore, ERC can facilitate the development of a database system which can be a platform for overall monitoring and assessment of the implementation of the energy efficiency plans of power plant projects.

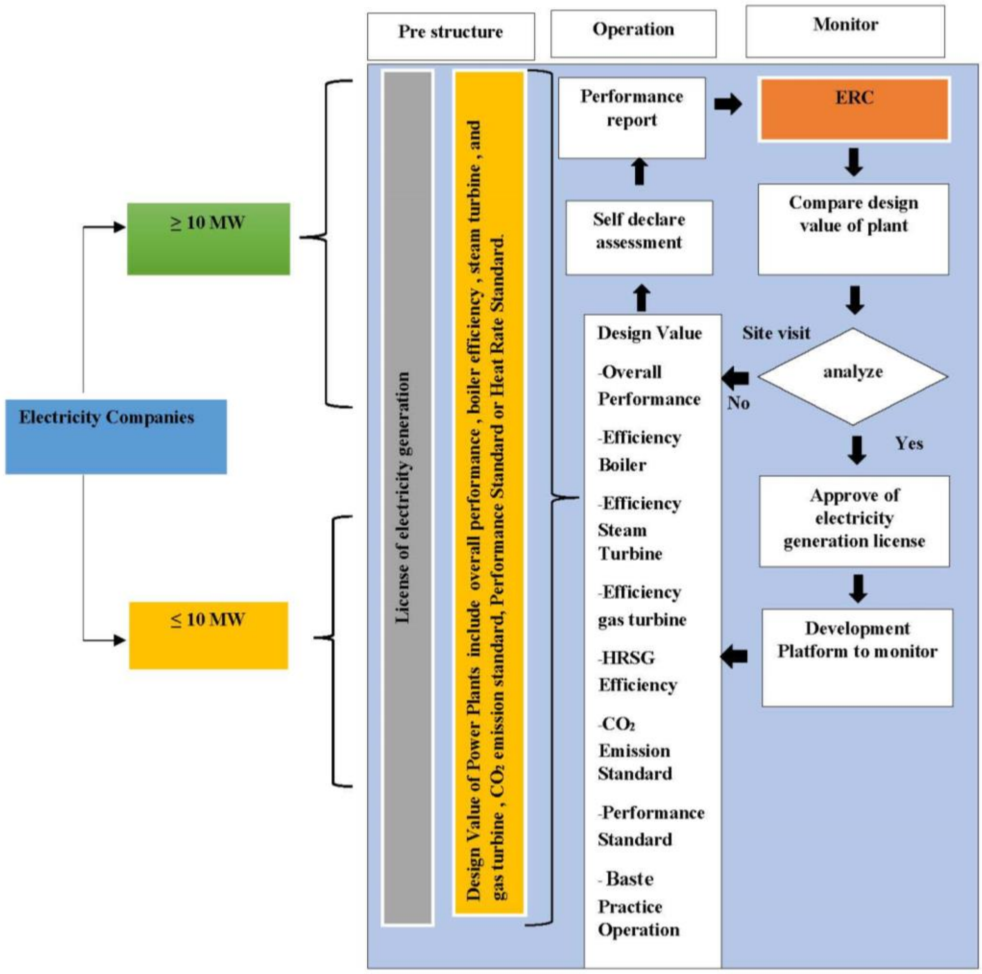


Figure 36 Monitor and Organizational structure Assessment Energy Efficiency Operation of Thermal Power Plants

CHAPTER V

CONCLUSION

Conclusion and Recommendation

The organizational structure to monitor and assess the energy efficiency of operations of thermal power plants in Thailand can play a key role in developing a mechanism to regulate and increase the efficiency of this sector. The development of such an organizational structure using an appropriate methodology is the focus of the study of this research. The organizational structure and the methodologies used were developed from the current guidelines used by the government agencies requiring electric companies to submit Environmental Impact Assessment (EIA), Code of Practice (CoP) and Environmental & Safety Assessment (ESA) reports for their proposed thermal power plants. This new organizational structure and methodology proposed by this study also supports the improvement of business operation of electric companies and help save fuel consumption and reduce negative environmental impacts.

Thus, this study would like to recommend to the Energy Regulatory Commission (ERC) to promote the adoption of this organizational structure and its methodology. In addition to being a mechanism to monitor and regulate the energy efficiency of thermal power plants, this model will also monitor parameters that, show if the plants are operating up to standards, help improve maintenance and achieved the design standard efficiency of the equipment, and achieved the designed standard and baseline CO_2 emissions. This mechanism for monitoring and regulating the efficiency of thermal power plants can be adjusted to the different factors affecting the performance of the power plants such as modernity of the technology, operational conditions, plant load, efficiency of main equipment used for electricity generation, and preventive maintenance plans of the companies.

The high performance of the boiler, the condensing extraction turbine, and the back pressure turbine will result to the overall high performance or heat rate of the power plant. The long-term regulation and monitoring of energy efficiency and CO_2 emissions of power plants can increase efficiency of power plants, reduce negative environmental impacts, particularly local air, land, and water pollution affecting the people living around the power plants. However, developing a methodology for the long term regulation of energy efficiency and GHG emissions from SPP thermal power plants should be based on the principles of power engineering and mechanical engineering. It should also be based on the Energy Industry Act of 2007 and the mandate of the ERC.

As such, a company proposing to implement a new SPP thermal power plant in Thailand should go through the following process developed from the proposed framework for monitoring and assessing energy efficiency of thermal power plants:

1. Electricity companies proposing new projects first obtain the license for electricity generation from the ERC.

2. The company submits the designed values for the main equipment and a management plan to operate the power plant.

3. Once the plants are operational, ERC will then monitor and assess the energy efficiency of the operation of the power plants from the performance reports.

4. Electricity companies are expected to prepare and submit annual self-assessment performance reports on energy efficiency of power plants based on the comparison of the test values and design values of the power plant equipment.

5. It will therefore be the ERC which will monitor the performance reports of the electricity companies.

6. The electricity companies are expected to have a maintenance plan that shows the efficient design values for the plant, and how to restore back and improve the efficiency of the plant in case efficiency goes down.

7. It will be the ERC staff who shall act as regulators to enforce electricity companies to continually improve and increase the energy efficiency of electric power plants.

ERC can facilitate the development of a database system which can be a platform for overall monitoring and assessment. In addition, ERC should develop data system to monitor and revise the legislation for the implementation of the thermal power plant standards for operation performance and reduction of CO_2 emission such as:

1. Performance standard or heat rate standards by type of thermal power plant technology.

2. CO_2 emission standard by type technology to generate electricity (such as: combined cycle power plants, co-generation power plants, steam turbine power plants, gas turbine power plant, and heat recovery steam generation). This include benchmarking the performance of thermal power plants.

3. Revisions in legislations to license electricity plants based on environmental standards for CO_2 emissions (i.e., Code of Practice).

4. Support for seminars and international cooperation to update knowledge on best practice in the operation of thermal power plants.

5. Support the electricity companies in the installation of SCADA and essential measurement tools which follows the standards for ASME PTC 6S report tests.

6. Establish industry awards for best examples of plant performance operations and CO_2 emission reductions.

7. Establish an ERC Sand Box together with a Power Development Fund to support further development and improvement of the method.

