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EVALUASI KERUGIAN TERMAL PADA PEMBANGKIT TENAGA BATUBARA 660 MW MENGGUNAKAN METODE EFISIENSI TIDAK LANGSUNG

THERMAL LOSSES EVALUATION IN 660 MW COAL-FIRED POWER PLANT USING INDIRECT EFFICIENCY METHOD

Muhammad Rizaldi Zaman[1]*, Nazaruddin Sinaga[2]

[1]Master of Energy, Engineering Faculty, Diponegoro University
[2]Mechanical Engineering Department, Engineering Faculty, Diponegoro University
Jl. Imam Bardjo SH No.5, Pleburan, Kec. Semarang Sel, Kota Semarang, Jawa Tengah
*email : mrizaldizaman@students.undip.ac.id

ABSTRAK

Boiler adalah salah satu alat utama pada PLTU selain turbin dan generator. Setiap tahunnya pasti ada perbedaan nilai efisiensi boiler aktual dengan kondisi ketika commisioning. Secara periodik evaluasi performa boiler dilakukan dengan tujuan untuk mengidentifikasi kerugian dari beberapa faktor. Dalam studi ini, metode yang digunakan untuk evaluasi adalah metode neraca energi. Selama percobaan, petunjuk standar pengujian (ASME PTC - 4) digunakan. Boiler yang diuji ini memiliki kapasitas 660 MW. Evaluasi dilakukan dengan membandingkan nilai efisiensi boiler pada saat komisioning dengan uji kinerja terkini. Dari hasil pengujian kinerja diketahui penurunan efisiensi boiler jika dibandingkan dengan hasil komisioning dari 86.92% menjadi 82.625%. Penurunan efisiensi boiler disebabkan adanya peningkatan kehilangan panas akibat gas kering, kandungan hidrogen dalam batubara, dan pembakaran yang tidak sempurna.

Kata Kunci: *boiler, efisiensi, evaluasi, penurunan, kinerja*

ABSTRACT

Boilers are one of the main equipment in the PLTU apart from turbines and generators. Each year there must be a difference in the actual boiler efficiency value with the conditions during commissioning. Periodically, boiler performance evaluations are carried out in order to identify losses from several factors. In this study, the method used for evaluation is the energy balance method. During the experiment, the standard test guide (ASME PTC - 4) was used. The boiler under test has a capacity of 660 MW. Evaluation is done by comparing the boiler efficiency value at the time of commissioning with the latest performance tests. From the results of performance testing, it is known that the decrease in boiler efficiency when compared with the commissioning results from 86.92% to 82.625%. The reduction in boiler efficiency is due to an increase in heat loss due to dry gas, hydrogen content in coal, and incomplete combustion.
Keywords: *boiler, efficiency, evaluation, reduction, performance*

1. INTRODUCTION

A boiler are a critical component for coal-fired power plant to provide steam for the turbine, the account of fuel consumption is about 616 million tons of standard coal every year. The actual thermal efficiency of a subcritical coal-fired boiler can average only 40%, while supercritical plants can go up to 46% and advanced ultra-supercritical plants can be greater than 48% (Chao et al., 2017)It is

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important to establish appropriate combustion system and boiler design based on fuel types and characteristics in terms of energy economy. Typical problems of boiler combustion for example is incomplete combustion and high carbon content in slags. Boiler manufacturer will ensure the predicted boiler thermal performance and emission behavior.(Behbahaninia, Ramezani and Lotfi Hejrandoost, 2017) To reach this goal, it is to realize a boiler design created most properly in terms of efficiency, boiler safety, environmental compliance, reliability, boiler safety.

The performance of a boiler can be improved by different analyses endeavored based on the first and second laws of thermodynamics. Common boiler analyses and one of the most validated is energy auditing. Two method can be used for energy auditing of boilers, direct and indirect method. In the direct method, efficiency is calculated by dividing energy delivered by the boiler by energy input as fuel. The efficiency can be measured easily by measuring all the losses occurring in the boilers using the principles to be described. The disadvantages of the direct method can be overcome by this method, which calculates the various heat losses associated with boiler. (Tirumala Srinivas, 2017) One of the most well-known versions of this method is the standard ASME ptc4 2013. The indirect method calculates the different item of losses and subtracts all the loss percentages of 100 to calculate the efficiency. The greatest advantage of indirect method is that it also speaks about the sources of losses. By finding out indirect efficiency, one can come to know where the losses are increased and can be reduced..

