A STUDY OF USING HYDROGEN GAS FOR STEAM BOILER IN CHOLOR–ALKALI MANUFACTURING

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Abstract. Main products of manufacturing of Cholor – Alkali, which commonly known as industrial chemical, are chlorine gas (Cl₂), Sodium Hydroxide (NaOH) and hydrogen gas (H₂). Chorine gas and sodium hydroxide are two main products for commercial profit; where hydrogen gas is by product. Most industries release hydrogen gas to atmosphere as it is non-profitable and less commercial scale. This study aims to make the most use of hydrogen as a substitute energy of natural gas for steam boiler to save energy cost. The second target of this study is to reduce level of CO₂ release to air as a consequence of boiler combustion. This study suggests to install boiler that bases on hydrogen as main power with a high turndown ratio of at least 1:6. However, this case study uses boiler with two mode such as natural gas (NG) mode and mixed mode as they need to be flexible for production. Never the less, the best boiler selection is to use single mode energy of hydrogen. The most concerned issue about hydrogen gas is explosion during combustion stage. Stabilization measures at emergency stop is introduced to control H₂ pressure to protect the explosion. This study varies ratio of natural gas to hydrogen gas to find the optimal level of two energy sources for boiler and measure total consumption through costing model; where CO₂ level is measured at the boiler stack. The result of this study shows that hydrogen gas can be a substitute energy with natural gas and can reduce cost. Natural gas cost saving is 248,846 baht per month and reduce level of NOx is 80 ppm 7% O₂ and 2 % of CO₂ release to air as a consequence of boiler combustion.

1. Introduction

Energy could be divided into two types, which are nonrenewable and renewable. Most energy consumption nowadays comes from nonrenewable energy such as fossil, crude oil, coal and natural gas. The nonrenewable energy is accounted as one of the factor that contributes to the Green House effect and global warming. On the other hand, renewable energy is a source of power that not only saves cost but also does not cause such global warming effect. Those energy include solar energy, wind energy, geothermal energy and hydrogen energy. Hydrogen is an ideal renewable energy carrier due to its high combustion heat and the fact that its only combustion product is water [1]. Natural gas contains 70% of methane. After separation process, it produces clean energy with complete combustion that causes less effect to environment, comparing to other types of petroleum energy. [2] The hydrogen gas is clean energy. The different property between hydrogen and natural gas is level of concentration of flammable content. Hydrogen must contain 4-75% of flammable content while natural gas has 5.3-15%. Therefore, natural gas is more dangerous as it has the shorter range of flammable combustion time frame. [3] Sources of hydrogen can come from many processes. One of those processes is the exchange of proton by using electrical power and running water through membrane. The equation could be shown as [4]

\[
\frac{3}{2} H_2 + \frac{3}{4} O_2 \rightarrow \frac{3}{2} H_2O \text{ fresh water (}+214kJ\text{ )electric energy(}+214kJ\text{ )heat energy} \tag{1}
\]

And the chemical reaction in the fuel cells is:

\[
H_2 + \frac{1}{2} O_2 \rightarrow H_2O + \text{electric energy} + \text{heat energy} \tag{2}
\]
However, this case study uses concentrated salt solution. When concentrated salt solution runs through membrane, the process separates anode and cathode from each other. The outcome of the process is soda, choline and hydrogen. Hydrogen gas, as by product, will be released to the air to balance the process. The equation is shown as

\[ 2\text{NaCl} + 2\text{H}_2\text{O} \rightarrow 2\text{NaOH} + \text{H}_2 + \text{Cl}_2 \]  

(3)

According to many studies about hydrogen gas, it is considered clean energy, the combustion equation follow as below and applicable for combustion as show in figure1 and 2, respectively

Natural gas combustion as

\[ \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \]  

(4)

Hydrogen gas combustion as

\[ \text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O} \]  

(5)

![Figure 1. Principle of combustion](image1.png)  
![Figure 2. Principle of combustion for hydrogen](image2.png)

Hydrogen gas is also known as high efficiency power that could generate outstanding yield. By using 2% of hydrogen gas, it could generate 100% of energy. In short, hydrogen gas is a low cost source of energy that encourages business for high return. [5]

In case study of chemical manufacturing of NaOH and Cl₂ for domestic customers, that shows that process of 50 % Caustic soda solution and Caustic Soda Flake 98% uses steam energy from boiler and natural gas as much as 50.85 million baht per year. This study aims to reduce consumption of natural gas for the production by using hydrogen gas as substitute energy source for boiler’s steam production. Expected result from using hydrogen substitute is to reduce energy cost by 80% comparing to the existing method.

