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# Redesign of Boiler Heat Recovery Steam Generator (HRSG) on The Utilization of Waste Gas in The Cement Industry

**Fiqri Hadi Hendriyansyah[1)], Rifania Nendry Wilie Permatasari [1)], and Vibianti Dwi Pratiwi[1,2*)]**

[1)]Department of Chemical Engineering, Faculty of Industrial Engineering, Institut Teknologi Nasional Bandung
Jl. Phh. Mustofa No. 23, Neglasari, Bandung, Indonesia
[2)] Department of Chemical Engineering, Faculty of Industrial Engineering, Institut Teknologi Sepuluh Nopember
Jl. ITS Raya, Keputih, Surabaya, Indonesia

[*)] Corresponding author: vibiantidwi@itenas.ac.id

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## Abstract

*Approximately, 20%-50% of the total energy consumption during cement production is disposed of unintendedly as waste heat. This is very unfortunate considering that this waste heat still has the energy that can be further utilized. The heat recovery steam generator (HRSG) boiler system is one of widely used solutions in the chemical industry process to save operating costs in the chemical industry process. The purpose of this research is to determine the amount of energy that can be saved by implementing the HRSG system under ideal operating conditions. Based on the simulation results, the HRSG boiler design can produce steam with a temperature of 235°C and subsequently reduce the flue gas temperature from 244°C to 140.6°C. The HRSG system produces energy in the power turbine up to 1,756 kW with total energy exchanged in the system of 17,567.38 kW from the total energy in the flue gas of 20,693.96 kW and provides an overall efficiency of 84.61% at steady state conditions.*

**Keywords:** Aspen HYSYS, Waste Heat, Heat Recovery Steam Generator (HRSG)

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## INTRODUCTION

The steady population growth and growing economy have encouraged the industry to develop rapidly following the community's needs in Indonesia. As a state-owned company, PT. Semen Gresik has engaged in cement production for decades, with the main product being portland cement, and is one of the subsidiaries of PT. Semen Indonesia Persero (Tbk). In addition, there is also PT. X has with a production capacity of about 24.9 million tons/year (Situmorang, 2020).

Basically, cement production process includes material preparation, grinding, burning-cooling, final grinding, and packing. The primary raw material for cement products is limestone, which is crushed and pulverized into fine solid powder. It is mixed with other materials, such as clay, silica sand, and iron sand. After the mixing process, this solid mixture will then go through a calcination process where this mixture will be calcined at a very high temperature reaching a temperature of 1300-1400°C to form a product, called clinker. Through this process, it can be seen that the cement industry is an industry that requires a large amount of energy, so that the use of heat in the production process must be as efficient as possible to save fuel consumption which in the end will have an impact on reducing fuel purchase expenditures (Yuninto, 2015). Rufaidah et al. (2014) utilized 20-50% of the heat lost as waste during cement production process at PT. Semen Gresik by designing a Heat Recovery Steam Generator (HRSG) boiler system. The HRSG system can generate electrical energy in the power turbine up to 1,142 kW, with the research variables used, namely the flow rate of water entering the economizer and the rate of steam entering the steam drum (Rufaidah, Pratiwi, Sutikno, & Handogo, 2014). Looking at the success in utilizing waste heat from this research, the HRSG system can also be applied to other cement factories, one of which is the PT. X, where the utilization analysis will be evaluated in this study. Rufaidah et al. (2004) research focused on the simulation by changing the steady state to a dynamic state. Differences in the selection of factories with very different capacities, production processes and operating conditions make a difference in the simulations and the values of the manipulation variables where in Rufaidah et al. is the feed water flow rate that enters the economizer while in this study the temperature of the feed water that enters the economizer will be optimized so that the optimum conditions obtained from this study are very different.

