ISSN: 2354-6751

Performance Efficiency of Heat Recovery Steam Generator (HRSG) Unit 822-B-202 at TPPI Refinery

Irwan Syahrir [1*], Puja Ningrat Wibowo [2], M. Arif Batutah[2], Jamaaluddin Jamaaluddin[3]

[1]Teknik Industri, Fakultas Teknik, Universitas Muhammadiyah Surabaya, Indonesia
[2]Teknik Mesin, Fakultas Teknik, Universitas Muhammadiyah Surabaya, Indonesia
[3]Teknik Elektro, Universitas Muhammadiyah Sidoarjo, Indonesia

E-mail: *Irwan.syahrir@ft.um-surabaya.ac.id*[*]

Abstract

The steam generator is vital equipment in oil and gas refinery industry. One of the steam generator equipment in TPPI Refinery other than boiler is Heat Recovery Steam Generator (HRSG). Determine efficiency performance HRSG Unit 822-B202 in this research using compare between energy heat flow for produce steam and energy heat flow from exhaust gas on HRSG stack. The analyze result of efficiency HRSG Unit 822- B-202 when Start-up Commissioning was gotten 96.42%, on September 2021 92.47%, on October 2021 91.46% and November 2021 88.41%. Has occurred decrease of efficiency from start-up Commissioning until November 2021 about 16.95%. Over the past 3 months, efficiency has tended to decrease since commissioning. The calculated decrease in efficiency after commissioning in September was 3.96%. Then from September to October it decreased by 4.97%. However, in November it decreased again by 8.02%. So, the accumulated decrease in efficiency of HRSG 822-B-202 during the quarter from Commissioning to November 2021 is 16.95%. So, the average decrease in efficiency per month is 5.65%. The decrease in efficiency is caused by changes in the flow of Feed Water and Superheater. If the Feed Water Flow value is smaller and the Superheater Flow value is relatively small, then the HRSG efficiency value will be smaller.

Keywords: *efficiency, performance, HRSG, steam generator, decrease*

1. Introduction

PT. Trans-Pacific Petrochemical Indotama (TPPI Refinery) is a petrochemical company and crude oil processing into Petroleum/Mogas products (LPG, Light Naphtha, Diesel/Solar/Pertadex, PTCF, Premium, Pertamax) and Petrochemical (Paraxylene, Benzene, Ortho-xylene, Toluene, Mixed-xylene. The raw material of the TPPI refinery is condensate which can be processed at around 100,000 barrels/day. The need for steam for the operation of the TPPI Refinery is very vital. Therefore, the continued performance of the steam generator or steam generator is expected to be optimal in maintaining the production process at the TPPI Refinery. Currently, the TPPI refinery has 3 CTG (combustion turbine gas) units and 3 HRSG (heat recovery steam generator) units which are the mainstay of Power Generation and Steam Generation as supporters of the refinery's sustainability. The HRSG unit is very dependent on the remaining exhaust gas from the CTG, where the exhaust gas which still has a high calorific value can be absorbed and utilized by the HRSG to generate steam through the principle of heat exchanger Generation and Steam Generation as a support for the sustainability of the refinery. TPPI has 3 Combustion Turbine Gas units each with a capacity of 23 MW (liquid fuel) with a gas flow rate of 13220 kJ/kW.h.

Heat recovery steam generator (HRSG) is a steam generator that utilizes the residual heat energy from exhaust gas from a CTG unit to reheat the condensed water raw material from the boiler unit so that it becomes steam and is used for steam needs in the Refinery. The main purpose of HRSG is to convert residual heat energy from CTG. When a major inspection or overhaul is carried out on CTG, it is sometimes not accompanied by an overhaul on HRSG due to considerations of work time and urgent steam production needs. Based on EN 12952- 15 thermal efficiency based on Higher Heating Value of HRSG is lower ranging from 70% - 77%. Based on EN 12952- 15 based on Lower Heating Value or DIN 1942 is 80% - 88%. If steam generators with direct combustion have an efficiency of around 95% [1].