8. Implementation of benchmarking for international and national performance by type of thermal power plant technology

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APPENDIX

APPENDIX A COLLECTION OF INFORMATION OF CONTROL SYSTEM OF POWER PLANTS

Table 38 Heat Rate Type Fuel of Thermal Power Plants

Month	Coal	Natural Gas
Jan	28,727.55	17,979.76
Feb	28,657.03	18,274.52
Mar	29,066.86	18,433.02
Apr	29,470.01	17,145.31
May	30,963.87	17,732.27
Jun	33,023.23	18,298.72
Jul	28,484.69	17,419.34
Aug	28,117.65	17,692.93
Sep	27,042.59	18,296.61
Oct	28,990.84	18,260.69
Nov	32,089.12	18,502.00
Dec	30,107.46	18,188.89

Table 39 Compare Design and Operation of Natural Gas Power Plant

Equipment	Design Performance %	Operation Performance %
Boiler	77.2	74.08
Turbine	96.01	69.83
Generator	98	97.17

Table 40 Compare Design and Operation of Coal Power Plant

Equipment	Design Performance %	Operation Performance %
Boiler	92.72	82.38
Turbine	83.6	75.41
Generator	99.99	99.80

Table 41 Compare Design and Operation of Rice Husk Power Plant

Equipment	Design Performance %	Operation Performance %
Boiler	70	63.49
Turbine	90	87.99
Generator	98	97.43

Table 42 Compare Design and Operation of Bagasse Power Plant

Equipment	Design Performance %	Operation Performance %
	Block # 1	
Boiler	70.1	60.92
Extraction Condensing Turbine	85	84.90
Generator	95	95
	Block # 2	
Boiler	70.1	60.92
Back Pressure Turbine	85	79.44
Generator	95	92.13

Table 43 tCO_2 Emission from Natural Gas Power Plant

Month	Fuel Used kg	HHV kJ/kg	Emission Factor tCO_2/TJ	tCO2 Emission tCO_2	Electricity generation kWh	gCO_2/kWh
Jan	6,566,080	46,707.00	17.20	5,274.93	17,731,000	297.50
Feb	6,396,080	46,707.00	17.20	5,138.36	17,901,000	287.04
Mar	6,881,080	46,707.00	17.20	5,527.99	17,759,000	311.28
Apr	6,081,080	46,707.00	17.20	4,885.30	17,873,000	273.33
May	6,081,080	46,707.00	17.20	4,885.30	17,416,000	280.51
Jun	6,881,080	46,707.00	17.20	5,527.99	18,216,000	303.47
Jul	6,231,080	46,707.00	17.20	5,005.80	17,000,000	294.46
Aug	6,681,080	46,707.00	17.20	5,367.32	18,632,000	288.07
Sep	6,031,080	46,707.00	17.20	4,845.13	17,216,000	281.43
Oct	6,931,080	46,707.00	17.20	5,568.16	18,416,000	302.35
Nov	5,981,080	46,707.00	17.20	4,804.96	17,816,000	269.70
Dec	6,981,080	46,707.00	17.20	5,608.32	17,816,000	314.79

Table 44 tCO_2 Emission from Coal Power Plant

Month	Fuel Used kg	HHV kJ/kg	Emission Factor tCO_2/TJ	CO_2 Emission tCO_2	Electricity generation kWh	gCO_2/kWh
Jan	13,526,719	21,511.78	26.20	7,623.78	15,902,027	479.42
Feb	13,776,719	21,511.78	26.20	7,764.68	16,302,027	476.30
Mar	13,298,719	21,511.78	26.20	7,495.27	14,602,027	513.30
Apr	14,004,719	21,511.78	26.20	7,893.18	16,252,027	485.67
May	13,284,719	21,511.78	26.20	7,487.38	16,402,027	456.49
Jun	14,018,719	21,511.78	26.20	7,901.07	15,802,027	500.00
Jul	13,501,719	21,511.78	26.20	7,609.69	16,242,027	468.52
Aug	13,651,719	21,511.78	26.20	7,694.23	16,242,027	473.72
Sep	13,801,719	21,511.78	26.20	7,778.77	16,452,027	472.82
Oct	13,901,719	21,511.78	26.20	7,835.13	15,752,027	497.40
Nov	13,401,719	21,511.78	26.20	7,553.32	16,072,027	469.97
Dec	13,651,719	21,511.78	26.20	7,694.23	16,132,027	476.95

Table 45 gCO_{2e} Emission from Rice Husk Power Plant

Month	Fuel Used kg	HHV kJ/kg	Heating of Combustion TJ	CO_2 Emission tCO_2	Electricity generation kWh	gCO_2/kWh
Jan	12,152,666.67	15,080.00	183.26	115.46	11,754,697	9.82
Feb	11,952,666.67	15,080.00	180.25	113.56	12,754,697	8.90
Mar	12,252,666.67	15,080.00	184.77	116.41	12,254,697	9.50
Apr	11,852,666.67	15,080.00	178.74	112.61	12,254,697	9.19
May	12,052,666.67	15,080.00	181.75	114.51	12,104,697	9.46
Jun	12,052,666.67	15,080.00	181.75	114.51	12,404,697	9.23
Jul	11,552,666.67	15,080.00	174.21	109.75	11,954,697	9.18
Aug	12,552,666.67	15,080.00	189.29	119.26	12,554,697	9.50
Sep	11,752,666.67	15,080.00	177.23	111.66	12,054,697	9.26
Oct	12,352,666.67	15,080.00	186.28	117.36	12,454,697	9.42
Nov	12,052,666.67	15,080.00	181.75	114.51	12,254,697	9.34
Dec	12,052,666.67	15,080.00	181.75	114.51	12,254,697	9.34

Table 46 gCO_{2e} Emission from Bagasse Power Plant

Month	Fuel Used kg	HHV kJ/kg	Heating of Combustion TJ	CO_2 Emission tCO_2	Electricity generation kWh	gCO_{2e}/kWh
Jan	1,936,973.15	6,447.00	12.49	7.87	3,888,095.83	2.023414503
Feb	1,936,973.15	6,447.00	12.49	7.87	3,887,995.83	2.023466545
Mar	1,736,973.15	6,447.00	11.20	7.05	3,888,195.83	1.814442430
Apr	1,936,973.15	6,447.00	12.49	7.87	3,888,345.83	2.023284408
May	2,136,973.15	6,447.00	13.78	8.68	3,887,845.83	2.232483455
Jun	2,036,973.15	6,447.00	13.13	8.27	3,888,095.83	2.127877206
Jul	1,836,973.15	6,447.00	11.84	7.46	3,888,095.83	1.918951800
Aug	1,836,973.15	6,447.00	11.84	7.46	3,888,095.83	1.918951800
Sep	2,036,973.15	6,447.00	13.13	8.27	3,888,095.83	2.127877206
Oct	1,936,973.15	6,447.00	12.49	7.87	3,887,945.83	2.023492568
Nov	1,936,973.15	6,447.00	12.49	7.87	3,888,245.83	2.023336444
Dec	1,936,973.15	6,447.00	12.49	7.87	3,888,095.83	2.023414503