The hot gas from the cement calcination process in the kiln then flows to the preheater, raw mill, coal mill, and atox mill. After the cement calcination process, a clinker is obtained, which will then be cooled in the clinker cooler using a fan. The hot air released from the clinker cooler still has a high enough temperature so that some of it is used for drying at the finish mill, and the other part is discharged through the stack where the air from the excess air cooler has a temperature of 275-325°C. The result of the mill finish is the cement ready to be marketed. The raw mill output gas also has a reasonably high temperature compared to other milling processes such as coal mill and atox mill, where the raw mill output gas has a temperature of 165-145°C. Because the temperature and flow are large enough, the hot air from the exhaust can be used as a source of electricity by flowing it to heat the water in the boiler so that an electric current can be generated to meet the electricity needs of the factory and save electricity costs (Yuninto, 2015).

The process of utilizing hot air exhaust as a source of electrical energy generation in this cement plant can use the principle of Waste Heat Recovery Power Generation, which is a system that utilizes wasted heat from the gas output of the raw mill and hot air from the clinker cooler. In the cement production process, heat to heat water and utilize the steam produced to drive a turbine is carried out through the Heat Recovery Steam Generator system. Implementing this system, in addition to cutting PLN's electricity consumption and reducing the costs required for electricity needs, the WHRPG system can also make factories more environmentally friendly because they can increase the efficiency of using coal as fuel in the kiln (Hidayat, 2011).

## RESEARCH METHOD

The analysis procedure for the sample is carried out by calculating the amount of energy produced by the HRSG system and calculating the energy efficiency produced by the system. After applying the variations that have been determined previously, the efficiency values for each variation are obtained. From this value, an analysis of the relationship between the variation applied and the increase or decrease in the value of the efficiency produced by the system is carried out. Based on this analysis, optimum conditions are obtained which will then be carried out by the process of calculating or designing the equipment.

### Research variable

The control variable is a variable that must be set in the study so that it is always in the expected condition. This study shows the temperature of the steam exiting the HRSG. In contrast, the manipulation variable is an output variable that can be manipulated and affect the research output. In this study, the manipulation variables for the temperature of the steam exiting the HRSG that can be manipulated are in the form of mass flow rates at 1250, 2500, 3750, 5000, 6250, 7500, 8750, 10000, 11250, and 12500 kg/h and temperatures at 25, 30, 40, 50, 60, and 70°C feedwater entering the economizer.

### Sampling Procedure

The sample used in this study was taken from field data at one of the plants from PT. X was analyzed using HYSYS software to utilize the heat dissipated by the HRSG design. Data obtained from PT. X include:

1. Sources of exhaust heat and magnitude.
2. Value the kiln's temperature, pressure, and flue gas flow rate.
3. Components of hot flue gas.

### Analysis Procedure

The analysis procedure carried out in this study:

1. Create a simulation model on Aspen Hysys V11.0.
2. Entering data obtained from PT. X.
3. Enter the control variable in the form of the temperature of the steam coming out of the HRSG, as well as the manipulation variable in the form of flowrate feed water and the temperature that enters the economizer.
4. Then perform calculations such as:
    a. The energy produced by each device in the system (kJ/s)
    b. Energy generated by the system (kJ/s)
    c. Energy received by the system (kJ/s)
    d. HRSG system efficiency (%)
    e. The blowdown (kg/hour)

This HRSG boiler simulation used the Peng-Robinson fluid package as this equation of state model widely is used to define chemical compounds in the hydrocarbons category and their derivatives (Binous & Zakia, 2009).

## HRSG System Efficiency Calculation

The efficiency value can be calculated using the following equation (Ilmar & Sandra, 2014):

$$\eta_{HRSG} = \frac{output}{input} = \frac{energy\ generated\ from\ the\ system}{exhaust\ gas\ energy\ in\ HRSG} \qquad (1)$$

$$\eta_{HRSG} = \frac{\sum energy\ (unit\ HRSG + separator)}{exhaust\ gas} \qquad (2)$$

## Blowdown

Boiler blowdown is the process of removing water from the boiler. Blowdown is also used to remove suspended solids in the system. The primary purpose of blowdown is to keep the solids content in the boiler water within a specific limit. This is necessary because there are particular reasons, such as contamination of boiler water. The following is the equation used to find the value of blowdown:

$$blowdown = 1\%\ x\ mass\ flow\ rate \qquad (3)$$

## RESULTS AND DISCUSSION

The fluid package was selected in this study to obtain a simulation model that fits the actual conditions. The HRSG boiler simulation uses the Peng-Robinson fluid package because the simulation is carried out using high pressure and high temperature, and the use of gas makes this simulation suitable for the Peng-Robinson fluid package. The HRSG boiler design in this study consisted of a superheater, an evaporator, and an economizer.

