Gas Fuel Mixing to Reduce Elemental Sulfur Formations on Gas Regulating and Metering Stations in Muara Karang Steam Power Plant

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Abstract. Muara Karang Steam Power Plant uses natural gas as a primary energy source. Gas supplied from three different suppliers, PHE, PGN, and NR. Each supplier has different gas quality because it sourced from different gas fields and processes. To feeds gas to the boiler in Unit 4 Muara Karang Steam Power Plant, it has gas regulating facilities to reduce the pressure of natural gas from 24 kg/cm² to 4 kg/cm². In 2019, Control Reducing Valve (CRV) opening climbs gradually although power output from Unit 4 is constant. Inspection of the strainer found that elemental sulfur formations occur, and a clogged strainer makes gas flow to the burner reduced. To compensate for elemental sulfur formation, a fuel mixing strategy was implemented. Before the fuel mixing strategy implemented, Unit 4 needs maintenance outage every three months with a CRV gas opening increase of 0.93%/day. After the fuel mixing strategy implemented, it needs maintenance outage every five months and CRV gas opening increase of 0.44%/day because elemental sulfur formation occurs slower. The fuel mixing strategy can save up to 11.7 billion rupiahs of outage cost.

1. Introduction
Muara Karang Power Plant that located in the Jakarta coast consists of four blocks, three blocks of combined cycle power plant (Block 1, Block 2, and Block 3), and one block of steam power plant that has two units, unit 4 and 5. All these blocks are using natural gas as the primary fuel.

To meets the primary fuel demand, there are three natural gas suppliers to Muara Karang Power Plant, PT PHE ONWJ (PHE), PT PGN Tbk (PGN), and PT Nusantara Regas (NR). PHE supplies natural gas from the North West Java gas field, PGN from the Corridor Block gas field operated by ConocoPhillips, meanwhile NR has an LNG regasification facility that supplied from Bontang and Tangguh.

Because each supplier supplied from different sources, each gas has different qualities. The difference in gas quality and gas quantity from each supplier makes gas prices vary from one to the other. Gas prices from the cheapest to the most expensive are PHE, PGN, and NR. Because of its quality, PHE, PGN, and NR can supply to Block 1 and 45, meanwhile Block 2 and 3 are normally use NR gas because its newer engines need cleaner fuel from processed LNG.
Based on the 2019 Pareto loss output in Block 45, there were several deratings in Unit 4 because Control Reducing Valve (CRV) cannot supply adequate gas flow. CRV is used to reduce gas pressure from 24 kg/cm² from supplier to 4 kg/cm² that needed by the gas burner in Unit 4. Assessment from CRV found that elemental sulfur formation occurs in CRV strainer. Elemental sulfur formation makes plugging in the strainer, thus reduce gas flow to the gas burner. Normally, CRV is open 46% when Unit 4 on base loads. Meanwhile when elemental sulfur formation plugged the CRV strainer, CRV gas will 100% opened but the gas flow still inadequate to supply unit 4 needs. CRV assessment also found that for the same flow, the elemental sulfur formation will increase CRV opening on average 1% each day.

Derating from the elemental sulfur formation problem will make losses in Unit 4 power production, then will reduce Muara Karang Power Plant income in general. This paper will analyze elemental sulfur formation and mitigation to minimize future potential losses.

2. Basic Theory

2.1. Gas Regulating and Metering Stations in Muara Karang Block 45

Gas Regulating and metering station in Muara Karang Block 45 consist of several main components as shown in Figure 1

*Pressure Regulators* used to control constant pressure downstream in lower pressure than upstream unaffected with fluctuation in inlet pressure [2]. Two mechanisms work in opposition inside the pressure regulator, the spring that determined to provide force to the valve to open, and the diaphragm that acting against the spring to permit the valve to close. These two forces work harmoniously against each other to determine the position of the valve and the amount of gas that through. When boiler power output increases, the gas burner will ask for more flow then the gas pressure in the pressure regulator downstream will drop. The drop in the pressure regulator outlet will make gas pressure in the diaphragm reduced then the spring force will overpower the diaphragm and the pressure regulator opening will increase. will maintain gas pressure constant by maintaining gas flow and vice versa.