Table 47 Data Operation Boiler of Natural Gas Power Plant

Steam flow rate ton/hr	Temp feed water °C	Temp steam generation °C	Pressure of steam bar_g	Fuel Used ton/hr	HHV kJ/kg
132	208	505	112	9.53	46,707.00
133	209	502	115	9.6	46,707.00
131	202	501	113	9.7	46,707.00
134	210	506	116	9.2	46,707.00
130	201	500	111	9.1	46,707.00
129	201	499	110	9.3	46,707.00
134	209	507	115	9.4	46,707.00
130	201	501	112	9.1	46,707.00
131	203	502	113	9.5	46,707.00
130	199	501	110	9.5	46,707.00
129	198	500	109	9.46	46,707.00
132	206	506	111	9.7	46,707.00

Table 48 Data Operation Turbine Generator of Natural Gas Power Plant

Steam inlet ton/hr	Pressure steam inlet bar_g	Temp steam inlet °C	Pressure steam outlet bar_g	Temp steam outlet °C	Energy actual kW
132	112	505	0.068	45.4	25,517.00
133	115	502	0.062	46	25,287.20
131	113	501	0.062	47	24,901.00
134	116	506	0.061	45	25,829.70
130	111	500	0.064	48	24,703.20
129	110	499	0.063	46	24,464.80
134	115	507	0.06	44	25,976.00
130	112	501	0.061	45	24,758.10
131	113	502	0.065	47	24,993.60
130	110	501	0.059	48	25,042.70
129	109	500	0.058	46	24,612.10
132	111	506	0.06	45	25,671.00

Table 49 Data Operation Boiler of Coal Power Plant

Steam flow rate ton/hr	Temp feed water °C	Temp steam generation °C	Pressure of steam bar_g	Fuel Used ton/hr	HHV kJ/kg
130	171	507	98	19.50	21,511.78
135	169	504	96	19	21,511.78
132	170	502	95	18.9	21,511.78
131	172	507	97	20	21,511.78
129	174	501	93	21	21,511.78
134	176	503	91	22	21,511.78
135	172	508	95	20	21,511.78
129	170	503	91	19	21,511.78
132	169	499	90	18	21,511.78
130	172	509	99	20	21,511.78
134	171	501	89	21	21,511.78
130	174	502	89	20	21,511.78

Table 50 Data Operation Turbine Generator of Coal Power Plant

Steam inlet ton/hr	Pressure steam inlet barg	Temp steam inlet °C	Pressure steam outlet bar_g	Temp steam outlet °C	Energy actual kW
72.17	98	507	0.103	45.4	14,632.10
71	96	504	0.11	44.3	14,291.20
70	95	502	0.108	43	14,015.60
72	97	507	0.12	44	14,628.40
73	93	501	0.14	45	14,618.70
71	91	503	0.11	46	14,359.80
74	95	508	0.104	41	15,134.40
72	91	503	0.106	45	14,565.30
72	90	499	0.156	44.6	14,347.30
73	99	509	0.123	43	14,870.10
70	89	501	0.11	47	14,106.10
71	89	502	0.16	43	14,318.70

Table 51 Data Operation Boiler of Bagasse Power Plant

Steam flow rate ton/hr	Temp feed water °C	Temp steam generation °C	Pressure of steam bar_g	Fuel Used ton/hr	HHV kJ/kg
229	253	475	70.93	121.13	6,447.00
210	264	475	65	123.5	6,445.00
220	262	475	68	122.7	6,423.00
207	257	474	63	121	6,456.00
208	258	474	69	122	6,421.00
214	253	483	70.93	123	6,443.00
215	254	484	74	120.5	6,447.00
220	253	484	70	120	6,454.00
231	250	485	71.2	119	6,453.00
224	249	481	70	121	6,442.00
220	253	484	69	121	6,441.00
215	263	484	68	121	6,454.00

Table 52 Data Operation Turbine Generator of Bagasse Power Plant

Steam inlet ton/hr	Pressure steam inlet bar_g	Temp steam inlet °C	Pressure steam outlet bar_g	Temp steam outlet °C	Energy actual kW
119	66	475	1.1	135.96	21,840.50
110	65	477	1	136.29	20,446.30
107	65	474	1	127.51	19,671.50
114	65	473	1.2	124.87	20,741.60
114	66	479	1.2	125.81	21,163.60
117	64	481	1.1	127.39	22,031.30
117	66	486	1.3	147.87	22,206.70
116	65	484	1.1	144.48	22,036.70
114	66	488	1	127.39	21,995.90
104	63	481	1	126.39	19,685.10
112	64	482	1.2	125.37	21,098.10
116	65	481	1.1	125	21,802.10

Table 53 Data Operation Boiler of Rice Husk Power Plant

Steam flow rate ton/hr	Temp feed water °C	Temp steam generation °C	Pressure of steam bar_g	Fuel Used ton/hr	HHV kJ/kg
25	95	171	480	65	15080
25	96	172	481	66	15072
27	92	172	475	61	15082
28	93	175	479	62	15071
26	92	173	470	60	15070
22	94	169	475	62	15075
24	97	171	482	66	15073
28	98	171	485	64	15072
29	91	173	474	62	15080
28	93	172	473	62	15083
24	95	170	480	67	15083
28	97	174	481	68	15083

Table 54 Data Operation Turbine Generator of Rice Husk Power Plant

Steam inlet ton/hr	Pressure steam inlet bar_g	Temp steam inlet °C	Pressure steam outlet bar_g	Temp steam outlet °C	Energy actual kW
95	65	480	0.087	43.11	20,838.40
96	66	481	0.087	42	21,088.60
92	61	475	0.084	45	20,005.60
93	62	479	0.079	43	20,444.90
92	60	470	0.075	46	19,740.60
94	62	475	0.08	41	20,411.20
97	66	482	0.086	42	21,375.00
98	64	485	0.086	43	21,861.80
91	62	474	0.087	46	19,690.90
93	62	473	0.085	47	20,063.40
95	67	480	0.082	44	20,776.70
97	68	481	0.081	45	21,246.70

Table 55 Performance of Natural Gas Power Plant

Eff. Boiler %	Eff. Turbine %	Eff. Generator %	Overall Performance %
73.63176109	70.33564965	97.03021515	50.25134443
73.18175006	69.25609242	97.030118	49.17760049
72.25186891	69.43696966	98.70527288	49.51995006
77.09053014	69.76474719	97.0297758	52.18456708
76.56239964	69.63630316	97.02993944	51.73173026
70.22943995	69.63996994	97.02920114	47.45480967
75.70668026	70.10290359	97.02995072	51.49629927
76.60521977	69.61190354	97.03006289	51.74259258
73.71981885	69.62723178	97.03003969	49.80461615
73.71666368	69.96281531	97.03027229	50.04263837
73.5494193	69.96844439	97.02991618	49.93293829
72.73348506	70.63863978	97.02972225	49.85187686

Table 56 Performance of Coal Power Plant

Eff. % Boiler	Eff. % Turbine	Eff. % Generator	Overall Performance %
82.76705445	74.87941054	99.79964494	61.85131148
88.32785914	74.84144564	99.80016189	65.97374201
86.55250345	74.09659841	99.8017118	64.0052938
81.22119601	75.18653755	99.80058183	60.94562554
75.62142364	75.16664925	99.79983876	56.72831443
74.94511041	75.72673051	99.80123236	56.64067424
83.8549855	75.6497266	99.80016582	63.30930033
84.37377102	75.6998521	99.79991526	63.74302411
90.9755802	75.58894277	99.79795429	68.62853751
80.68277009	75.93007537	99.80001463	61.13997213
79.0864133	75.83735059	99.80150291	59.85798783
80.23859485	76.32221318	99.80165617	61.11840591