Based on the HRSG design showed in Figure 1, the HRSG flue gas out temperature is 140.6°C, and the turbine power produced is 1,756 kW. The temperature of the HRSG flue gas out is still relatively high because there is no heat loss in the system, and the incoming feed water's low flow rate is 12,500 kg/h. The approach point and pinch point values follow the requirements suggested in the literature. Thus, the HRSG boiler design has met the requirements of the literature.

The energy efficiency of the HRSG boiler is calculated based on the amount of energy used compared to the amount of energy that enters the HRSG boiler system. The energy used from the boiler in this study comes from the energy generated from the superheater, evaporator, and economizer based on the Aspen HYSYS simulation. The energy produced by the superheater is 552.8 kW, the energy produced by the evaporator is 7,351 kW, and the energy produced by the economizer is 1,994 kW. In the HRSG boiler system design in the study, there are several supporting separators such as steam drums that produce energy of 7,669.58 kW, so that the total energy exchanged in the system is 17,567.38 kW. After calculating the energy from the exhaust gas used as the HRSG system's inlet, the energy is 20,693.9 kW. In contrast, the turbine that moves with the energy generated from the HRSG boiler is 1,756 kW. Based on these results, it can be concluded that the total energy used is 17,567.38 kW of the total wasted energy of 20,693.9 kW to be exchanged in the system, and produces energy in the form of electricity of 1,756 kW. So that energy efficiency is obtained from the HRSG boiler design in utilizing waste heat from PT. X amounted to 84.61%. Based on the design that has been done, in addition to looking at the energy exchanged and produced by the system, a calculation of the specifications for heat transfer devices (superheater, evaporator, economizer) is carried out on the HRSG system. In Table 1, the specifications of the calculation tools that have been carried out for the heat exchanger components in the system.

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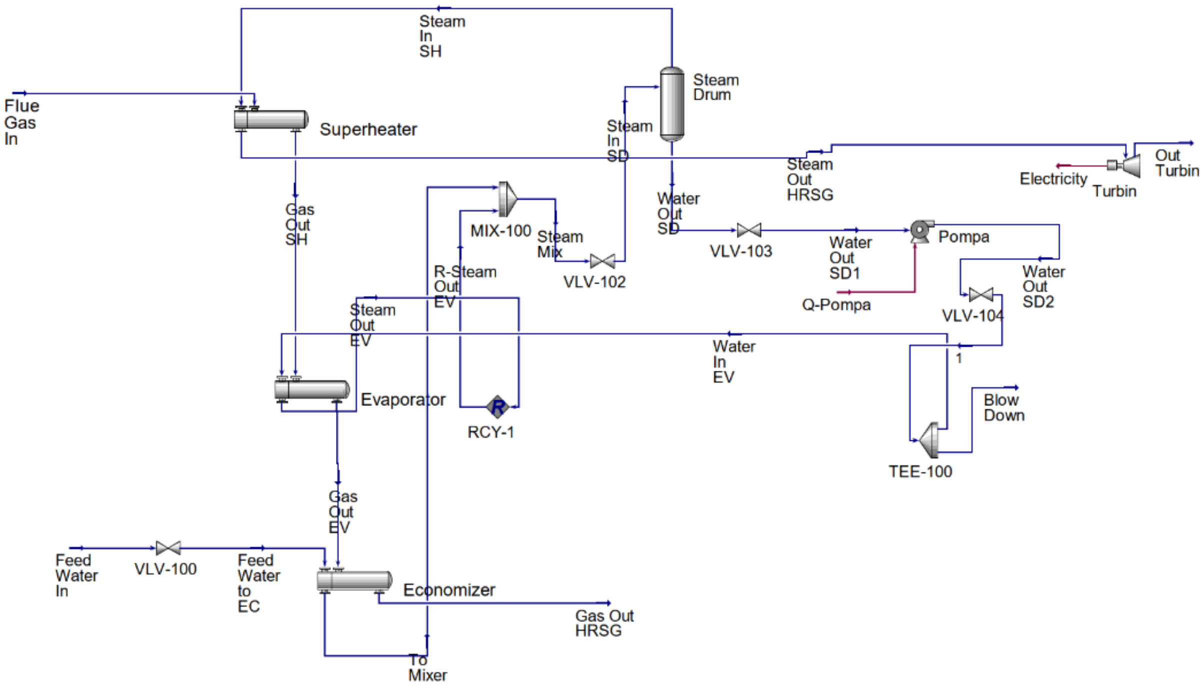

