Journal of Engineering and Applied Technology
Vol. 3, No. 2, August 2022, pp. 64-72

Online ISSN 2716-2265
Printed ISSN 2716-2257

# Applied energy and mass balance optimization re-engineering: case on the Industri Gula Glenmore, Ltd.

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ABSTRACT

The Industri Gula Glenmore, Ltd. was designed for 8000 tons of cane per day (TCD) production or 273 tons per hour (TPH). The process required approximately 136 TPH based on the Steam on Cane (SoC) 50%. As the factory's primary input, sugar cane could not supply 8000 TCD factory capacity, so 6000 TCD was chosen as an alternative. After commissioning, a lack of steam for servicing the process occurred because the turbine at full load required 7.6 kg/kWh. Desuperheater supported the additional steam for the process, which was only 20 TPH. Meanwhile, the steam from the turbine supplied 84 TPH. The need for 32 TPH must be solved, and a specific strategy should be prepared. The applied thermodynamics re-engineering is a potential method that can be applied in which the findings show that the deficit of 32 TPH steam for the process can be solved precisely.



ARTICLE INFO

**Article history**
Received:
1 June 2022
Revised:
15 July 2022
Accepted:
23 July 2022

**Keywords**
Glenmore
optimization
re-engineering
Steam on Cane
sugar
thermodynamics

## 1. Introduction

Sugar industries require a lot of energy and produce excess energy [1]. Industri Gula Glenmore, Ltd. has been one of the largest sugar factories in Indonesia with a milling capacity design of 8000 TCD with a generated power of 20 MW. This company can sell excess energy to PLN (State Electricity Company). The production process of white crystalline sugar is done through several stages: milling, purification, evaporation, cooking, and crystallization. Those processes produce output in the form of biomass [2], [3]. The additional low-pressure steam is created by passing some high-pressure steam through the expansion valve [4]. The Industri Gula Glenmore's design of mass and energy balance can be seen in Fig. 1. Since the readiness of sugarcane raw materials is limited, the current operational plan is only sufficient for a milling capacity of 6000 TCD with a generated power of 11 MW. The mass and energy balance at 6000 TCD conditions are shown in Fig. 2. These conditions show a deficit in the steam balance for the sugar production process.

Therefore, re-engineering of thermodynamic and milling strategies is urgently needed to reduce the mass gap between the produced steam and the required steam so that the sugar manufacturing process of the factory can run well [5]–[7]. It is usually equipped with turbine technology, i.e. condensation-extraction steam turbine (CEST) to produce excess electric power [8]. Using a DC motor as a mill drive can also increase efficiency in steam use [9]. The use of a more efficient cogeneration system, especially reducing the demand for thermal energy in the production process, is realized by optimizing the process layout and operational parameters to increase the surplus of electricity which can be sold [10], [11].

### 1.1. The comparison of steam usage based on milling capacity

The Industri Gula Glenmore, Ltd. (IGG) is designed with a milling capacity of 8000 TCD or can be simplified to 333 TPH. The planned process steam requirement is 500 kg of steam per ton of sugar cane or can be shortened to 50% SoC (Steam on Cane). The steam requirement for the process equals 333 TPH x 50% = 166.6 TPH.

Each turbine requires 76.4 TPH of steam, so the total incoming steam to the turbine is 152.8 TPH. The steam entering the desuperheater is 20 TPH so that the total steam for the process involves 172.8 TPH. Mass Balance = 172.8 TPH – 166.6 TPH = 8.2 TPH.

This condition indicates that the steam for the process excessive by 8.2 tons per hour. The schematic drawing of the IGG mass balance for 6000 TCD is shown in Fig. 1.