Thermal efficiency reflects boiler operation & maintenance. Reductions in boiler efficiency and evaporation ratio concerning time are reported due to fouling of heat transfer, poor combustion, operation & maintenance. (Erbas, 2021) Fuel and water quality reduction can also lead to poor boiler efficiency. This paper will discuss the evaluation of efficiency performance using the indirect method on a coal-fired power plant boiler with a capacity of 660 MW in Indonesia.

Coal-fired boilers are used to produce steam at the high pressure and temperature (subcritical) required by the steam turbine to drive an electric generator. The boiler consists of a furnace, steam drum, superheater, reheater, economizer, water pre-heater. Equipment for airflow and exhaust gas includes the forced draft fan, primary air fan, air pre-heater, electrostatic precipitator, induced draft fan as shown in Figure 1.

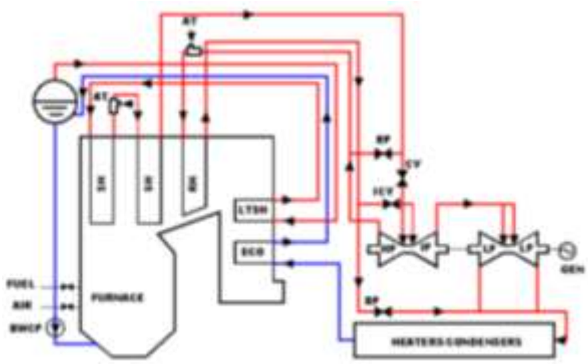

Figure 1. Schematic Diagram of Boiler

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2. Research Methodology

2.1 Experimental Produre

The performance test of the pulverized coal boiler (2300 t/h capacity) was organize ensuing ASME PTC - 4. Continuous opertaing conditions is being maintained for 4 hours. Some condition that need to satisfied before test are boiler cleaning was checked, and soot blowing was performed. During the experiments, soot blowing process is stopped. And before running, measuring instruments and sensors were calibrated and checked.(Ghalandari, Majd and Golestanian, 2019)

From the started, coal sample were taken from the coal feeder spot. Every hour each coal feeder is taken separately. The samples were taken and analyzed in a certified laboratory. As reported by the results of the analysis, the average caloric value (lower thermal value) of coal was 4777 kcal/kg.

Table 1.

	Fuel Used
LHV (kcal/kg)	4,331
Moisture (%)	31.7
Ash (%)	3.5
Sulfur (%)	0.2

2.2 ENERGY BALANCE METHOD

Energy audit of a boilers that developed to the thermal loss method of ASME ptc-4 that is based on the first law of thermodynamics is used as a method in this study. The energy balance method (ASME PTC-4) used in the analysis of the boiler's efficiency and emission values is also called the "heat balance method" A method of determining steam generator efficiency by a detailed accounting of all energy entering and leaving the steam generator envelope. (Codes, 2008)

Efficiency can be obtained, by reducing the total heat loss from 100. An important advantage of this method is that an error in measurement does not make a significant change in the efficiency, since the calculated heat loss is a small part of the boiler system. (Aravind et al., 2020) So, if the boiler losses are 10% with an error of 1% in the indirect method it will result in a change in boiler losses, which is 10% ± 0.1% = 9.9% to 10.1% or equivalent to an efficiency boiler 89.9% to 90.1%. The Energy balance in the boiler is shown in figure 2.