Figure 1 Model Simulation of Heat Recovery Steam Generator PT. X

Table 1 Heat Exchanger Specifications

| Equipment | Shell | | | Tube | | |
|---|---|---|---|---|---|---|
| | specification | value | unit | specification | value | unit |
| *Superheater* | ID | 23.25 | in | Qty | 229 | *pcs* |
| | n' | 1 | | Lenght | 16 | ft |
| | As | 0.0737 | $m^2$ | OD | 1 | in |
| | c | 0.0076 | m | BWG | 14 | |
| | B | 0.5419 | m | *Pitch* | 1.25 | in |
| | vs | 924.73 | m/s | *Passes* | 2 | *Triangular* |
| | | | | a"t | 0.2618 | |
| | | | | a't | 0.546 | |
| | | | | ID | 0.834 | in |
| | | | | ID | 0.0212 | m |
| | | | | At | 0.0379 | $m^2$ |
| | | | | vt | 0.0950 | m/s |
| *Evaporator* | ID | 39 | in | Qty | 1,537 | *pcs* |
| | n' | 1 | | Lenght | 20 | ft |
| | As | 0.0254 | m2 | OD | 1.25 | in |
| | c | 0.00125 | m | BWG | 18 | |
| | B | 0.6773 | m | *Pitch* | 1.5625 | in |
| | vs | 2,791.77 | m/s | *Passes* | 2 | *Triangular* |
| | | | | a"t | 0.3271 | |
| | | | | a't | 1.04 | |
| | | | | ID | 1.15 | in |
| | | | | ID | 0.0292 | m |
| | | | | At | 0.6696 | $m^2$ |
| | | | | vt | 0.0060 | m/s |
| *Economizer* | ID | 35 | in | Qty | 388 | *pcs* |
| | n' | 1 | | Lenght | 16 | ft |
| | As | 0.0182 | m2 | OD | 1.25 | in |
| | c | 0.00125 | m | BWG | 18 | |
| | B | 0.5418 | m | *Pitch* | 1.5625 | in |
| | vs | 3,463.65 | m/s | *Passes* | 2 | *Triangular* |
| | | | | a"t | 0.3271 | |
| | | | | a't | 1.04 | |
| | | | | ID | 1.15 | in |
| | | | | ID | 0.0292 | m |
| | | | | At | 0.0539 | $m^2$ |
| | | | | vt | 0.0640 | m/s |

Optimization of the heat exchange process in the system is essential, so in this study, several variations were carried out, such as varying the cooling water flow rate and the cooling water temperature entering the system to get the best conditions

In the experiments carried out, the temperature of the cooling water that enters the HRSG system is varied from 25°C to 70°C, and the effect of these variations on the total power output produced by the system is represented as an efficient system. Figure 2 shows that the lower the cooling water temperature, which is 25°C, the highest HRSG system efficiency can be achieved, which is 84.61%. Meanwhile, the higher the temperature of the cooling water that enters the system, which is 70°C, the efficiency produced by the HRSG system decreases with a value of 81.35%. Based on this, the higher the cooling water temperature, the smaller the HRSG system efficiency value obtained.

