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# POTENTIAL ENVIRONMENTAL BENEFITS OF FLUE GAS QUENCH INTEGRATION WITH EXISTING BIOMASS/WASTE-FUELLED CHP PLANT

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## ABSTRACT

Flue gas quench (FGQ) at advanced combined heat and power (CHP) plays a vital role by linking flue gas (FG) cleaning and wastewater treatment. In this paper, we have performed a detailed mass balance of pollutants in the flue gas and the process water with and without FGQ at a CHP plant. The results show that the system with FGQ puts less wastewater load (about 74 tonnes/day) together with less pollutant load on the municipal wastewater treatment plant (MWWTP) than the system without FGQ. Meanwhile, it results in fewer burdens on the external water use.

**Keywords:** flue gas, quench, mass balance, contaminant concentrations, water consumption, wastewater treatment

## NONMENCLATURE

| | |
|---|---|
| *Abbreviations* | |
| *C* | contaminant concentrations in rejection water, mg/Nm$^3$ |
| $C_{FG,i}$ | contaminant concentrations in the FG, mg/L |
| *dm* | flow rate of water evaporation in FGQ, kg/s |
| $dm_{FGC}$ | flow rate of water condensing by flue gas condenser (FGC) ,kg/s |
| *m* | flow rate of rejection water, kg/s |
| $m_{C,FGC}$ | Flow rate of whole condensate from FGC, kg/s |
| $m_{FG,j}$ | flow rate of flue gas in different steams, kg/s |
| $m_{inlet,WWT}$ | condensate water of FGC injected into WWT, kg/s |
| $\Delta m_{FGQ,i}$ | mass of contaminants captured by quench water from FG, kg/s |
| *Symbols* | |
| λ | coefficient of removing pollutant from flue gas by the water |

| | |
|---|---|
| *Subscript* | |
| i | different contaminants: $NH_4$-N, Cl and S |
| j | different steams |
| R | rejection water from wastewater treatment |
| C | condensate from FGC |
| clean | clean water |
| F | external water |
| D | discharged water from FGQ to the boiler |

## 1. INTRODUCTION

Biomass and waste fuels in power plants contain high moisture content. To improve the efficiency of power plants, FGCs are employed. The condensed water gets contaminated with the organic and inorganic compounds in the FG, such as acidic gases ($SO_2$ and HCl), $NH_3$ and heavy metals [1]. Therefore, the polluted water needs to treat before it can be discharged. Currently, there are stricter regulations to further reduce the negative impacts on the environment due to released pollutants like organic compounds, acids and heavy metals, polluted water and solids. At the same time, stricter rules for sludge management require new integration methods with municipal wastewater treatment. According to the European Commission's reference document, the large incineration power plants are expected to reduce emission through water, such as organic compounds solved in the discharge water [2,3]. Furthermore, the EU Water Framework Directive requires to reduce withdrawing fresh water externally, and increase water recycle and reuse internally, in order to reduce the disturbance to natural water [4]. For the biomass CHP plant, added FGQ before FGC, it can reduce the cost of wastewater treatment, as well as more thorough removal of water-soluble pollutants.