![Figure 1. Muara Karang gas regulating and metering facilities](image-url)
Control Reducing Valve (CRV) is used to reduce gas pressure from 24 kg/cm\(^2\) to 4 kg/cm\(^2\). CRV is a pilot-operated type, which means that the main valve is controlled and actuated from the pilot pressure via the spool valve. In gas regulating and metering stations, it has strainer after CRV to reduce contaminants into the boiler.

2.2. Elemental Sulfur Formation

There are three hypotheses on how the formation of elemental sulfur occurs, chemical reaction hypotheses, condensation, and desublimation. Each potential could happen simultaneously and resulted in higher deposits of elemental sulfur [4] [6].

According to Pack in [3] and [7], sulfur vapor in the wellhead gas gathering system may react with other gases to form polysulfides or sulfates. The reaction that forms polysulfide is

\[
H_2S + S_x = H_2S_x + 1 \quad \text{with} \quad 2 \leq x \leq 8 \tag{1}
\]

The chemical reaction that occurs when sulfur interacts with ferrous metal can generate deposits along the pipeline. These deposits can contribute to coagulation processes associated with the sulfur vapor desublimation. Sulfur is a highly reactive element; therefore Pack [7] concludes that potential chemical reaction can occur between sulfur and another component along the gas pipeline.

The chemical reaction usually occurs fast within the high temperature, hence compared to the actual condition in Unit 4, this mechanism does not occur because gas is reduced in pressure and temperature.

Another hypothesis is condensation. Serin [5] explains that when gas expanse, the heaviest components of gas will liquefy then solving a part of the gaseous sulfur. After gas expansion, heavy hydrocarbons components will vaporize because of temperature increase, but sulfur formations already occur. This hypothesis can explain how sulfur deposit occurrences along the wall of the gas distribution line. Cezac [1] concludes that the condensation process probable to occur when the gas is rich in heavy hydrocarbon.

According to Cezac [1], elemental sulfur deposition usually occurs at a point of pressure reduction. When gas expanse, its pressure and temperature will decrease thus the gas could become oversaturated in sulfur. When pressure and temperature are below the temperature of the triple point of sulfur, some gaseous sulfur becomes solid particles. To reduce elemental sulfur formation around control facilities, Cezac [1] propose to heat the gas stream before pressure reduction because temperature drop in gas transmission has a bigger effect on elemental sulfur deposition than pressure drop.
Figure 2. Phase envelope of typical gas transported in transmission and distribution networks [1]

According to Figure 2, condensation and desublimation can occur when natural gas has pressure or temperature lower than its phase envelope limits. In Block 45, the pressure drop will be induced temperature drop, hence gas will change its phase into liquid or solid.

The changing phase will make elemental sulfur formation occur in control reducing valve strainer as shown in Figure 3.

Figure 3. Elemental Sulfur Formation in CRV at Gas Station

Figure 3(a) shown inspection in Gas Regulating Station to uninstall strainer, figure 3(b) shown elemental sulfur formation that clogged control reducing valve strainer, figure 3(c) shown control reducing valve strainer cleaning, and figure 3(d) shown clean filter ready to install into Gas Regulating Station.

3. Result and Discussion

Natural gas that consists of hydrocarbon, carbon dioxide, and a small amount of hydrogen sulfide can have sulfur solubility in it [8] [9]. Li [10] found that sulfur solubility in hydrogen sulfide in gas
transmission stations mainly impacted by the chemical reaction between sulfur and hydrogen sulfides when the pressure above 5 MPa and by both physical and chemical reactions for pressure below 3 MPa.

The natural gas suppliers to Muara Karang Steam Power Plant have different compositions because they come from different gas fields and processes. Every supplier has a different contract, and if their gas composition still complied, we cannot reject delivered gas. Based on a gas chromatograph, CO₂ in PHE gas climbing steadily, and the methane percentage gradually reduced.