This study does not take heat credits from outside the boiler system that enters the boiler into account. In this study, only seven types of boiler heat losses are calculated, the boiler efficiency equation using the indirect method as follows:

$$\eta \text{ indirect} = 100\% - (L1+L2+L3+L4+L5+L6+L7) \quad (1)$$

where,

L1: Heat Loss due to Heat in Dry Flue Gas
L2: Heat Loss due to Moisture in Fuel
L3: Heat Loss due to Moisture from Burning of Hydrogen in Fuel
L4: Heat Loss due to Moisture in Air
L5: Heat Loss due to Combustible in Refuse
L6: Heat Loss due to Surface Radiation and Convection (determined by ABMA Chart)
L7: Unmeasured Losses (determined by manufacture)

$$L1 = 100 \times MqDFg \times HDFgLvCr, \% \quad (2)$$

Where,

MqDFg: dry gas mass flow leaving the steam generator, kg/kJ
HDFgLvCr: enthalpy of dry gas at the temperature leaving the gas air preheater (excluding leakage), kJ/kg

$$L2 = 100 \times MqWF \times (HStLvCr - HWRe), \% \quad (3)$$

Where,

MqWF: moisture from H2O in fuel, kg/kJ
HStLvCr: enthalpy of steam (water vapor) at 1 psia at temperature leaving

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the gas air preheater (excluding leakage), kJ/kg

HWRe: enthalpy of water at the reference temperature (TRe: 25°C(77°F)), kJ/kg

L3 = 100 x MqWH2F x (HStLvCr - HWRe), % (4)

Where,

MqWH2F: moisture from the combustion of hydrogen in the fuel, kg/kJ

HStLvCr: enthalpy of steam (water vapor) at 1 psia at temperature leaving the gas air preheater (excluding leakage), kJ/kg

HWRe: enthalpy of water at the reference temperature (TRe: 25°C(77°F)), kJ/kg

L4 = 100 x MFrWDA x MqDA x HWLvCr ,% (5)

Where,

MFrWDA: moisture in air, kg H2O/kg dry air

MqDA: mass of dry air corresponding to the excess air used for dry gas loss, kg/kJ

HWLvCr: enthalpy of water vapor at temperature leaving the gas air preheater (excluding leakage), kJ/kg

L5 = MpUbC x HHVCRsHHVF , % (6)

Where,

MpUbC: unburned carbon in fuel, % mass

HHVCRs: heating value of carbon as it occurs in residue = 33,700 kJ/kg

HHVF: the higher heating value of fuel at constant pressure, kJ/kg.