Some gas turbine HRSG applications larger than 20MW produce steam at two orthree steam pressure levels. High-pressure steam (600-1800 psig or 4.1 to 12.4 Mpa) which is usually used to drive steam turbines. Intermediate pressure steam (200 – 400 psig or 1.4 – 2.8 MPa) is used for process steam needs in factories or injected into gas turbine combustion chambers to reduce NOX emissions. Low pressure steam (5 – 120 psig or 35 – 825 kPa) is used for factory processes or heating feed water in generators [2]. Such as the research of Rahmad Sugiharto [3], who designed a HRSG with a two-level steam pressure system with a generating capacity of 77 MW. Sahala Hadi Putra Silaban [4], designed a HRSG that utilizes exhaust gas from gas turbines at the steam-fired power plants PT. PLN (Persero) for the generation and distribution of the Belawan Sector in North Sumatra with an efficiency result of 42.76% on the HRSG. Burlian and A. Ghafara [5] redesigned a heat recovery steam generator with a dual pressure system by utilizing the exhaust gas of a 160 MW gas turbine with an efficiency result of 72.14%. Anwar Ilmar and Ali Sandra [6] conducted a performance analysis of HRSG at the Muara Tawar Block 5 steam-fired power plants with an efficiency result of 84.48%.

Research related to HRSG has been conducted previously by several researchers. Example, Bambang Setyoko [7] conducted an analysis of HRSG performance efficiency at steam-fired power plants with the most optimal efficiency result of 54.04%. Eflita Yohana and Rahmat Julyansyah [8], conducted an analysis of the total efficiency of HRSG (heat recovery steam generator) at the 120 MW Combined Cycle Power Plant of PT. Krakatau Daya Listrik with an actual efficiency result of 79.88%.

The above research mostly reviews the efficiency of HRSG in steam-fired power plants. Given the importance of research related to HRSG efficiency, the author also conducted research related to the performance of HRSG unit 822-B-202 at the TPPI Refinery. Observations were made at the beginning of commissioning with existing conditions where the steam needs of the HRSG were not used for the PLTGU but for the process needs at the Refinery. The results of this study are expected to be an evaluation so that HRSG performance can be optimized through overhaul.

1.1 Heat Recovery Steam Generator (HRSG)

HRSG is a steam boiler that utilizes the residual heat energy of exhaust gas from a Combustion Turbine Gas (CTG) unit to reheat the condensed water raw material from the Boiler unit so that it becomes steam and is used for steam needs in the Refinery.

1.2 HRSG Working Principle

HRSG utilizes heat from the combustion residue of Gas Turbine and has a capacity of 75 tons of steam per hour with additional firing. The heat from the turbine has 2 combustions, namely using fuel oil and fuel gas where if using fuel gas can provide a turn down ratio of 1:10.

The first step of the flue gas exiting the furnace passes through the Superheater. The Superheater uses a hairpin tube and convective tube type. Then through the economizer which is used for preheating the feed water (raw material water) that enters the Economizer consists of a Spiral finned tube construction. The HRSG system is also equipped with a Bypass Damper and Duct Burner. The bypass damper is located downstream of the HRSG Inlet Gas Duct and its function is to gradually divert exhaust gas to the HRSG. The duct burner is located upstream of the secondary superheater. Duct burner provides additional energy through heat enhancement with burner thus increasing steam production in HRSG. Duct burner as additional combustion and related equipment such as fuel igniter, flame scanners and burner management system with logic are available. Fuel flow control is done through the Distribute Control System. Flame control on the burners in a row is seen through the ceramic fiber module line combustion chamber located under the HRSG.

Steam drum is equipped with cyclone separator and water drum, feed water, feed water distribution piping, continuous blowdown piping and chemical injection piping vortex braker. There are also 2 safety valves on the drum and one secondary superheater.