2. Analysis data and Experimental

2.1. Understanding of Current Situation

Experimental boiler in this case study has 6mt steam capacity per hour and powered by natural gas) NG(. Estimated energy consumption of boiler is 13,000 MMBtu, given a 22 years life span. The quantity of natural gas consumption from steam boiler is increasing every year. Figure 3 and 4 show the consumption data from the last 2 years. And the process flow of target facility and the structure of recycling hydrogen for boiler, respectively

![Figure 3. Quantity of natural gas consumption hydrogen for boiler.](image3.png)
2NaCl + 2H₂O → 2NaOH + H₂ + Cl₂

Figure 4. Shows structure of recycling from steam production in 2014-2015

Hydrogen is produced after concentrated salt solution pass through electrolysis process. It is contained in hydrogen station with header and will be pressurized by root blower to transport to customer gas station. Later, hydrogen will be sent to synthetic tower for 35% hydrochloric acid production and the excess hydrogen from the system will be released to atmosphere to stabilize as show in figure 5

Figure 5. Hydrogen flow before implementation

2.2. Analysis of Current Situation

Production can generate hydrogen 6.94Mts per day per plant. The remaining from production is 1.32 Mts per day per plant. Hydrogen will be released to air to stabilize as show in figure 6

Figure 6. Balancing of material in case of study
The production capacity is relevant with electrical cost calculation from Provincial Electricity Authority (electricity power plant of Thailand) It accounts for peak consumption of electrical power. Monday to Friday between 9am to 10pm is considered peak hour and the production would run with 42% capacity while 10pm to 9am Monday to Friday, Saturday, Sunday and public holiday; which considered off peak, the production is on 100% capacity. As a result, quantity of hydrogen on each period of time are different as shown in figure 7.

![H2 capacity based on Time of Use Tariff](image)

**Figure 7.** H₂ capacity based on Time of Use Tariff.

### 2.3 Experimental and Procedure

The experimental setup and Procedure are summarizing in Table 1

| Target Settings                                                      | Procedure                                                                 | Requirement                                                                 |
|---------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------|
| To reduce natural gas consumption and energy cost for boiler by using hydrogen as substitute energy. | Use boiler that base on hydrogen as main power.                            | * Selection of boiler with a high turndown ratio                             |
|                                                                    |                                                                           | * Measures to reduce NOₓ generation                                           |
|                                                                    |                                                                           | * Stabilization measures at emergency stop                                     |
|                                                                    |                                                                           | * Selection of boiler with three mode such as NG mode, H₂ mode and mixed mode |
|                                                                    |                                                                           | * Determination of ratio for balance hydrogen gas and natural gas in case mixed mode |
| To reduce level of H₂ and CO₂ release to air as a consequence of boiler combustion | By using a new hydrogen boiler and adjust the fluctuated pressure.        | * Determination of holder capacity and pressure regulation for balancing load |

**Table 1** The Target Settings, Procedure and requirement
2.4 Boiler selection
The most efficient way is to apply the concept with hydrogen base boiler. Nevertheless, this study introduces both hydrogen base energy boiler and mixed mode energy boiler.

Specification of boiler
Fire Tube, Cylindrical Horizontal, 3 pass, and wet back design

Fuel System:
Gaseous fuel: Natural Gas

| Item                        | Steam | Flow NG | % Load | NOx | CO2 | Excess O2 |
|-----------------------------|-------|---------|--------|-----|-----|-----------|
| NG Fire mode                | 1,836 | 66,428  | 72     | 80  | 2   | -         |

Second fuel: Hydrogen (H2)

| Item                        | Burner capacity | Heat value | Standard volume flow max. | Standard volume flow min. | Gas temperature | Gas pressure max. | Gas pressure min. | Protection pressure |
|-----------------------------|-----------------|------------|---------------------------|---------------------------|-----------------|------------------|-------------------|---------------------|
| Natural Gas                 | 3.5 MW          | 10.76 MJ/m3| 1167 m3/hr                | 300 m3/hr                 | 15 ºC           | 0.08 bar          | 0.07 bar           | 0.5 bar (by others) |
| Natural Gas                 | 4.5 MW          | 31.4 MJ/m3 | 516 m3/hr                 | 125 m3/hr                 | 15 ºC           | 3.8 bar           | 2 bar              | 4 bar (by others)   |

Stabilization measures at emergency stop
As double electromagnetic valve, when the new boiler stops for an emergency, a maximum pressure of hydrogen equal 500 mbar with initial shut-off and minimum pressure monitor with initial shut-off and venting.

3. Combustion process analysis
The following average results were obtained from the operations in this study

Case 1. The operations for natural gas (NG)

Table 2. NG mode

Case 2. The operations for mixed mode (H2+NG)
Mixed mode H2+NG details for mixed mode as following:
Mixed mode operation for 2 main fuels with priority logic. If the burner is supplied with more than one main fuel, in dual-fuel mode with two main fuels, one of them will be fired by priority and the other main fuel is fired along with it at minimum firing rate. When not enough of the priority fuel is available, the rest of the firing plant’s power requirement is made up by the other main fuel. If the supply of the priority fuel drops below a set minimum, the fuel valves for it will be closed and will not be opened again until it is available again.
Table 3. H2 and NG mixed mode (80:20)

| Item                        | Steam | Flow NG | Flow H2 | NOx ppm 7%O2 | CO2 | Excess O2 |
|-----------------------------|-------|---------|---------|---------------|-----|-----------|
| H2 and NG mixed mode        | 840   | 19,478  | 119,278 | -             | -   | -         |

4. Conclusion
This case study investigated the hydrogen energy performance of boiler and the aim is to use hydrogen efficiently. The experimental results show that hydrogen could be used as substitute energy and reduce energy cost. Natural gas cost saving is 248,846 bath per month and reduce level of NOx and CO2 release to air as a consequence of boiler combustion are 80 ppm 7% O2 and 2 %. Hydrogen gas is clean energy. Hydrogen can implement substitute energy concept to other kind of industry.

5. Reference
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