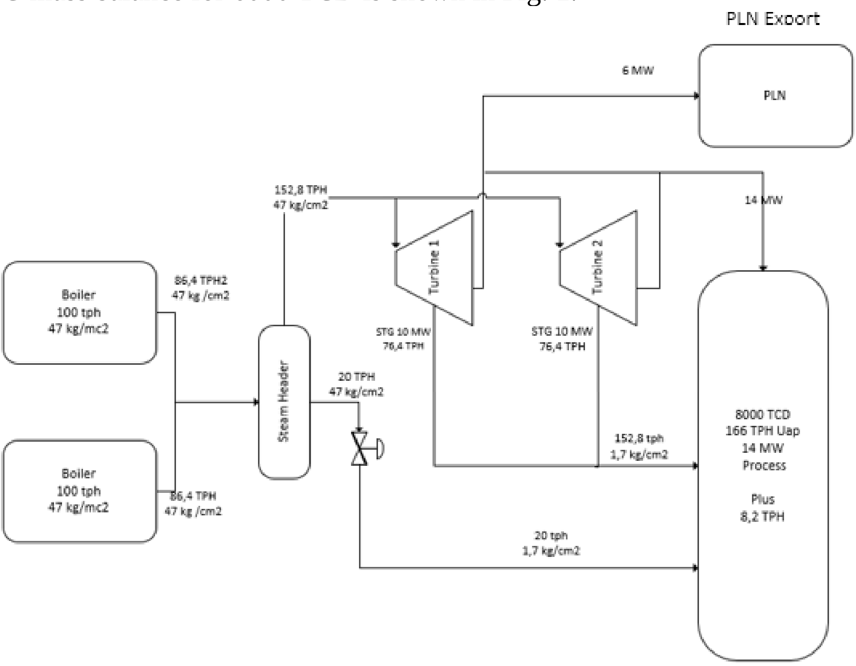


Fig. 1. Industri Gula Glenmore's Mass and Energy Balance for 8000 TCD

For comparison, the Industri Gula Glenmore, Ltd., is designed with a milling capacity of 6000 TCD or can be simplified to 273 TPH. The planned process steam requirement is 500 kg of steam per ton of sugar cane or can be shortened to 50% SoC (Steam on Cane). The steam requirement for the process equals 273 TPH x 50% = 136 TPH.

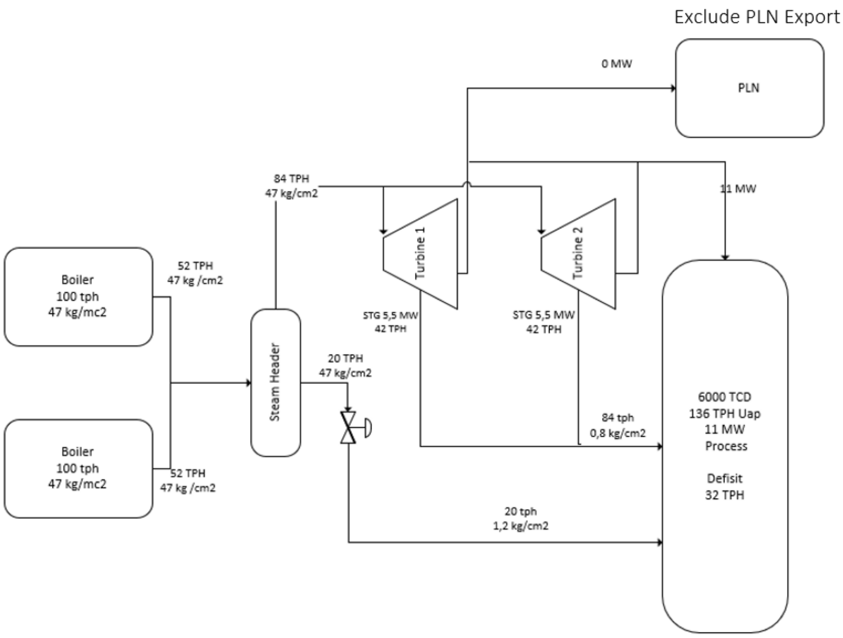


Fig. 2. Industri Gula Glenmore's Mass and Energy Balance for 6000 TCD

Each turbine requires 42 TPH of steam so that the total steam entering the turbine is 84 TPH. The steam entering the desuperheater is 20 TPH so that the total steam that can be used for the process is 104 TPH. Mass Balance = 104 TPH – 136TPH = -32 TPH.

This condition indicates a shortage of steam for the process of 32 tons per hour. The schematic drawing of the IGG mass balance for 6000 TCD is shown in Fig. 2.

## 2. Method

The research scheme started from secondary and primary data collection, processing, and analysis to the engineering process as described in Fig. 3.