Table 57 Performance of Rice Husk Power Plant

Eff. % Boiler	Eff. % Turbine	Eff. % Generator	Overall Performance %
66.62599469	87.91980288	97.43982264	57.07775676
67.27898089	87.75216378	97.43984902	57.52728007
59.47712996	88.46594351	97.43971688	51.26985992
57.91287904	88.68419683	97.43994835	50.04474007
61.45934358	87.96314038	97.4403007	52.67775507
74.20515604	88.08676101	97.44013091	63.69166211
70.99261372	87.89423907	97.44	60.80101814
61.70979299	88.98051219	97.43982655	53.50390657
54.61206897	87.99733652	97.43993418	46.82687102
57.83817638	87.82518483	97.44011484	49.49615362
69.43551239	87.24317333	97.43992068	59.02690612
60.3924475	87.07770997	97.44007305	51.24213667

Table 58 Performance of Bagasse Power Plant

Eff. % Boiler	Eff. % Turbine	Eff. % Generator	Overall Performance %
65.90230307	83.68520676	95.00011447	52.39301778
58.05913004	83.86161355	95.00007336	46.25489282
61.60039416	83.3075708	95.00038126	48.75209803
59.24006882	84.23668927	94.99990358	47.40673094
59.02027415	84.98243219	94.9999055	47.64897384
61.21970147	85.5415044	94.99984114	49.74975775
62.56575319	86.81444125	95.00015761	51.6003892
64.50185931	85.70589608	94.99970504	52.51763863
68.77293735	85.46976332	94.99997727	55.84105008
65.60089906	85.33620604	95.0002794	53.18240887
64.13459231	86.29432697	95.0000237	52.57730217
61.22098666	85.16412045	95.00002293	49.53141104

Table 59 Control Temperature Steam Inlet Turbine

Temp inlet °C	Turbine Performance %
475	83.68520676
477	83.86161355
474	83.3075708
473	84.23668927
479	84.98243219
481	85.5415044
486	86.81444125
484	85.70589608
488	85.46976332
481	85.33620604
482	86.29432697
481	85.16412045

Table 60 Control Mass Steam Flow Rate Inlet Turbine

Electricity generation kW	Steam Inlet ton/hr
20,304.90	95
20,548.70	96
19,493.40	92
19,921.50	93
19,235.30	92
19,888.70	94
20,827.80	97
21,302.10	98
19,186.80	91
19,549.80	93
20,244.80	95
20,702.80	97

Table 61 Control Exhaust Pressure Turbine

Pressure bar_g	**Turbine Performance** %
0.103	74.8797388
0.11	74.84262896
0.108	74.71041957
0.12	75.07364488
0.14	74.92696278
0.11	75.72615858
0.104	75.65081777
0.106	75.70046828
0.156	75.58809119
0.123	75.12655734
0.11	75.8376164
0.16	76.32243828

Table 62 Control Quality Steam Outlet Turbine

X %	**Turbine Performance** %
0.99	84.5
0.98	86.7
0.97	89.5
0.96	93.5
0.95	96.3
0.94	98.4

Table 63 Control Moisture in Fuel

Moisture %	Eff. % Boiler
56	60.92
55	60.94362927
54	60.96239881
53	60.98116835
52	60.9999379
51	61.01870744
50	61.03747698

Table 64 Control Blow Down Rate

Blow down rate (kg/h)	Eff. % Boiler
3,409	60.92
3,309	60.94
3,209	60.95
3,109	60.96
3,009	60.98
2,909	60.99
2,809	61.00
2,709	61.01

Table 65 Control Temperature Flue Gas

Temperature Flue Gas	Boiler Efficiency
146.65	59.12
141.65	59.72
136.65	60.32
131.65	60.92
126.65	61.25
121.65	62.12
116.65	62.72

Table 66 Control Condenser Pressure

Condenser pressure (bar_g)	Performance of Turbine %
0.9	93.4
0.8	92.7
0.7	92
0.6	91.3
0.5	90.5
0.4	89.8
0.3	89

APPENDIX B PERFORMANCE TESTED OF EQUIPMENT

Gas Analyzer Measure of Outlet Air Heater

Gas Analyzer Measure of Inlet Air Heater

Figure 37 Measure of Gas Emission of Boiler.