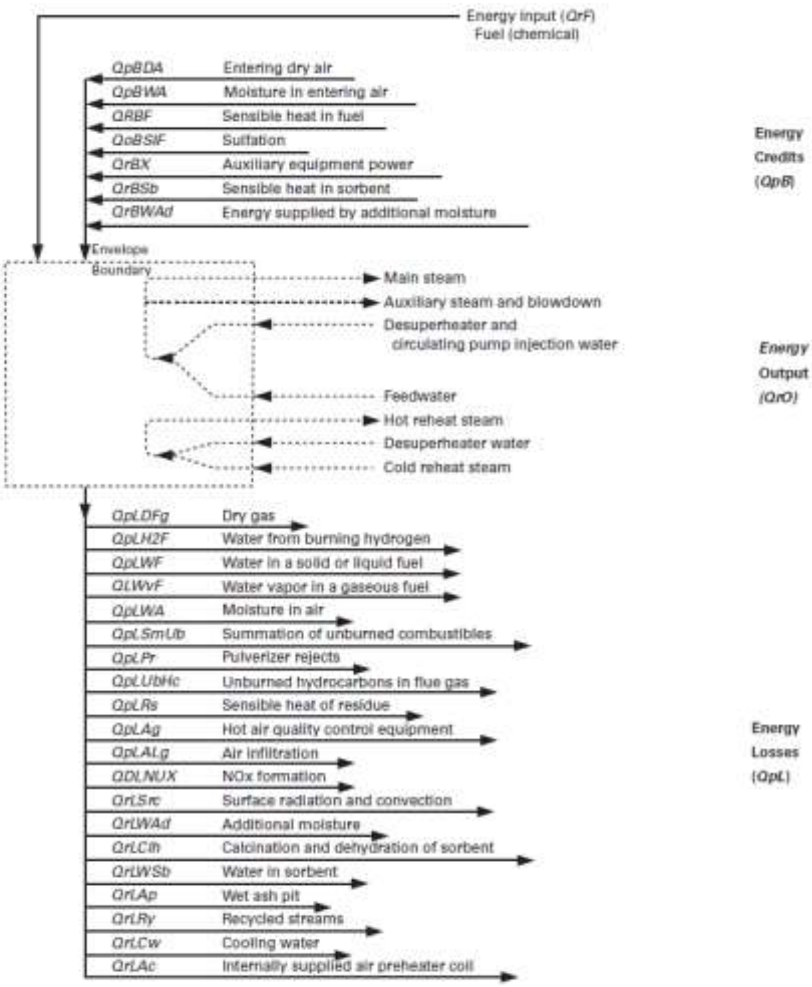

Figure 2. Energy balance in the boiler

This study does not take heat credits from outside the boiler system that enters the boiler into account. In this study, only seven types of boiler heat losses are calculated, the boiler efficiency equation using the indirect method as follows:

$$\eta \text{ indirect} = 100\% - (L1+L2+L3+L4+L5+L6+L7) \quad (1)$$

where,

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L2: Heat Loss due to Moisture in Fuel
L3: Heat Loss due to Moisture from Burning of Hydrogen in Fuel
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L1 = 100 x MqDFg x HDFgLvCr, % (2)

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MqDFg: dry gas mass flow leaving the steam generator, kg/kJ
HDFgLvCr: enthalpy of dry gas at the temperature leaving the gas air preheater (excluding leakage), kJ/kg

L2 = 100 x MqWF x (HStLvCr - HWRe), % (3)

Where,

MqWF: moisture from H_2O in fuel, kg/kJ
HStLvCr: enthalpy of steam (water vapor) at 1 psia at temperature leaving the gas air preheater (excluding leakage), kJ/kg
HWRe: enthalpy of water at the reference temperature (TRe: 25°C(77°F)), kJ/kg

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L4 = 100 x MFrWDA x MqDA x HWLvCr ,% (5)

Where,

MFrWDA: moisture in air, kg H_2O/kg dry air
MqDA: mass of dry air corresponding to the excess air used for dry gas loss, kg/kJ
HWLvCr: enthalpy of water vapor at temperature leaving the gas air preheater (excluding leakage), kJ/kg

L5 = MpUbC x HHVCRsHHVF , % (6)

Where,

MpUbC: unburned carbon in fuel, % mass
HHVCRs: heating value of carbon as it occurs in residue = 33,700 kJ/kg
HHVF: the higher heating value of fuel at constant pressure, kJ/kg

3. RESULT AND DISCUSSION

The performance test on the boiler aims to determine the efficiency of the boiler after operating for a certain period of time. Evaluation of boiler efficiency performance is carried out by comparing the boiler efficiency value during the performance test with the commissioning results using the indirect method according to ASME PTC-4 standard (Asme, 2008). Before the performance test data collection process, it is necessary to stabilize the load and operating parameters for 1 hour. Before the load stabilization process, a soot blower

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operation is carried out to clean the coal ash attached to the boiler pipe surface and air preheater (AH) element, so that the boiler is in clean condition.

The performance test is carried out at a stable load of 660 MW for 2 hours for the data retrieval process. The blowdown and makeup water valves were closed during the performance test. Coal samples are taken from all coal feeders which operate for 3 times sampling during the performance test, then all collected samples are mixed to get a representative coal sample. Bottom ash and fly ash samples was taken once during the last 15 minutes before the performance test ended. Data of flue gas temperature, % CO, and% O2 were taken from the inlet and outlet of AH using a portable flue gas analyzer. The coal sample is then analyzed in the laboratory to obtain the ultimate analysis result. The comparison of the coal ultimate analysis during the performance test and commissioning is shown in the following table.