1.3 HRSG Efficiency

To calculate the thermal efficiency of HRSG, use the ratio between net work and heat entering the system with the following equation. [9];

$$\eta = \frac{Heat\ that\ is\ utilized}{Heat\ comes\ in} x\ 100\% = \frac{Q_h}{Q_g}\ x\ 100\ \% \quad (1)$$

Q_h = The heat used to produce superheated steam (superheated vapour) → *Output*

Q_g = Heat generated from gas turbine exhaust gases → *Input. used*

To calculate the amount of heat energy from the exhaust gas then supplied to the HRSG, you can use the following equation [7]:

$$Q_g = \dot{m}_{Eg} \; x \; C_p \; (T_{Ex.\,gas} - T_{Ex.stack}) \quad (2)$$

$\dot{m}_{Eg}$ = Exhaust gas mass flow rate, $(\frac{kg}{s})$

C_p = Specific heat of flue gas, $(\frac{kJ}{kg.K})$

$T_{Ex.gas}$ = The temperature of the exhaust gas from the turbine entering the HRSG, (K)

$T_{Ex.stack}$= HRSG exhaust gas temperature to Stack, (K)

To calculate the amount of heat energy absorbed by the HRSG to produce superheated steam, you can use the following equation:

$$Q_h = \sum(h_{HP\,SH} \; x \; \dot{m}_{HP\,SH}) - (h_{HP\,FW} \; x \; \dot{m}_{HP\,FW}) \quad (3)$$

$h_{HP\,SH}$ = Superheated HP Enthalpy, $(\frac{kJ}{kg})$

$\dot{m}_{HP\,SH}$ = Mass flow rate of superheated steam, $(\frac{kg}{s})$

$h_{HP\,FW}$ = HP Feed Water Enthalpy, $(\frac{kJ}{kg})$

$\dot{m}_{HP\,FW}$ = Feed Water Mass Flow Rate, $(\frac{kg}{s})$

2. Methodology

The research stages were carried out by following the flowchart as shown in Figure 1. The data taken from the object of this research were quantitative data obtained through observations for 3 months, namely September, October and November 2021. Observation data is only based on a 3-month period. Parameter data is calculated based on the average per month. Furthermore, to obtain the HRSG efficiency value, an interpolation method approach is used. After that, calculations and analysis were carried out to produce conclusions that could be used for further evaluation.

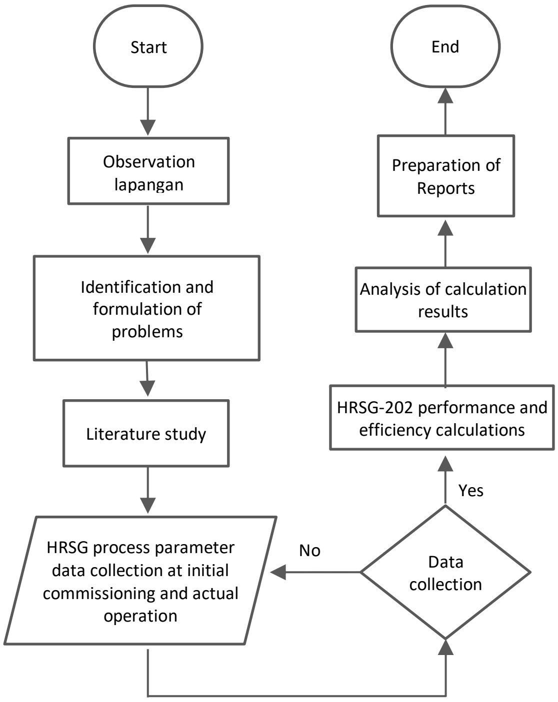

Figure 1. Research Flow Chart

3. Result and Discussion

3.1. HRSG 822-B-202 Operational Data

HRSG 822-B-202 operational data is monitored through process historical data (PFD) and monitoring by distributed control system (DCS) by the operator through daily logsheet. In this study, data was taken for 3 months, namely September, October and November 2021 with CTG load adjusting to operational needs because the electricity requirement at the refinery is 9MW with CTG operating 3 units.