Figure 38 Monitor Control Operation of Boiler System

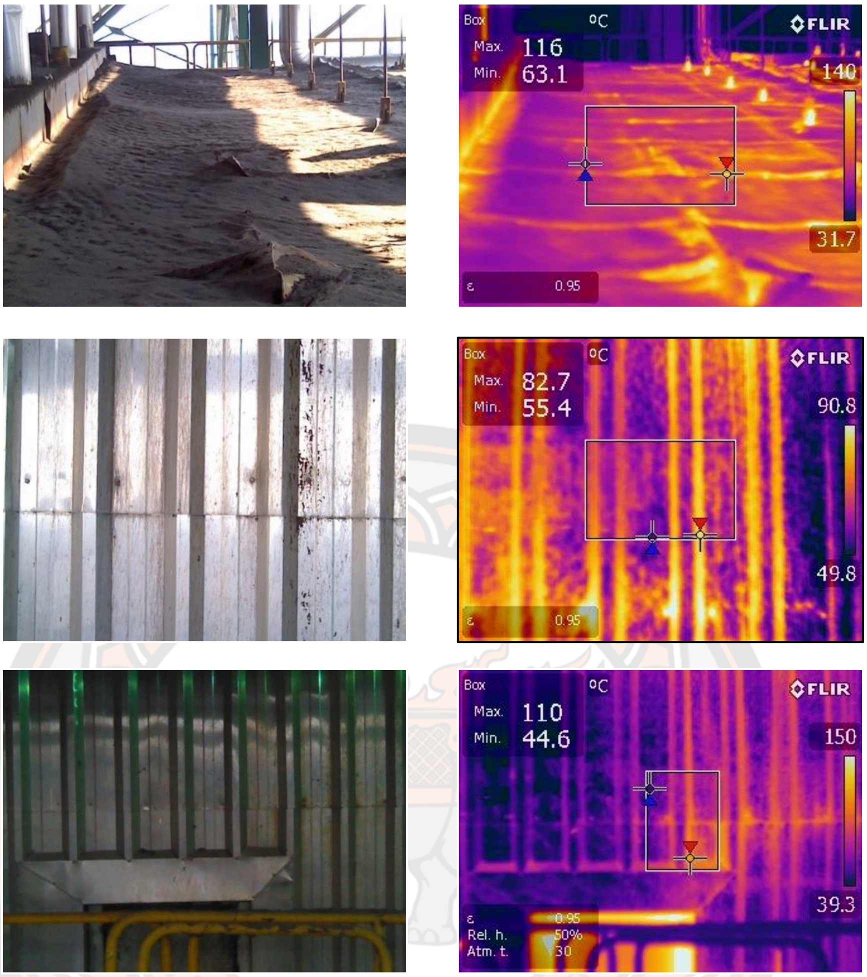


Figure 39 Result Test of Thermal in Surface Boiler

Blowdown steam = 3,409 kg/hr at pressures 72.1 bar

Blowdown flash tank 1 = 3,409 kg/hr at 0.62 bar

Blowdown flash thak 2 = 2,108 kg/hr

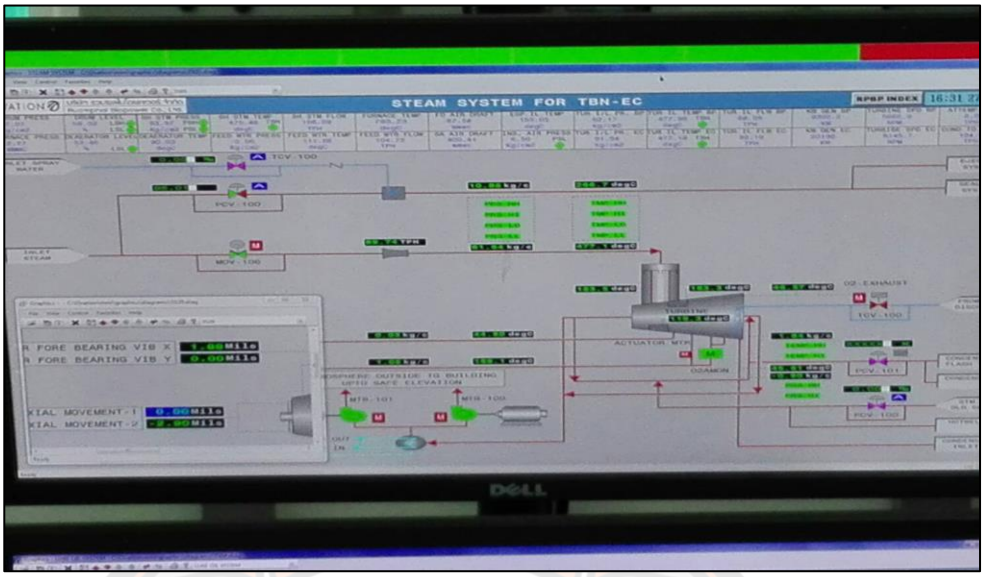
Blow down tank

Figure 40 Blown Down in Boiler

Back pressure steam turbine.

Extraction condensing steam turbine.

Figure 41 Technology of Steam Turbine



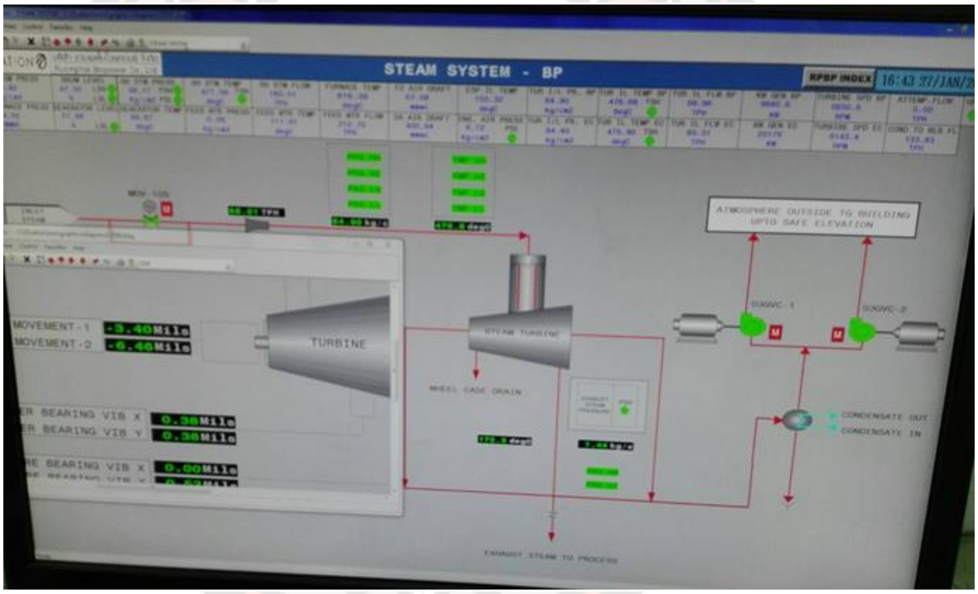


Figure 42 Monitor Operation of Steam Turbine.

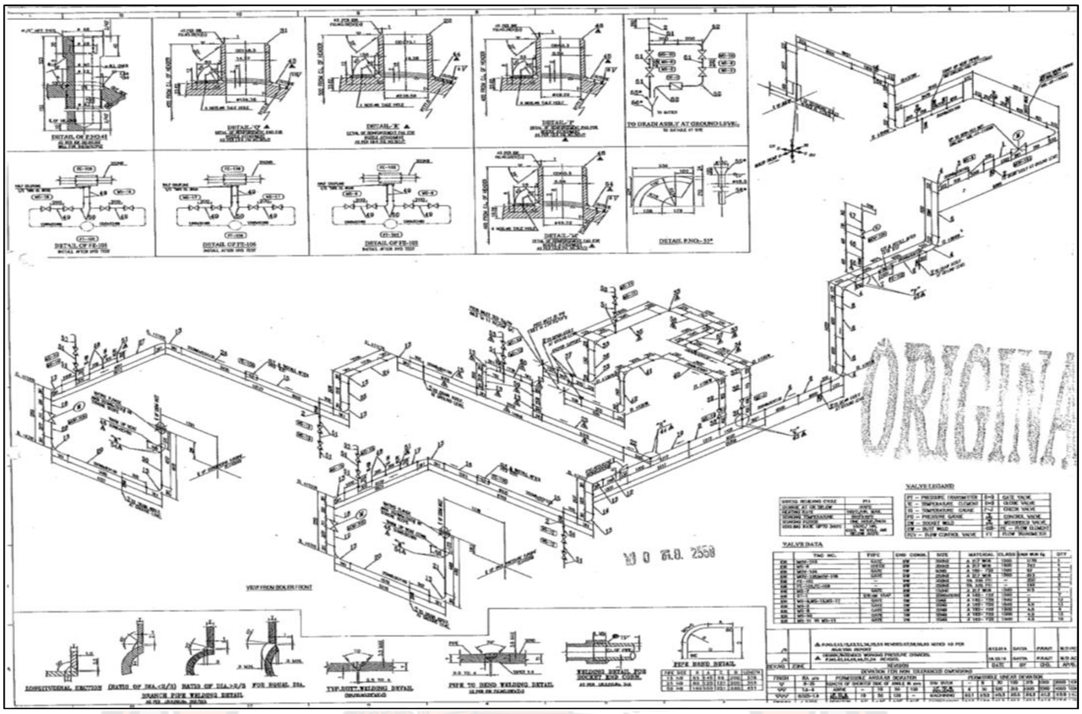


Figure 43 Diagram of Steam Pipe Line.