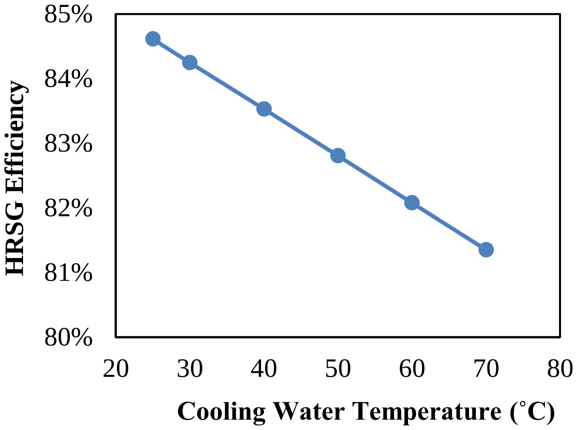

Figure 2 Effect of Cooling Water Temperature on HRSG Efficiency

This happens because of the application of the principle of heat exchange in each heat exchanger in the system, where the lower the temperature of the cooling water, the greater the ΔT that occurs between the hot and cold fluids so that more heat is exchanged in the system and produces power output. When ΔT in the system is small, the heat exchanged is less, and the resulting power output is lower.

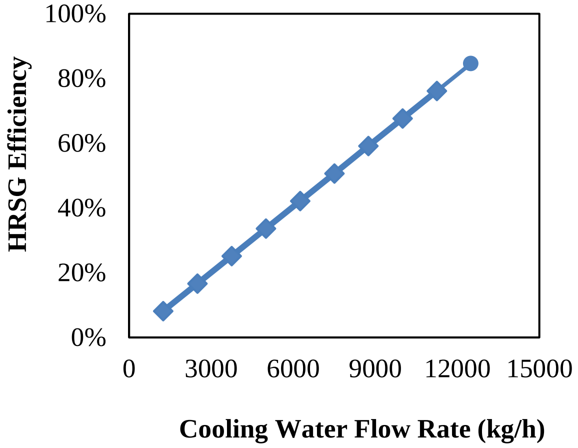

Figure 3 Effect of Cooling Water Flow Rate on HRSG Efficiency

The simulation results in Figure 3 show that for every 10°C increase in cooling water temperature, the HRSG efficiency value decreases unevenly. The decrease in the HRSG efficiency value represents the amount of power output that can be generated by the system, which will later be considered whether the HRSG system is feasible to implement.

The influence of the flow rate of cold fluid flowing in the Shell and Tube Heat Exchanger can cause changes in the rate of heat transfer. This is because the increase in flow rate will cause the Reynold Number to increase, followed by an increase in the Stanton Number and the film coefficient heat transfer coefficient (Murugan, Kanna Dasan T., & Ramasamy E., 2008). Figure 3 shows the relationship between the cooling water flow rate and the efficiency obtained by the system. When the cooling water flow rate is low, namely 1250 kg/h, HRSG efficiency of 8.17% can be achieved. Meanwhile, with the increased cooling water flow rate of 12,500 kg/h, the HRSG efficiency increased to 84.61%. Based on these results, it can be concluded that the greater the cooling water flow rate, the greater the efficiency value generated by the HRSG system. For every 1250 kg/h increase in cooling water flow rate, the HRSG efficiency value increases. The increase in the HRSG efficiency value is directly proportional to the cooling water flow rate.

## CONCLUSION

Based on the findings obtained in this simulation study, it can be concluded that the HRSG boiler design consisting of a superheater, evaporator, and economizer can be used to produce steam at 235°C and can reduce the flue gas temperature from 244°C to 140.6°C. The turbine, driven by the HRSG output steam, is driven by the energy converted in the system of 17,567.38 kW of a total of 20,693 kW of energy being discharged into the flue gas. From this energy exchange, 1,756 kW of electrical energy can be generated under steady state conditions. The energy efficiency obtained from redesigning of HRSG boiler for reusing waste heat from the kiln of PT. X with Aspen HYSYS simulation was 84.61%.

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