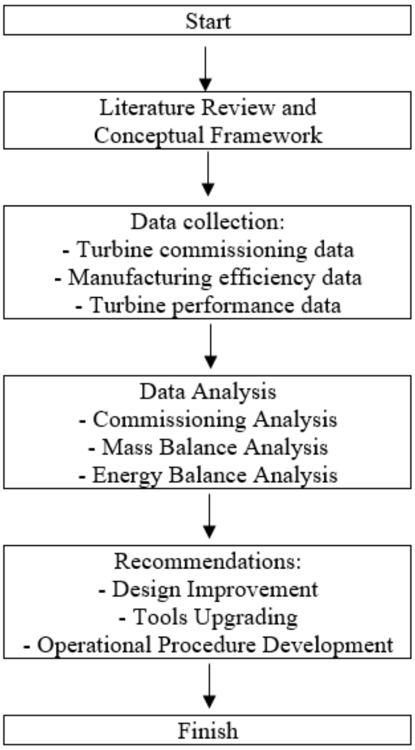


Fig. 3. Scheme of Research Method

### 2.1 Turbin Performance

The power generated by the turbine can be formulated as:

$$P = \dot{m}\,(h_1 - h_2) \qquad (1)$$

where $\dot{m}$ is mass of steam entering the turbine, $h_1$ is enthalpy of steam entering the turbine, $h_2$ is enthalpy of steam leaving the turbine. Turbine performance can be calculated in terms of theoretical steam rate (TSR) and actual steam rate (ASR), as the following:

$$TSR = 3600 / (h_1 - h_{2s}) \qquad (2)$$

where $h_1$ is enthalpy of steam entering the turbine, $h_{2s}$ is enthalpy of steam leaving the turbine at isentropic condition

$$ASR = TSR / \text{isentropic efficiency} \qquad (3)$$

The review of turbine efficiency uses the approach that the losses are based on losses in the turbine, the transmission gear, and the alternator. It refers to turbine efficiency with a thermodynamic process regarding isentropic turbine efficiency and is based on the design from the manufacturer.

### 2.2 Losses and Isentropic Turbine Efficiency

A review of the laws of thermodynamics I and II makes a turbine will experience isentropic efficiency in the process, so it applies as shown in Fig. 4.

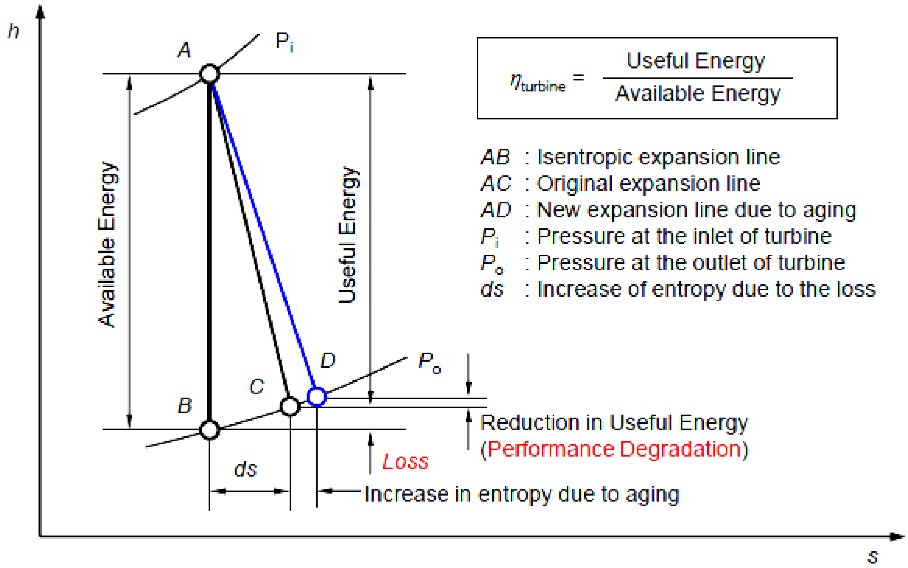


Fig. 4. Isentropic efficiency diagram

### 2.3 Turbin Efficiency

Siemens manufacturing design has released a comparison of the efficiency of single stage and multistage turbines in several variations of incoming steam as presented in the following Fig. 5.