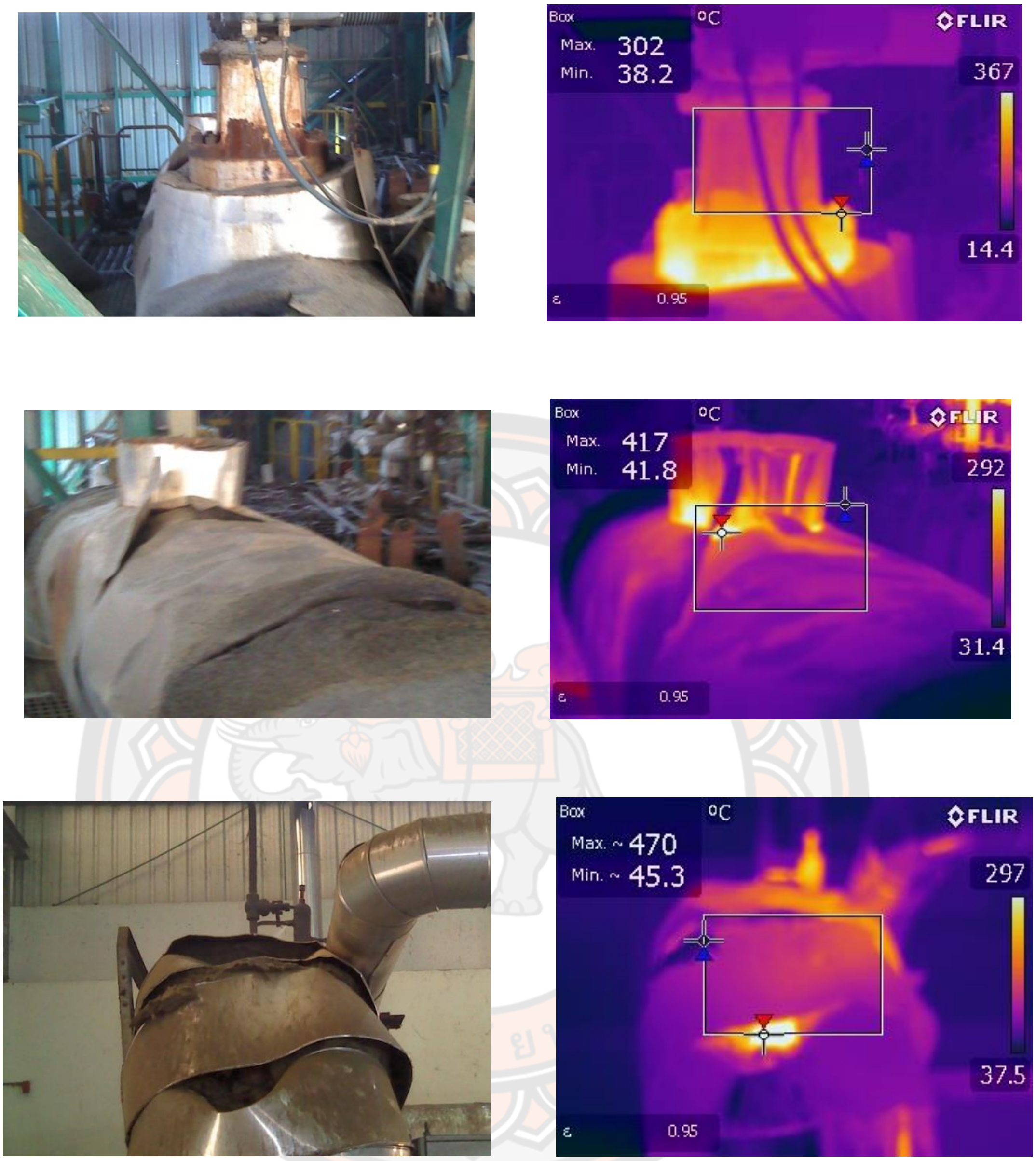


Figure 44 Result of Test Thermal Steam Pipe

Figure 45 Transport of Sugarcane Leaves and Bagasse Feed to Boiler

APPENDIX C PERFORMANCE TESTING TOOLS

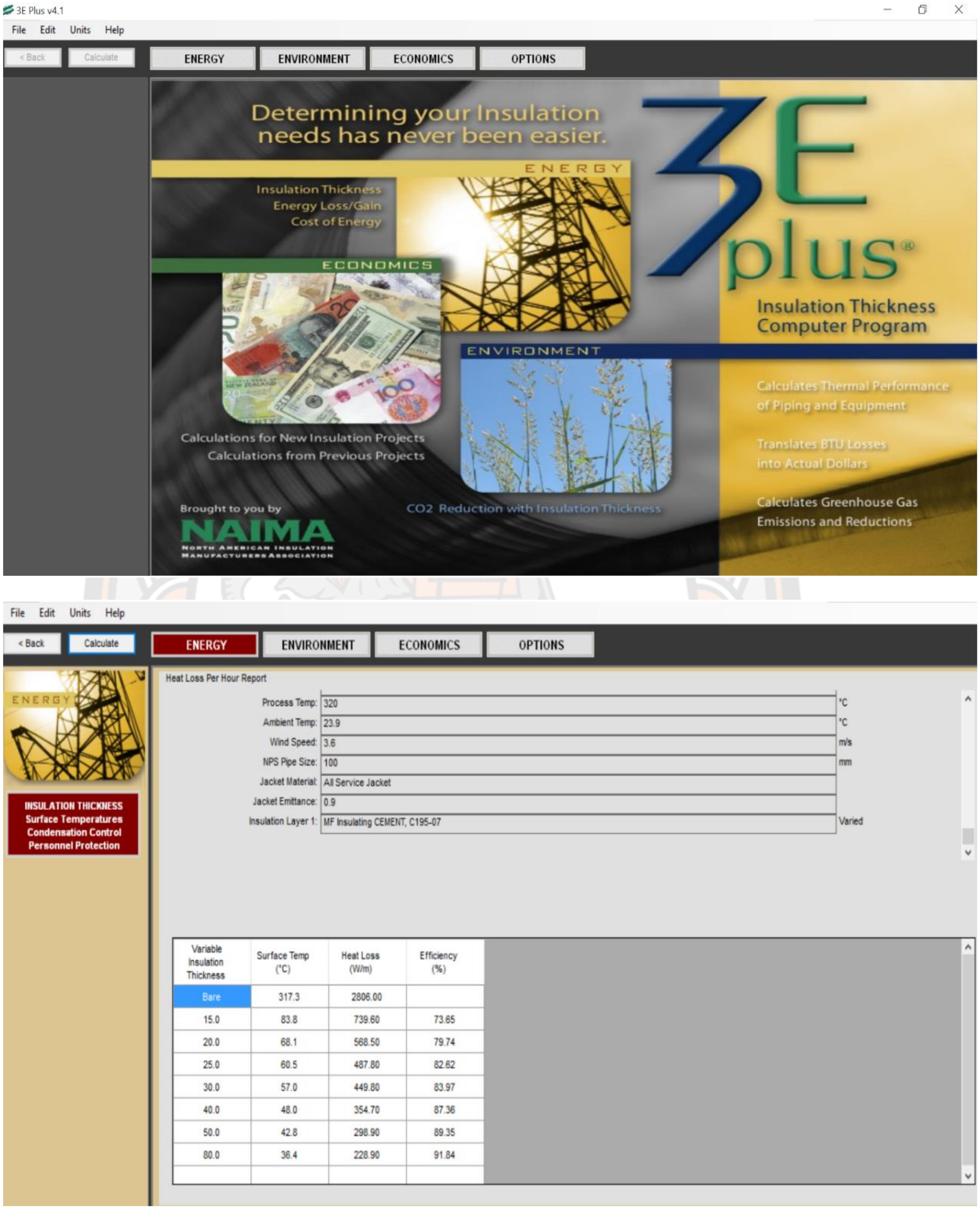


Figure 46 3E-Plus Program of Determine Heat Loss Steam Pipe

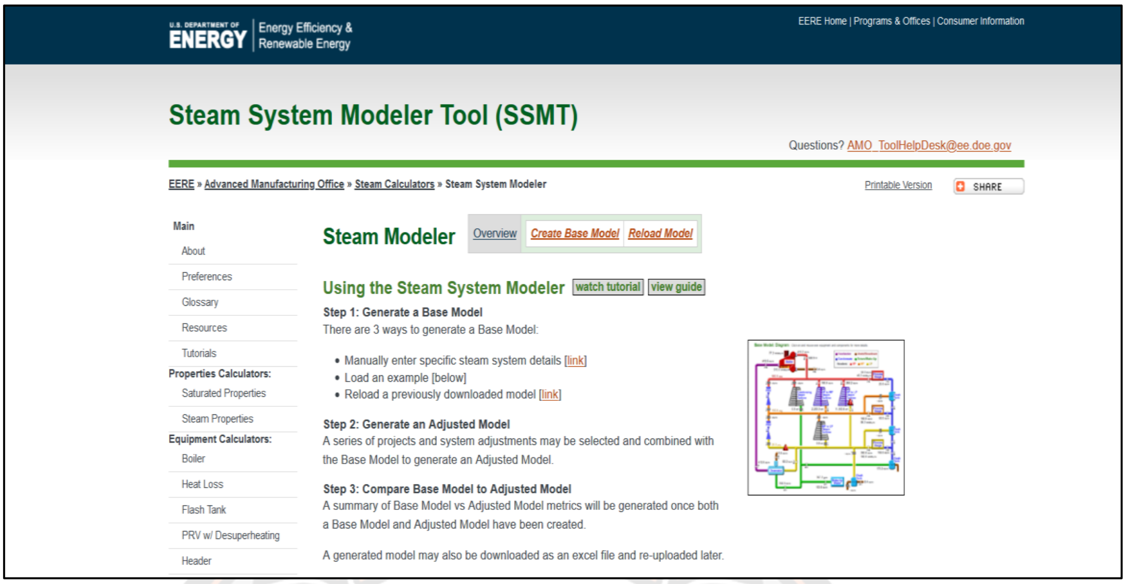


Figure 47 Steam System Modeler Tool (SSMT)

Figure 48 Infrared Thermometer

Figure 49 Testo 350 XL Flue Gas Analyzer

Figure 50 Flow Rate Meter

Figure 51 Pressure Gauge

APPENDIX D DATA RECORD SHEET

Data Sheet of Back Pressure Steam Turbine											
Time	HP Steam (inlet)			Process (Exhaust)			Sugar Factory	Load Plant	Gross power	Install Capacity	Percentage of Rated Output
	Steam Flow rate	Pressure	T	Steam Flow rate	Pressure	T					
	(ton/h)	(bar)	(°C)	(ton/h)	(bar)	(°C)	MW	MW	MW	MW	%
7:00 AM											
8:00 AM											
9:00 AM											
10:00 AM											
11:00 AM											
12:00 PM											
1:00 PM											
2:00 PM											
3:00 PM											
4:00 PM											

Data Sheet of Extraction Steam Turbine

Time	HP Steam (inlet)			Cond (extraction)				EGAT	Install Capacity	Percentage of Rated Output
	Steam Flow rate	Pressure	T	Steam Flow rate	Actual Pressure	Vacuum pressure	T			
	(ton/h)	(bar)	(°C)	(ton/h)	(bar)	(bar)	(°C)	MW	MW	%
7:00 AM										
8:00 AM										
9:00 AM										
10:00 AM										
11:00 AM										
12:00 PM										
1:00 PM										
2:00 PM										
3:00 PM										
4:00 PM										

Time	Data Boiler System												
	Pressure (bar)		Temperature °C						Flow rate (T/h)				
	Steam drum	Main steam	Furnace	FW Outlet ECO	Main steam	Steam inlet BP	Steam inlet EC	Stack	Feed water	Main Steam	Steam inlet BP	Steam inlet EC	Feed Fuel
7:00 AM													
8:00 AM													
9:00 AM													
10:00 AM													