To calculate mixing gas composition for each gas component, we use the proportional formula from each gas as Formula (2)

\[
\frac{\% mol_{mixed}}{V_{total}} = \frac{(V_{PHE} \times \% mol_{PHE}) + (V_{PGN} \times \% mol_{PGN}) + (V_{NR} \times \% mol_{NR})}{V_{total}}
\]

Table 1 and Table 2 show fuel gas mixing in Unit 4 in May 2019, before our mixing strategy implemented.

| Table 1. Unit 4 gas fuel consumption |
|-------------------------------------|
| Unit 4 Gas Consumption | PHE | NR 350 | PGN | Total |
|-------------------------|-----|--------|-----|-------|
| CH₄ (% mol<sub>mixed</sub>) | 84.01 | 0% | 65% | 100% |
| CO₂ (% mol<sub>mixed</sub>) | 5.70 | 65% | 35% | 100% |
| C₂H₆ (% mol<sub>mixed</sub>) | 4.42 | 0% | 65% | 100% |
| C₃H₆ (% mol<sub>mixed</sub>) | 2.89 | 0% | 65% | 100% |

| Table 2. CRV reducing gas opening |
|---------------------------------|
| 1<sup>st</sup> month | 2<sup>nd</sup> month | 3<sup>rd</sup> month |
|------------------------|------------------|-----------------|
| 46.63% | 74.53% | 102.44% |

The fuel mixing in Table 1 happened when NR zero flow because of annual maintenance. From the table 1 and 2, we can see that CRV reducing gas opening gradually on average 0.93%/day thus in three months, Unit 4 needs to be shut down to clean the CRV reducing gas strainer because it’s already fully opened. This unplanned shut down will impact on income opportunity for Block 45.

![Figure 4. CRV reducing gas opening for Unit 4 trend in May 2019](image)

To compensate for degradation in PHE gas quality, we try to increase NR gas consumption. Table 3 and Table 4 show fuel gas mixing in Unit 4 in July 2019, when NR have a small percentage.
Table 3. Unit 4 gas fuel consumption

| Unit 4 Gas Consumption | PHE    | NR 350 | PGN    | Total |
|------------------------|--------|--------|--------|-------|
| 24.55%                 | 23.25% | 52.20% |        | 100%  |
| CH₄ (%molMixed)        | 86.85 |        |        |       |
| CO₂ (%molMixed)        | 4.18  |        |        |       |
| C₂H₆ (%molMixed)       | 3.90  |        |        |       |
| C₃H₈ (%molMixed)       | 2.57  |        |        |       |

Table 4. CRV reducing gas opening

|         | 1st month | 2nd month | 3rd month | 4th month | 5th month |
|---------|-----------|-----------|-----------|-----------|-----------|
| 46.63%  | 72.37%    | 98.10%    |           |           |           |

From Table 3 and Table 4, CH₄ increased and CO₂ reduced respectively, and with this fuel mixing, CRV reducing gas opening increased 0.86%/day thus reach fully opened in the fourth month.

Ideally, by using NR gas 100% we get the best gas quality but with a higher price than mixing it with PHE and PGN. By optimizing NR gas consumption to Unit 4 by trial and error method and considering each supplier has monthly minimum consumption volume in their contract, we get data as Table 5 and Table 6

Table 5. Unit 4 optimized gas fuel consumption

| Unit 4 Gas Consumption | PHE    | NR 350 | PGN    | Total |
|------------------------|--------|--------|--------|-------|
| 19.79%                 | 51.60% | 28.60% |        | 100%  |
| CH₄ (%molMixed)        | 88.80  |        |        |       |
| CO₂ (%molMixed)        | 2.75   |        |        |       |
| C₂H₆ (%molMixed)       | 3.70   |        |        |       |
| C₃H₈ (%molMixed)       | 2.53   |        |        |       |

Table 6. CRV reducing gas opening

|         | 1st month | 2nd month | 3rd month | 4th month | 5th month |
|---------|-----------|-----------|-----------|-----------|-----------|
| 46.63%  | 60.12%    | 73.62%    | 87.12%    | 100.62%   |           |