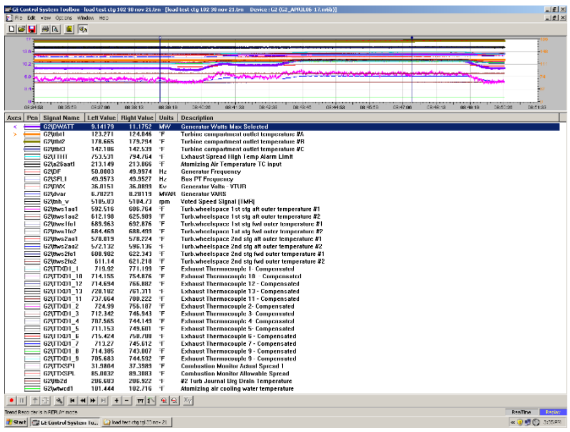

Figure 2. Data parameter monitoring through Process Historical Data (PHD) by OPR

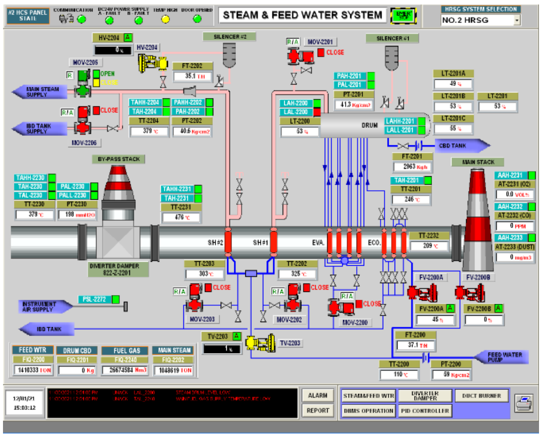

Figure 3. Control the HRSG 822-B-202 via the Distribute Control System (DCS) panel

Based on the system in Figure 2 and Figure 3, a schematic diagram of an HRSG 822-B-202 unit can be drawn to determine the details of the specified parameter configuration.

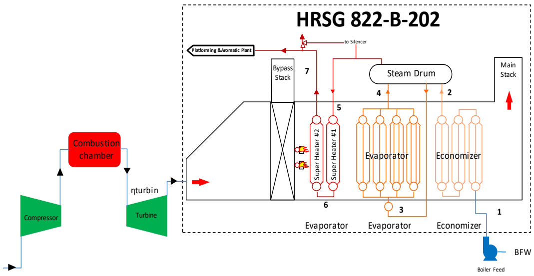

Figure 4. *Schematic diagram HRSG 822-B-202*

Figure 4 shows a schematic diagram of the exhaust gas flow from the combustion turbine gas (CTG) to the HRSG. The CTG 821-G-102 parameters used in calculating HRSG performance are as shown in Table 1.

Table 1.
CTG 821-G-102 Exhaust Parameter Data

Process Parameters	Notation	Value	Unit
Temp. exhaust gas	$T_{Ex.\,gas}$	665.9	°K
Exhaust gas flow rate	$\dot{m}_{Eg}$	116.9	kg/s
Exhaust gas pressure	$P_{Ex.\,gas}$	1.0458	kg/cm^2
Temp. exhaust stack	$T_{Ex.\,stack}$	473.1	°K
Specific heat (Cp)	C_p	1.240	kJ/kg.K

3.2 Performance Calculation of HRSG 822-B-202

HRSG 822-B-202 operational data collection was carried out for 3 months based on the DC daily logsheet. Where in 1 day consists of 3 shifts and 2 data collection was carried out on each shift from September to November 2021. The results of the data collection were then averaged as shown in Table 1 and Table 2. Furthermore, the performance efficiency calculation of HRSG 822-B-202 was carried out by comparing the performance of each month.

In calculating the performance efficiency of HRSG 822-B-202, several assumptions are required to simplify and simplify the calculations as follows:

a. The enthalpy calculation that occurs in HRSG 822-B-202 refers to operational data in this case the DCS Operator's Daily Logsheet.
b. The performance calculation of HRSG 822-B-202 is determined using the output - input method with consideration of operating parameters.