11:00 AM													
12:00 PM													
1:00 PM													
2:00 PM													
3:00 PM													
4:00 PM													

Time	Data Generator System					
	Energy Input		Energy Output			
	HHV kJ/kg	**M_f kg/hr**	**V_p (V)**	**I_p (A)**	**Pf %**	**P (kWh)**
7:00 AM						
8:00 AM						
9:00 AM						
10:00 AM						
11:00 AM						
12:00 PM						
1:00 PM						
2:00 PM						
3:00 PM						
4:00 PM						

Day-Month- Year	Data Fuel Using and Transport Fuel				
	Fuel Using Ton/day	Distance km/day	Type of Transport Ton	Supplementary Fuel Liter/day	
				Type Fuel	Unit

APPENDIX E DESIGN PARAMETERS

DESIGN PARAMETERS

1) **DESIGN BASIS & PHILOSOPHY:**

1.0	**Final output**	**50 MW power plant (25 MW from EC type turbine + 25 MW from Back pressure type**
	Boiler Parameters	**1x250 TPH superheated steam at 67 bar (g) and 500 ± 5°C**
2.0	**Site Conditions**	
2.1	Location	Ruampol Bio Power,Thailand
2.2	Site Altitude	Client to confirm
3.0	**Meteorology**	
3.1	Dry Bulb temperature /	40°C (Max) – (Client to confirm)
3.2	Wet Bulb Temperature	28°C - (Client to confirm)
3.3	Electrical design	50°C - (Client to confirm)
3.4	Relative Humidity	Client to confirm
3.5	Rainfall	Client to confirm
4.0	**Wind / Seismic Data**	
4.1	Wind Velocity	Client to confirm
4.2	Area Classification	Safe & Non – hazardous , Non – Corrosive
4.3	Seismic Zone	Client to confirm

FUEL FIRING:

Main / Guarantee fuel	Bagasse	100% MCR
Auxiliary fuel	Woodchips	30% max

FUEL SIZE:

Fuel size required at the inlet of feeding hopper is as follows

Fuel	**Fuel size**
Bagasse	Milled Pith not more than 20 %

SATURATED STEAM PURITY AT DRUM OUTLET:

Total Dissolved Solids	**PPM**	**0.1**
Silica	**PPM**	**0.02**
Saturated steam purity mentioned above is based on feed water total		

RECOMMENDED FEED WATER AND BOILER WATER REQUIREMENT:

FEED WATER & BOILER WATER REQUIREMENT				
S.No	Description	Unit	Feed Water & Condensate Return	Boiler Water
1	Total Hardness (Max.)	PPM	0	0
2	pH Value at 25°C		8.8 to 9.2	10 to 10.5
3	Oxygen (Max.)	PPM	0.007	--
4	Iron (Max.)	PPM	0.01	0.02
5	Copper (Max.)	PPM	0.01	0.02
6	Silica (Max.)	PPM	0.01	2
7	Total CO_2 (Max.)		0	0
8	Permanganate No. (Max.)		0	0
9	Total Dissolved Solids (Max.)	PPM	0.1	<25
10	Total Suspended Solids (Max.)	PPM	0	0
11	Oil (Max.)	PPM	0	0
12	Specific electrical conductivity at 25°C after Degassing (Max.) in micro siemens / Centimeter		0.2	<50
13	Residual Hydrazine (Max.)	PPM	0.01 to 0.02	0
14	Residual Phosphate (Max.)	PPM	--	15 to 20

INSTRUMENT AIR

S no.	**Parameters**	**Unit**	**Value**
1.	Pressure	Bar (g)	7
2.	Temperature	°C	28
3.	Dew point	°C	-40
4.	Quality		Dry and oil free

COOLING WATER

Sr. no.	Parameters	Unit	Value
1.	Supply Pressure	Bar (g)	3 – 4
2.	Supply Temperature	°C	32 – 40
3.	Quality		Soft

SERVICE WATER

Sr. no.	Parameters	Unit	Value
1.	Supply Pressure	Bar (g)	3 – 4
2.	Supply Temperature	°C	32 – 40
3.	Quality		Soft
A	Clarifier Plant	m^3/h	200
	-TSS	ppm	200
	-Outlet Turbidity	NTU	15
	-Back Wash (average, three days)	m^3	11.04
B	Demin Plant	m^3/h	80
	-Softener Plant	m^3/h	110
	-Multi Grade Filter	m^3/h	80
	-Activated Carbon Filter	m^3/h	80
	-Back Wash (average, once a week)	m^3	24

COOLING TOWER

S no.	Parameters	Unit	
1.	Capacity	m^3/h	8,000
2.	Inlet Pressure	Kg/cm^2g	2.5
3.	Inlet Temperature	°C	32
4.	Temperature Rise (ΔT)	°C	8
5.	Consumer / Purpose		Continues Demand
6.	Turbine Oil Cooler	m^3/h	207
7.	Generator Air Cooler	m^3/h	101
8.	Gland Vent Condenser		Condensate Cooled
9.	Surface Condenser	m^3/h	4,419.23
10.	Evaporation Loss (%)	%	1.11
11.	Reject Water	m^3/h	2.5

PLANT AIR

S no.	Parameters	Unit	Value
1.	Pressure	Bar (g)	7
2.	Temperature	°C	32
3.	Quality		Oil free, clean air

INSTRUMENTATION

S no.	Parameters	Unit	Value
1.	Voltage	Volt	230
2.	Frequency	Hz	50
3.	Type		1 Phase, AC

FIELD TRANSMITTERS

S no.	Parameters	Unit	Value
1.	Voltage	Volt	24
2.	Type		DC

ELECTRIC POWER

S no.	Parameters	Unit	Low Tension	High Tension
1.	Voltage	Volt	400 ± 10	3300 ± 10
2.	Frequency	Hz	50 ± 5	50 ± 5
3.	Combined variation	%	± 10	± 10
4.	Type		3 Phase, AC	3 Phase, AC

2) TECHNICAL SPECIFICATIONS & SCOPE OF SUPPLY OF BOILER

TECHNICAL SPECIFICATIONS

Number of Boilers	:	1
M.C.R. (Maximum Continuous Rating)	:	250 TPH.
Peak Capacity of Boiler	:	287.5 TPH
Minimum possible duration for Peak Capacity	:	2 Hours per Shift (8 Hours)
Pressure at outlet of MSSV	:	67bar (g)
Steam Temperature at outlet of MSSV	:	500 ± 5°C at MCR
Steam Temperature Control range	:	60 - 115 %
Minimum Boiler turndown	:	30 %
Feed water temp at Economizer inlet	:	115°C
Type of furnace	:	Traveling grate, Membrane Wall Construction
Main Fuel	:	100% Bagasse
Auxiliary Fuel	:	30% max Woodchips
Temperature of flue gases at Air heater outlet at MCR approx.	:	130 ± 10°C
Thermal Efficiency at MCR (determined as per ASME PTC 4, indirect i.e. heat loss method)	:	70.5 % (On Gross Calorific Value)
Design Ambient Temperature for Performance Test	:	28 to 45°C
Design Relative Humidity for performance test	:	60 %
Type of Construction	:	Single drum, top supported, Balanced draft, natural circulation, membrane panel, water tube boiler.
Code of design & construction of pressure parts Regulations	:	As per Indian Boiler (IBR) 1950 with latest Amendments / ASME

Boiler will be designed for generating 100% steam at rated pressure & temperature on firing Bagasse.

3) **TECHNICAL SPECIFICATIONS & SCOPE OF SUPPLY OF EXTRACTION CONDENSING TYPE TURBINE**

It is proposed to install One No. TG set of 25 MW Capacity. The new TG set will operate at a boiler steam pressure of 65 bar (g) and temperature of 480 °C. The Turbine will be multi stage impulse reaction, fully condensing.

Sr. No	Description	Capacity (During Season)
1.	Turbine Type	Extraction Condensing
2.	Boiler Steam parameters Pressure (bar (g)) Temperature (°C)	 67 500 ± 5°C
3.	**STEAM FLOW AT TURBINE STOP VALVE (MAX.)**	**150 TPH**
4.	Steam pressure at turbine stop valve (bar (g))	65
5.	Steam temperature at turbine stop valve °C	480
6.	Extraction steam requirement	
	1) Pressure (bar (g))	2.5
	Temperature (°C)	Max. 130
	Flow (TPH)	55TPH (to Steam Transformer)
	2) Pressure (bar (g))	20
	Temperature (°C)	Max. 130
	Flow (TPH)	55TPH (to Mill Turbine and Dryer)
7.	Condenser Operating Pressure (max.)	0.10 ata
8.	Steam to condenser (During crushing)	45 TPH
9.	Cooling water inlet temperature (°C)	32
10.	Power factor (lagging)	0.8
11.	Generation Voltage (kV)	11± 10%

4) <u>TECHNICAL SPECIFICATIONS & SCOPE OF SUPPLY OF BACK PRESSURE TYPE TURBINE</u>

It is propose to install a new TG set of 25 MW. The new TG set will operate at steam pressure 65 bar (g) & temperature of 480 ^{0}C. The turbine will be back pressure type.

S. No	Description	Capacity
1.	Turbine Type	Back Pressure Turbine
2.	Boiler Steam parameters Pressure bar (a) Temperature (°C)	 67 500 ± 5°C
3.	Capacity of turbine	25 MW
4.	Turbine Back pressure	2.5 bar (a)
5.	**STEAM FLOW AT TURBINE STOP VALVE (MAX.)**	**150 TPH**
6.	Steam pressure at turbine stop valve (bar (g))	65
7.	Steam temperature at turbine stop valve °C	480
8.	Power factor (lagging)	0.8
9.	Generation Voltage (kV)	11 ± 10%

The turbine will be designed for the operation with inlet steam parameters of 65 bar (g) & 480°C. The turbine will be design to provide back pressure 2.5 bar (g).

BIOGRAPHY