With more NR gas consumption, CH₄ increased significantly, and CO₂ reduced. With this composition, we get CRV reducing gas opening increased by 0.44%/day, in the end, will delay Unit 4 shut down for cleaning.
Table 7 and Table 8 shows the realized loss when Unit 4 shut down because of CRV reducing gas maintenance cleaning

| Loss of Production | 1st cleaning | 2nd cleaning | 3rd cleaning | 4th cleaning | Total (in one year) |
|--------------------|--------------|--------------|--------------|--------------|--------------------|
| Unit 4             | Rp 5,856,719,175.00 | Rp 5,856,719,175.00 | Rp 5,856,719,175.00 | Rp 5,856,719,175.00 | Rp 23,426,876,700.00 |

Table 8. The start-up cost for Unit 4

| Date                  | Explanation                        | Cost (Rp)     |
|-----------------------|------------------------------------|----------------|
| March 30th - 31st 2019| Start-up unit 4 after MO CRV       | Rp 399,960,602.00 |
|                       | Reducing Gas                       |                |
| August 31st - September 1st 2019 | Start-up unit 4 after MO CRV       | Rp 336,657,769.00 |
|                       | Reducing Gas                       |                |
|                       | Total                              | Rp 736,618,371.00 |

By using low NR consumption data, we found that Unit 4 needs maintenance outage to clean CRV reducing gas four times. In rupiahs, production losses in 2019 will be 23.4 billion.

When we implement fuel mixing strategy, projected loss from CRV reducing gas maintenance outage shown in Table 9

Table 9. Projected losses from Unit 4 maintenance outage

| Loss of Production | MO CRV Reducing Gas PLTU 4 | 1st cleaning | 2nd cleaning | Total (in one year) |
|--------------------|-----------------------------|--------------|--------------|--------------------|
| Rp 5,856,719,175.00 | Rp 5,856,719,175.00 | Rp 5,856,719,175.00 | Rp 11,713,438,350.00 |

By using the fuel mixing strategy, we found that unit 4 only needs two times maintenance outage a year. This strategy will save production loss as much as 11.7 billion rupiahs.
4. Conclusion
Several factors that cause elemental sulfur formation along gas facilities are chemical reaction, condensation, and desublimation. In Block 45 Muara Karang Steam Power Plant elemental sulfur formation occurs on gas regulating and metering station. The gas fuel mixing strategy implemented in Block 45 can reduce elemental sulfur formation without any investment being made. This strategy should consider every supplier contract to eliminate any penalty when optimized mixing implemented. By using this strategy, Muara Karang Steam Power Plant unit 4 can save 11.7 billion rupiahs a year from production loss.

References
[1] Cezac P, Serin J 2008 The J. of Supercritical Fluids Vol 44 Issue 2 115—22
[2] Mobley R K 2000 Fluid Power Dynamics (Oxford: Butterworth-Heinemann)
[3] Pack D J, Parks D W and Chesnay A B 2012 Journal of Petroleum Science and Engineering Vol 94-95 12—18
[4] Santos J P L, Lobato A K C L, Moraes C and Santos L C L 2015 Brazilian Journal of Petroleum and Gas Vol 9 No 2 45—53
[5] Serin J, Cezac P, Broto F and Mouton G 2005 Comp. Aided Chem. Eng. Vol 20 799—804
[6] Santos J P L, Lobato A K C L, Moraes C and Cunha A L 2016 J. of Natural Gas Science and Eng. Vol 32 364—72
[7] Pack D 2005 ‘Elemental Sulphur’ Formation in Natural Gas Transmission Pipelines (Perth: University of Western Australia)
[8] Li C, Liu G and Peng Y 2018 RSC Adv. 8 16069—81
[9] Mokhatab S, Poe W A and Mak J Y 2019 Handbook of Natural Gas Transmission and Processing 4th Ed (Houston: Gulf Professional Publishing)
[10] Li C, Liu G and Peng Y 2019 Ind. Chem. Res. Vol 58 Issue 1 440—47