Based on observations of HRSG performance data for the period of September 2021, the following data was obtained:

Table 2.
Average data on HRSG performance for the period September 2021

	T(°C),	P(kg/Cm^2)
Feed Water	107.9	45.8
Superheater	371.3	41.6

Based on the data in Table 2, the Enthalpy (h) values of HP Feed Water and HP Superheater can be calculated using steam table data from Thermodynamics An Engineering Approach ed 8th [9] as shown in Table 3 and Table 4 with the following interpolation method approach:

Table 3.
Saturated Water Thermodynamics Table
(Table A-4 p.904 Cengel and Boles, 2015)

T(°c)	h (kJ/kg)
105	440.3
110	461.4

Table 4.
Superheated Water Thermodynamics Table.
(Table A-6 p.910 Cengel and Boles, 2015)

T(°c)	$h_{4.0}$ (kJ/kg)	$h_{4.5}$ (kJ/kg)
350	3093.3	3081.5
400	3214.5	3205.7

HP Feed Water (FW) and Super Heater (SH) Enthalpy Values:

$$h_{FW;107.9} \quad \frac{(T_{107.9} - T_{106})}{(T_{111.4} - T_{107.9})} \; x \; (h_{111.4} - h_{106})$$

$$= \frac{(107.9 - 105)}{(110 - 107.9)} \; x \; (461.4 - 440.3) + 440.3$$

$$= 469{,}44 \text{ kJ/kg}$$

$$= \frac{(371{,}3 - 350)}{(400 - 371.3)} \; x \; (3214.5 - 3093.3) + 3093.3$$

$$h_{SH;371,3} = \frac{(T_{371.3} - T_{350})}{(T_{400} - T_{371.3})}\ x\ (h_{400} - h_{350}) + h_{350}$$

$$= 3183.25 \text{ kJ/kg.}$$

With the same calculation method, the HP Superheater & HP Feed Water Enthalpy values for September, October, November 2021 and during commissioning are presented in the table below.

Table 5.
Enthalpy Calculation Result Data

Parameter	Notation	*Commissioning*	2021 Sept	Oct	Nov	Unit
Entalpi FW	$h_{HP\ FW}$	486.8	469.4	457.2	457.2	kJ/kg
FW flow	$\dot{m}_{HP\ FW}$	19.9	11.4	12.4	11.3	kg/s
Entalpi S/H#2	$h_{HP\ SH}$	3158.5	3183.2	3140.9	3145.9	kJ/kg
Flow S/H#2	$\dot{m}_{HP\ SH}$	11.6	9.8	9.8	9.6	kg/s

From the Enthalpy calculation data and Operation Parameter Data, the HRSG efficiency is calculated using equations (1), (2) and (3) as follows.:

$$\eta_{HRSG} = \frac{\{(h_{HP\ SH}\ x\ \dot{m}_{HP\ SH})\} - \{(h_{HP\ FW}\ x\ \dot{m}_{HP\ FW})\}}{\{(\dot{m}_{Eg}\ x\ C_p\ (T_{Ex.gas} - T_{Ex.stack})\}}$$

$$= \frac{\{(3183.25\ kJ/kg\ x\ 9.8\ kg/s)\} - \left\{\left(469.44\frac{kJ}{kg}4kg/s\right)\right\}}{\{116.9\ kg/s\ x\ 1.240\ kJ/kg.K\ x\ (665.96\ -\ 473.15)°K\}}$$

$$= 0.9247 = 92.47\ \%$$

So, the HRSG 822-B-202 Efficiency Result for September 2021 is 92.47%. Thus, the results of the HRSG efficiency calculation resume in September 2021, October 2021, November 2021 and during Commissioning can be seen in the following table,

Table 6.
Results of HRSG 822-B-202 Efficiency Calculation

Process Parameters	Notation	*Commissioning*	2021 Sept	Oct	Nov	Unit
FW Temp	$T_{HP\ FW}$	116	107.9	107.4	109	°C
FW Press.	$P_{HP\ FW}$	51.3	59.5	61	59.6	kg/cm^2
Entalpi FW	$h_{HP\ FW}$	486.8	469.44	459.78	524.7	kJ/kg
FW flow	$\dot{m}_{HP\ FW}$	19.9	11.4	12.4	11.3	kg/s
Temp S/H #2	$T_{HP\ SH}$	380	371.3	372.2	372.4	°C
Press S/H #2	$P_{HP\ SH}$	44.8	45.8	43,8	41.6	kg/cm2
Entalpi S/H #2	$h_{HP\ SH}$	3158.5	3183.2	3190.0	3191.6	kJ/kg
Flow S/H #2	$\dot{m}_{HP\ SH}$	11.6	9.8	9,8	9.6	kg/s
Efisiensi Total HRSG	η	**96.43**	**92.47**	**91.46**	**88.41**	**%**