Table 2. Coal Analysis

	Symbol	**Unit**	**Commisioning**	**Test**
Carbon	C_{ar}	kg/kg	0.472	0.45
Hydrogen	H_{ar}	kg/kg	0.034	0.057
Oxygen	O_{ar}	kg/kg	0.133	0.156
Nitrogen	N_{ar}	kg/kg	0.007	0.007
Sulfur	S_{ar}	kg/kg	0.004	0.002
Moisture	M_{ar}	kg/kg	0.307	0.317
Ash	A_{ar}	kg/kg	0.044	0.035
HHV	H_F	Kcal/kg	4519	4331

Table 3. Boiler Operating Parameters

Reference Air Temperature	**Symbol**	**Unit**	**Commisioning**	**Test**
Primary Air Temperature Entering AH A		^{O}C	44.150	45.054
Primary Air Temperature Entering AH B		^{O}C	43.720	44.521
Secondary Air temperature entering AH A		^{O}C	33.650	36.860
Secondary Air temperature entering AH B		^{O}C	33.840	36.164
Primary air temperature Outlet AH A		^{O}C		346.256
Primary air temperature Outlet AH B		^{O}C		356.681
Secondary air temperature Outlet AH A		^{O}C		350.202
Secondary air temperature Outlet AH B		^{O}C		361.036
FD Fan Air Flow 1	$W_{A8(1)}$	t/h	941.500	1157.367
FD Fan Air Flow 2	$W_{A8(2)}$	t/h	941.500	1050.992
Total air flow		t/h	2724.000	3026.21
PA Flow 1	$W_{A8(1)}$	t/h	420.500	408.925
PA Flow 2	$W_{A8(2)}$	t/h	420.500	408.925
Primary Air pressure at inlet AH A	P_{a2}	mbar		116.559
Primary Air pressure at inlet AH B	P_{a2}	mbar		114.158
Secondary Air pressure at inlet AH A	P_{a2}	mbar		18.093
Secondary Air pressure at inlet AH B	P_{a2}	mbar		17.603
Secondary air pressure at outlet AH A		mbar		108.185
Secondary air pressure at outlet AH B		mbar		104.638
Secondary air pressure at outlet AH A		mbar		12.774
Secondary air pressure at outlet AH B		mbar		11.767
Reference Gas				

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Flue Gas Temperature at AH A inlet	$t_{G14(1)}$	^{O}C	361.41	383.753
Flue Gas Temperature at AH B inlet	$t_{G14(2)}$	^{O}C	365.03	391.699
Flue Gas Temperature at AH A outlet	$t_{G15(1)}$	^{O}C	129.52	151.932
Flue Gas Temperature at AH B outlet	$t_{G15(1)}$	^{O}C	133.96	163.273
Flue Gas Pressure at AH A inlet		Mbar		-11.532
Flue Gas Pressure at AH B inlet		Mbar		-12.468
Flue Gas Pressure at AH A outlet		Mbar		-20.505
Flue Gas Pressure at AH B outlet		Mbar		-21.388
Excess Air	$[A'_X]_{15}$	Mbar		
Flue Gas Analysis				
Oxygen inlet AH A		%	3.210	1.897
Oxygen inlet AH B		%	3.490	3.088
Oxygen outlet AH A	$[O_2]_{15}$	%	4.460	3.472
Oxygen outlet AH B	$[O_2]_{15}$	%	4.460	5.521
Carbon Monoxide inlet AH A		%	4.000	0.001
Carbon Monoxide inlet AH B		%	4.000	0.000
Carbon Monoxide outlet AH A	$[CO]_{15}$	%	0	0.000
Carbon Monoxide outlet AH B	$[CO]_{15}$	%	0	0.000
Carbon Dioxide inlet AH A		%	0	17.261
Carbon Dioxide inlet AH B		%	0	16.214
Carbon Dioxide outlet AH A	$[CO_2]_{15}$	%	14.910	15.333
Carbon Dioxide outlet AH B	$[CO_2]_{15}$	%	14.910	13.500
Nitrogen inlet AH A		%	92.790	80.841
Nitrogen inlet AH B		%	91.510	80.698
Nitrogen outlet AH A	$[N_2]_{15}$	%	80.630	81.194
Nitrogen outlet AH B	$[N_2]_{15}$	%	80.630	80.979

Table 4. Ash and Slag Properties

Ash & Slag	**Symbol**	**Unit**	**Commisioning**	**Test**
Unburned carbon in fly ash	U_{CF}	%	0	0.74
Unburned carbon in ash of economizer hopper ash	U_{Ce}	%	0	0
Unburned carbon in bottom ash	U_{Cb}	%	0	8.33