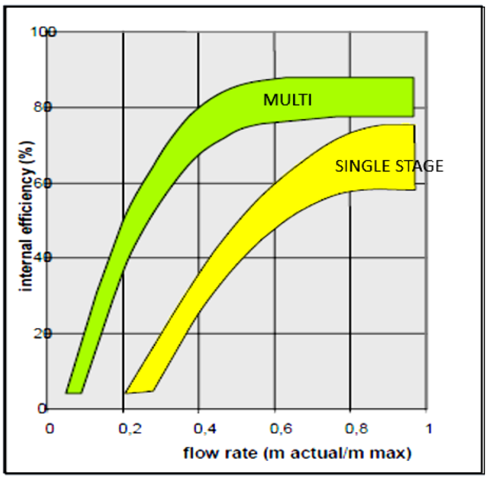


Fig. 5. The comparison of the efficiency of single-stage and multistage turbines on steam consumption

The other turbine used was turbin Shinko. Its specification comprises as follows: model: DNG 43-70, output: 10000 kW, steam pressure: 45 kg/cm$^2$G, steam temperature: 450 $^o$ C, exhaust pressure: 1.7 kg/cm$^2$G, turbine speed: 6879 rpm, output shaft speed: 1500 rpm.

## 3. Results and Discussion

The commissioning test results, and the 10 MW Shinko manufacturing test data show the data shown in Fig. 6.

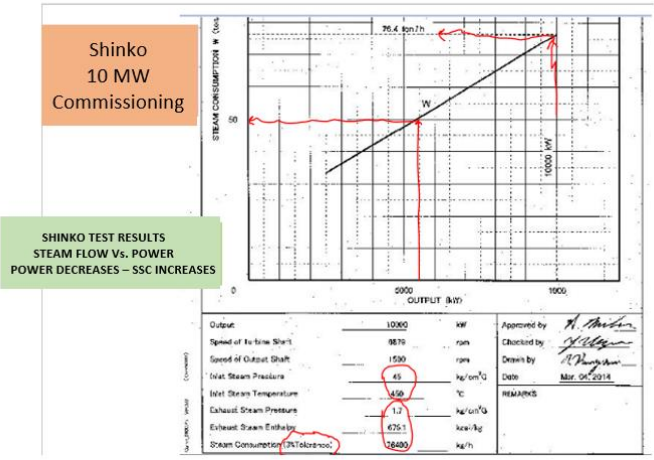


Fig. 6. Turbine Test of Shinko 10 MW

Table 1. Turbine Commissioning Scores at 5 MW, 4.5 MW, and 4 MW Loads

| No | *Steam (kg/h)* | *Power (kW)* | *SSC (kg/kWh)* |
|---|---|---|---|
| **1** | 76400 | 10000 | 7.63 |
| **2** | 50000 | 5500 | 9.09 |
| **3** | 47000 | 5000 | 9.4 |
| **4** | 45000 | 4500 | 10 |
| **5** | 42000 | 4000 | 10.5 |

Based on the commissioning test results, it was found that:

a. If the steam flow is 76400 kg/hour at a turbine load of 10 MW, the specific steam consumption (SSC) will be 7.63 kg/kWh.

b. If the steam flow and turbine load change, the turbine SSC will increase based on the commissioning test results.

c. When the inlet turbine pressure and inlet temperature change, the turbine power will change so that the SSC and turbine steam requirements will vary.

d. When the exhaust pressure and temperature change, the turbine power will change. It makes the SSC and the demand for steam simultaneously change.

Referring to Shinko commissioning, SSC is strongly affected by turbine load. Utilizing the properties of the turbine, the SSC can be engineered and increased in value so that the amount of steam entering the turbine will be increasing. This makes the used steam for the process also rises in number. Adding SSC to make it bigger than the standard of 7.63 kg/kWh (steam flow rate 76400 kg/hour) can be conducted by changing the input and output parameter variations in the form of pressure and temperature. With an increase in SSC at turbine power of 5.5 MW per turbine, the incoming steam capacity will automatically increase.