Based on the calculation of HRSG efficiency of unit 822-B-202 as shown in Table 6, the efficiency of HRSG unit 822-B-202 at the time of commissioning was 96.43%, in September 2021, October 2021 and November 2021 respectively it was 92.47%, 91.46% & 88.41% respectively. The highest efficiency was obtained in September, which was 92.47% and the lowest in November, which was 88.41%. During the 3 months, efficiency tended to decrease since commissioning. The decrease in efficiency after commissioning in September was 3.96%. Then in September to October it decreased by 4.97%. However, in November it decreased again by 8.02%. So that the accumulated decrease in efficiency of HRSG 822-B-202 during the quarter from Commissioning to November 2021 was 16.95%. So that the average decrease in efficiency per month was 5.65%.

A graphical comparison of HRSG 822-B-202 efficiency during Commissioning with September, October & November 2021 can be shown as in Figure 4.

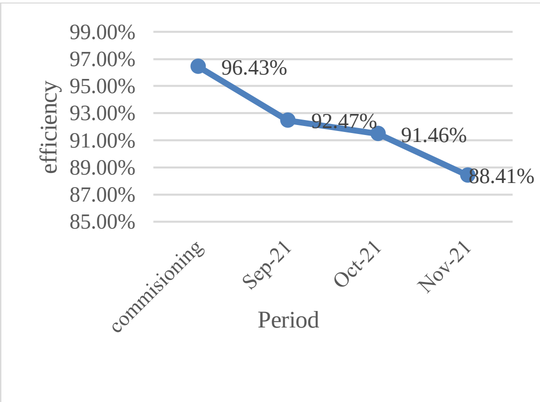

Figure 4. HRSG Efficiency Results Graph Unit 822-B-202

Based on Figure 4, the efficiency since the commissioning period sequentially starting from September, October and November shows a decreasing trend in efficiency. This decrease in efficiency is influenced by the performance factors of Flow Feed Water and Flow Superheater. According to [10], the decrease in HRSG efficiency is not only due to increased load, but there are several things that can reduce efficiency, including the quality of feed water temperature, mass flow of exhaust gas and mass flow of steam produced. A decrease below 95% according to the HRSG Design and Operation [1] standard can have an impact on the performance of the production process. The need for steam for the production process at the TPPI Refinery is very necessary. If the HRSG efficiency performance continues to decline, it can have fatal consequences for the production process, especially for critical equipment units that cannot be properly isolated from steam (insulation steam) so that hydrocarbons break down into the air and flash fire occurs/unit fire. It is hoped that HRSG can produce more Flow on the Superheater side so that efficiency can be more optimal.

Comparison of Flow Feed Water and Flow Superheater performance as shown in Figure 5.

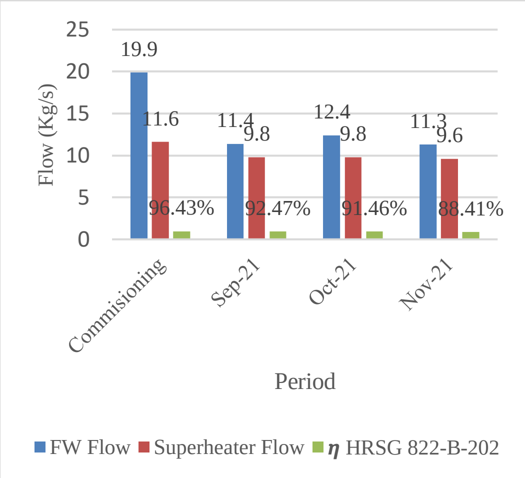

Figure 5. Correlation Graph of Water-Superheater Feed Flow with Efficiency

Based on the diagram, the efficiency value is influenced by the magnitude of Flow Feed Water and Flow Superheater. The relationship between the two is obtained if the Flow Feed Water value is smaller and the Flow Superheater value is relatively constant, then the efficiency value decreases.