Result of boiler efficiency with the indirect method can be seen in the following table
Table 5. Boiler heat loss and efficiency

Particulars	**Unit**	**Commisioning**	**Test**
Ambient Temperature	^{O}C	33.3	30.11
Excess air	%	27.13	27.98
Heat Losses			
Dry Flue Gas (L1)	%	4.07	4.5
Moisture in Fuel (L2)	%	4.21	4.95
Hydrogen in Fuel (L3)	%	4.17	7.01
Moisture in air (L4)	%	0.15	0.04
Unburnt carbon in ash (L5)	%	0	0.4
Radiation (L6)	%	0.18	0.18
CO Loss	%		0

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Unaccounted Loss (L7)	%	0.3	0.3
Total Heat Loss	Kcal/kg	591.09	752.79
Gross Boiler Efficiency on HHV	%	86.92	82.625
Guaranteed Efficiency	%	83.59	

The results of performance evaluation, there was a decrease in boiler efficiency during the performance test when compared against commissioning value from 86.92% to 82.65% or 4.295 % efficiency reduction. From the above analysis, there was an increase in heat loss due to dry gas from 4.5% to 4.07%. The increase in heat loss due to dry gas was caused by an increase in corrected flue gas outlet temperature (exclude air leakage) from 138.47 ^{O}C to 141.69 ^{O}C. Possible factors causing the increase in gas flue temperature include: decreased heat transfer effectiveness in boiler pipes due to slagging or fouling, decreased heat transfer effectiveness in AH due to fouling or corrosion. There was an increase in heat loss due to the moisture content in coal from 4.95% to 4.21%. This increase was caused by the use of coal with higher moisture content during the performance test, which is 30.7%, while compared against commissioning using coal with the moisture content of 31.07%. There was an increase in heat loss due to the hydrogen content of coal from 4.17% to 7.01%. This is due to the use of coal with a higher hydrogen content during a performance test, which is 5.7%, while the commissioning uses coal with a hydrogen content of 3.4%. There was an increase in heat loss due to the moisture content in the combustion air from 0.15% to 0.17%. This is due to the increase in relative humidity during the performance test, which is 72.778%, while the relative humidity during commissioning is 70%. There was an increase in heat loss due to incomplete combustion from 0.0% to 0.04%. This is because it was found that the amount of unburnt carbon during the performance test increased. Incomplete combustion can be caused by several factors, including the excess air value that is operated is too low, coal that is delivered to the boiler in wet conditions, unbalanced distribution of combustion air in the boiler.

Boiler efficiency depends on the quality of the coal and the boiler operating parameters. Coal with a higher HHV mostly results from higher boiler efficiency (Chen et al., 2021). Since typical coals with higher HHV contain lower moisture and hydrogen content (Nuraini, Salmi, and Aziz, 2020). While the operating parameters that affect boiler efficiency are AH flue gas outlet temperature and excess air being operated. Higher flue gas temperature will lead to higher dry gas loss. If the excess air is too high it will also result in higher dry gas losses because the mass of dry gas increases, but if the excess air is too low it can also have the potential for incomplete combustion. Flue gas temperature and excess air operating regime should follow the manufacturer's design recommendations to obtain optimal boiler efficiency. (Lu et al., 2010)

4. CONCLUSION

Thermal performance and thermal losses of a pulverized coal boiler were examined as stated in the energy balance method. There was a boiler efficiency reduction during the performance test when compared against the commissioning value from 86.92% to 82.625%. By using the indirect method, we can identify any losses in the boiler. The indirect method also has better accuracy than the direct method, since the calculated heat loss is a small part of the boiler energy system. In general, the boiler efficiency for each unit has decreased when compared to the conditions during commissioning (new and clean), the causes include lower GCV value, supply to the auxiliary steam header (not closed cycle), changes in operating patterns, decreased heat transfer. slagging and fouling), decreased air heater performance, decreased coal Pulverizer performance. Final Feed Water Temperature tends to decrease when compared to commissioning.

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