### 3.1 Thermodynamics Re-engineering I

Referring to the IGG mass balance design, using steam to generate 5.5MW (42 TPH per turbine) caused a mass balance deficit. Based on the Shinko test results, as shown by Fig. 6, the SSC would increase from 7.63 kg/ kWh to 9.09 kg/kWh at 55% load with a turbine generating power of 5.5 MW. There was a potential increase in SSC by 19% from 10MW load to 5.5 MW (55% rated). This condition demanded the steam requirements the following. ASR equals 2 x 50 TPH = 100 TPH. So, the additional steam for process equals 100 - 84 = 16 TPH.

### 3.2 Thermodynamics Re-engineering II

The boiler operation was reduced to make the entering steam pressure in the turbine was 40-42 barg, and the temperature was maintained at 400-400 °C. The turbine exhaust pressure followed the steam condition, which decreased from 1.7 barg, 180 °C to 1.2 barg at the temperature of 160 °C. It made the value of $h_2$ equal to 2787 kJ/kg. The thermodynamic calculations are shown in Table 2.

Table 2. Thermodynamics Calculation

| Turbine Calculation | | | | | |
|---|---|---|---|---|---|
| **Parameter** | Option 1 | Option 2 | Option 3 | Ideal | Unit |
| **Inlet Steam** | | | | | |
| **Pressure ($P_1$)** | 40 | 41 | 42 | 45 | barg |
| **Temperature ($T_1$)** | 400 | 400 | 400 | 450 | C |
| **Enthalpy ($h_1$)** | 3212.3 | 3210.6 | 3209 | 3322 | kJ/kg |
| **Entropy ($s_1$)** | 6.76 | 6.75 | 6.73 | 6.86 | kJ/kg |
| **Outlet Steam** | | | | | |
| **Pressure ($P_2$)** | 1.2 | 1.2 | 1.2 | 1.7 | barg |
| **Temperature ($T_2$)** | 160 | 160 | 160 | 180 | C |
| **Enthalpy ($h_2$)** | 2787 | 2787 | 2787 | 2825 | kJ/kg |
| **Entropy ($s_1$=$s_2$)** | 6.76 | 6.75 | 6.73 | 6.74 | kJ/kg |
| **Enthalpy Isentropic ($h_{2s}$)** | 2577 | 2574 | 2565 | 2653 | kJ/kg |
| **Analysis** | | | | | |
| **Eff. Isentropic** | 0.67 | 0.67 | 0.66 | 0.74 | |
| **TSR** | 5.67 | 5.66 | 5.59 | 5.38 | kg/kWh |
| **SSC** | 8.46 | 8.50 | 8.53 | 7.24 | kg/kWh |
| **Load 55%, SSC Escalation of 19%** | 10.07 | 10.11 | 10.15 | 8.62 | kg/kWh |
| **Power** | 5500 | 5500 | 5500 | 5500 | kw |
| **Number of Turbine Steam Requirements** | 55400 | 55623 | 55834 | 47408 | kg/h |
| **Number of Steam 2 turbines** | 110801 | 111246 | 111668 | 94816 | kg/h |

At the inlet steam pressure between 40-42 barg, it can be seen that the turbine SSC increased to 10 - 10.07 kg/kWh so that the amount of steam required for the turbine was between 110 TPH - 111TPH. The additional steam for process equals 111 TPH – 84 TPH = 27 TPH.

### 3.3 Thermodynamics Re-engineering III

This re-engineering uses a potential steam approach for the process generated from the desuperheater. It is a device that cools superheated steam to a temperature close to its saturation temperature [12]. This tool works by misting water droplets into a stream of superheated steam. The superheated steam is above its saturation temperature. Steam desuperheating is often used in sugar factories for the two following reasons.

1. Steam turbines are often designed at steam conditions that are slightly above the saturation temperature to prevent corrosion of the blades which in turn leads to blade failure [13].
2. The juice must be heated at a temperature of 125 °C to reduce the formation of colour and damage to the sucrose structure

The addition of water for the desuperheating process will cause an increase in the amount of steam produced for the mass balance process [14]. This phenomenon can be explained in the Fig. 7.