4. Conclusions

From the results of the discussion above, the following conclusions can be drawn:

1. The efficiency of HRSG unit 822-B-202 during commissioning was 96.43%, in September 2021 it was 92.47%, in October 2021 it was 91.46% and in November 2021 it was 88.41%.
2. Accumulated decrease in HRSG efficiency for 3 months starting from commissioning to November 2021 was 16.95%.
3. The average decrease in HRSG efficiency during the quarter (September, October & November) was 5.65%.
4. Changes in flow in Feed Water and Superheater affect the HRSG efficiency value. If the Feed Water Flow value is smaller and the Superheater Flow value is relatively constant, the efficiency value will decrease.

The decrease in HRSG efficiency performance will have an impact on the process side due to lack of steam so that critical equipment units are not isolated from steam (insulation steam) and hydrocarbons are released into the air, resulting in a flash fire.

Recommendations

To avoid greater risks due to decreased HRSG efficiency, it is advisable to carry out routine repairs and maintenance on the HRSG. Based on the HRSG efficiency decline data, to prevent an even greater decline in efficiency, repairs should be carried out at least once every 4 months.

Acknowledgement

We would like to express our heartfelt gratitude to the student who played a significant role in this research. Their dedication and participation have greatly contributed to the successful completion of this study. We also extend our deep appreciation to TPPI for providing support and facilitating the involvement of student in this research. The collaboration between the academic and professional environments has enriched the research process and produced meaningful outcomes.

References

[1] C. D. von Eichhain, *Heat Recovery Steam Generators Design and Operations*, 2nd edition. Essen, Germany: PP PUBLICO Publications, 2015.

[2] P. ALSTOM, *HRSG OPERATION & MAINTENANCE*, *West Delta Electricity Production Co. Nubaria Power Station I & II*. Heat Recovery and Plants 2000 Day Hill Road Windsor, Connecticut 06095 USA, 2005.

[3] R. Sugiharto, "Perancangan Heat recovery steam generator (HRSG) dengan Sistem Tekanan Uap Dua Tingkat Kapasitas Daya Pembangkitan 77 MW," Medan, 2009.

[4] S. H. P. Silaban, "Perancangan Heat Recovery Steam Generator (Hrsg) yang Memanfaatkan Gas Buang Turbin Gas di Pltgu PT. PLN (Persero) Pembangkitan dan Penyaluran Sumatera Bagian Utara Sektor Belawan," Universitas Sumatera Utara, Medan, 2013.

[5] F. Burlian and A. Ghafara, "Perancangan Ulang Heat Recovery Steam Generator Dengan Sistem Dual Pressure Melalui Pemanfaatan Gas Buang Sebuah Turbin Gas Berdaya 160 MW Berdaya 160 MW," *Jurusan Teknik Mesin, Fakultas Teknik, Universitas Sriwijaya*, vol. Vol 13, no. No 1 (2013).

[6] A. Ilmar and A. Sandra, "Analisis Unjuk Kerja Heat recovery steam generator

(HRSG) pada PLTGU Muara Tawar Blok 5," *SINTEK JURNAL : Jurnal Ilmiah Teknik Mesin*, vol. Vol 7. No 1, 2013.

[7] B. Setyoko, "Analisa Efisiensi Performa HRSG (Heat Recovery Steam Generation) Pada PLTGU," *Jurnal TRAKSI*, vol. 4, no. 2, 2006.

[8] E. Yohana and R. Julyansyah, "Analisis Total Efisiensi HRSG (Heat recovery steam generator) pada Combine Cycle Power Plant (CCPP) 120 MW PT. Krakatau Daya Listrik," *ROTASI*, vol. 18, no. 2, 2016.

[9] Y. A. Cengel and M. A. Boles, *Thermodynamics : An Engineering Approach Eigth Edition*. USA: Mc Graw Hill, 2015.

[10] B. Sugandi, F. Atabiq, and R. Adelia Asti, "Pengaruh Beban Gas Turbine Generator terhadap Efisiensi Heat Recovery Steam Generator pada Pembangkit Listrik Tenaga Gas Uap (PLTGU)," *ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika*, vol. 11, no. 3, pp. 639–648, Jul. 2023, doi: http://dx.doi.org/10.26760/elkomika.v11i3.639.