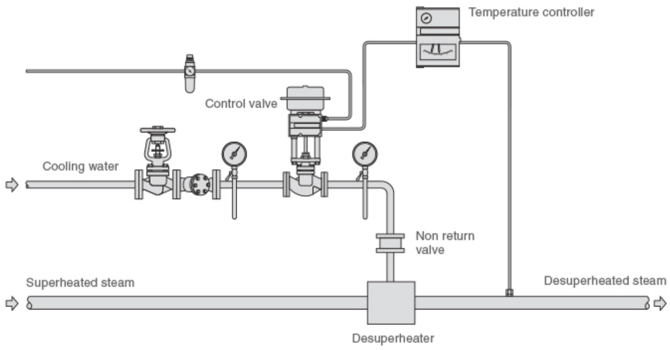


Figure 7. The water addition for the desuperheating process

In the desuperheating process, it applies the law of conservation of energy and mass, which is shown in the equation (4).

$$m_d = m_w + m_s \quad (4)$$

$$m_w = m_s (h_d - h_s) / (h_w - h_d) \quad (5)$$

where $m_w$ is mass of cooling water, $m_s$ is mass of superheated steam, $m_d$ is mass of desuperheated steam, $h_d$ is enthalpy at desuperheated condition, $h_w$ is enthalpy of cooling water at inlet connection, $h_s$ is enthalpy at superheated condition.

Several simple computations were carried out. It referred to the inlet steam temperature at 380 °C in different conditions of the inlet pressure in the desuperheater. The obtained mass of cooling water can be seen in Table 3. This additional water mass would enhance the amount of steam to support the process.

Table 3. The additional water mass calculation to increase the amount of steam process

| $h_s$ = h at P, 380 °C | | $h_w$ = h at 3 barg, 90 °C | | $h_d$ = h at P, $T_d$=120 °C-130 °C fraksi uap 97% | | |
|---|---|---|---|---|---|---|
| P (barg) | $m_w$ (kg/s) | $h_w$ (kJ/kg) | $m_s$ (kg/s) | $h_s$ (kJ/kg) | $h_d$ (kJ/kg) | $T_d$ (C) |
| 1 | 5143 | 377 | 20000 | 3234.5 | 2650 | 120 |
| 1.2 | 5140 | 377 | 20000 | 3234.2 | 2650 | 123 |
| 1.4 | 5137 | 377 | 20000 | 3233.8 | 2650 | 126 |
| 1.6 | 5134 | 377 | 20000 | 3233.5 | 2650 | 128 |
| 1.7 | 5133 | 377 | 20000 | 3233.4 | 2650 | 129 |
| 1.8 | 5132 | 377 | 20000 | 3233.2 | 2650 | 131 |

Based on the results of the above analysis, it is found that the addition of water is 5 TPH because of the mass balance. The amount of steam increase simultaneously by 5 TPH so that it can be used as the additional steam for the process.

## 4. Conclusion

Based on the research findings, several conclusions can be drawn as follows:

1. By making the turbine exhaust pressure above one barg, the potential for bleeding can be optimised.
2. If energy savings are obtained from 50% sugarcane steam to 48%, then the process steam needs will decrease from 136 TPH to 130 TPH; there is a potential for 6 TPH process steam reduction. By pressing SoC to 48%, steam saving reaches 6 TPH
3. The mass balance can be fulfilled by making operational changes to the various re-engineering options mentioned above. The turbine input and output parameters can be manipulated, so the SSC will get a more significant amount of steam entering the process compared to the steam of the turbine exhaust
4. Optimization of cogeneration with a milling capacity of 6000 TCD to 8000 TCD should be done immediately to enhance turbine steam exhaust so that the availability of process steam will be sufficient. It must be supported by the availability of sugarcane supply and the reliability of the factory
5. It is better to prepare an additional pressure reducing desuperheater device (PRDS) for the lack of supplementation to the used steam for processing.
6. It should prepare an excellent bleeding scheme for steam savings.
7. The nature of the re-engineering process is temporary because it forces operations in derated conditions - below the operational specification - because it will affect the efficiency of tools and factories at its peak performance (best efficiency)
8. Mitigation related to moisture and turbine trips, boiler trips in derated operational conditions when carrying out operational engineering outside the standard must be carried out.

## Acknowledgement

Our gratitude goes to the LPP Polytechnic for the support of this research activities. We would also like to dedicate this paper to the Indonesian nation and the advancement of science and the triumph of the national sugar industry.

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