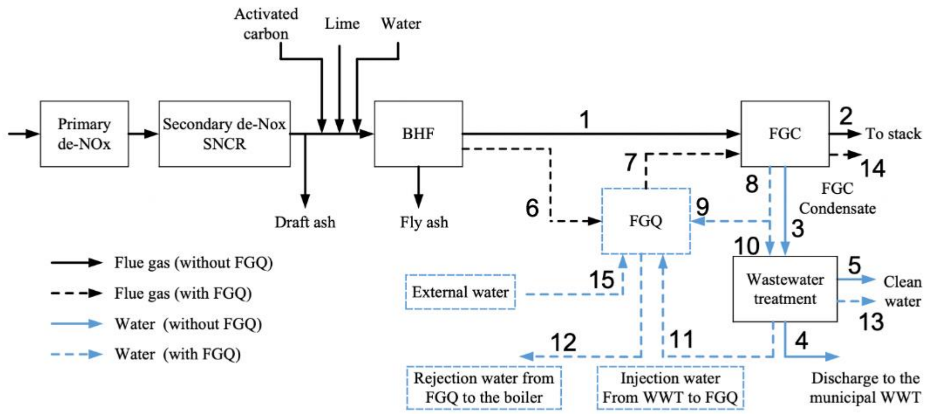


Fig 1 Schematic diagram of flue gas cleaning process

In this paper, a detailed mass balance of pollutants in the FG and the process water was performed for the cases with and without FGQ, in order to understand the role of FGQ in the FG cleaning and wastewater treatment. The following questions were investigated:

- The potential reductions in pollutants concentration (removal of pollutants) in water that will be discharged to municipal waste water treatment plant?
- Reductions in fresh water use?

## 2. METHODOLOGY

### *2.1 Mass balances of pollutants in flue gas and process water*

For the mass balances, the real data from a CHP plant is taken, which boiler thermal capacity is 170 MW. Fig. 1 shows the typical schematic diagram of flue gas cleaning process [5]. Although most of contaminants have been removed after BHF, the condensate from FGC still contains high levels of pollutions, and requires treatment, resulting in additional energy consumption [6, 7]. Therefore, the FGQ was proposed to reduce the amount of wastewater to be treated [8, 9]. In order to discuss the changes of pollutants in flue gas and process water under different operating conditions of the CHP plant, after BHF, it was divided into three cases included case 1: with FGC but without FGQ (1-5), case 2: with FGQ and FGC (6-14) and case 3: with FGQ but without FGC (6, 7, 12, 15), respectively. A mathematical model of mass balance was developed to calculate the pollutants concentration in flue gas and process water.

In FGQ, Most of contaminants are washed into the water (12). A part of the pollutant-rich wastewater is rejected to the boiler. The condensate from FGC is divided into two parts, one of which is sent to the FGQ and the other is sent to the wastewater treatment (WWT) (10). If there is no FGQ, all condensate goes to the WWT (3). In WWT, the rejection water is discharged to the MWWT in the absence of FGQ (4). If with FGQ, it is sent to the FGQ (11).

To quantitatively describe the variation of pollutants in flue gas and process water, the mathematical model was developed as follows:

For FGQ, the water balance can be calculated by the Eqn 1:

$$m_{\mathrm{R}} + m_{\mathrm{C}} + m_{\mathrm{F}} - m_{\mathrm{D}} = dm \quad (1)$$

where $m_R$, $m_C$ and $m_F$ are the rejection water from WWT, part condensate from FGC and make-up water respectively (kg/s); $m_D$ is the water discharged from FGQ to the boiler (kg/s); and $dm$ is water evaporation in FGQ (kg/s). When FGC is not running, $m_R$ and $m_C$ are zero. The sum of $m_R$, $m_C$ and $m_F$ is the injection water to FGQ. In the steady state, the concentration of contaminants remains unchanged. Therefore, the governing equation of the contaminant balance can be expressed as follows:

$$m_{\mathrm{R}}C_{\mathrm{R,i}} + m_{\mathrm{C}}C_{\mathrm{C,i}} + m_{\mathrm{F}}C_{\mathrm{F,i}} - m_{\mathrm{D}}C_{\mathrm{D,i}} + \Delta m_{\mathrm{FGQ,i}} = 0 \quad (2)$$

where $C_R$, $C_C$, $C_F$ and $C_D$ are contaminant concentrations in the rejection water from WWT, condensate from FGC, make-up water and water discharged from FGQ to the boiler respectively (mg/L); $i$ represents the different contaminants; and $\Delta m_{FGQ,i}$ is the amount of contaminants captured by quench water from FG (mg). Similarly, in FGC and WWT, the Eqns of mass balance are as follows:

$$m_{\mathrm{C,FGC}} = dm_{\mathrm{FGC}} \quad (3)$$

$$m_{\mathrm{C,FGC}}C_{\mathrm{C,i}} + \Delta m_{\mathrm{FGC,i}} = 0 \quad (4)$$

$$m_{C,FGC} = m_C + m_{inlet,WWT} \quad (5)$$

$$m_{inlet,WWT} = m_{clean} + m_R \quad (6)$$

$$m_{inlet,WWT} C_{C,i} = m_{clean} C_{clean,i} + m_R C_{R,i} \quad (7)$$

where $m_{C,FGC}$ is the condensate of FGC (kg/s); $m_{inlet,WWT}$ is the part condensate of FGC sent to WWT (kg/s); $m_{clean}$ represents the clean water produced by WWTP (kg/s); $C_{clean}$ is contaminant concentrations in the clean water (external water, mg/L); and $dm_{FGC}$ represents the amount of water condensing by FGC (kg/s).The amount of contaminants removed from the flue gas can be calculated by the Eqn 8:

$$\Delta m_i = \lambda_i m_{FG,j} C_{FG,i} \quad (8)$$

where $\Delta m_{FGQ,i}$ is the amount of contaminants captured by water from flue gas (mg); $C_{FG,i}$ is contaminant concentrations in the flue gas; $m_{FG,j}$ represents the mass flow rate of flue gas in different steams; and $\lambda_i$ is the coefficient of removing pollutant from flue gas by the water.In the calculation, it has been assumed that 90% of the $NH_3$ and $SO_2$ and 80% of the HCl can be removed from FG by water [5]. The contents of these contaminants in external water and flue gas (1/6) are listed in Table 1 and Table 2 [10]. According to the previous work [11], the profile in various streams are identify as shown in Table 3.

Table 1 Content of major pollutants in external water

| Contaminant | $NH_4$-N (mg/L) | Cl (mg/L) | S (mg/L) |
|---|---|---|---|
| External water | 0.08 | 16 | 14.3 |

Table 2 Content of major pollutants in flue gas (1/6)

| Contaminant | $NH_3$ (mg/Nm$^3$) | HCl (mg/Nm$^3$) | $SO_2$ (mg/Nm$^3$) |
|---|---|---|---|
| External water | | | 7.59 8.3 42.52 |

Table 3 Profile in various streams

| | 1/6 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| T (K) | 436.1 | 320.1 | 320.1 | 318.1 | 318.1 |
| P (Pa) | 101353 | 101325 | 101325 | 101325 | 101325 |
| Flow rate (kg/s) | 93.68 | 85.25 | 8.42 | 0.85 | 7.57 |
| | 7 | 8 | 9 | 10 | 11 |
| T (K) | 337.5 | 320.1 | 320.1 | 320.1 | 318.1 |
| P (Pa) | 101325 | 101325 | 101325 | 101325 | 101325 |
| Flow rate (kg/s) | 95.68 | 10.42 | 1.27 | 9.16 | 0.92 |
| | 12 | 13 | 14 | 15 | |
| T (K) | 339.9 | 318.1 | 320.1 | 319.1 | |
| P (Pa) | 101325 | 101325 | 101325 | 101325 | |
| Flow rate (kg/s) | 0.18 | 8.23 | 85.25 | 2.19 | |

## 3. RESULTS AND DISCUSSIONS

### *3.1 Summarized mass balance results*

Based the above model of mass balance and measurement data, the pollutions concentration was calculated in various streams under different operation conditions.

Case 1: with FGC but without FGQ

Fig. 2 and 3 show that the pollutions concentration in flue gas and process water. It can be seen that most of contaminant concentrations were removed after FGC, which made the emission of flue gas cleaner to reduce the air pollution. Meanwhile, these pollutions went into the condensate. The concentrations of $NH_4$-N, Cl and S are up to 978.44, 928.33 and 5358.05 mg/L after WWTP, respectively. And then, they will be discharged to the MWWTP.

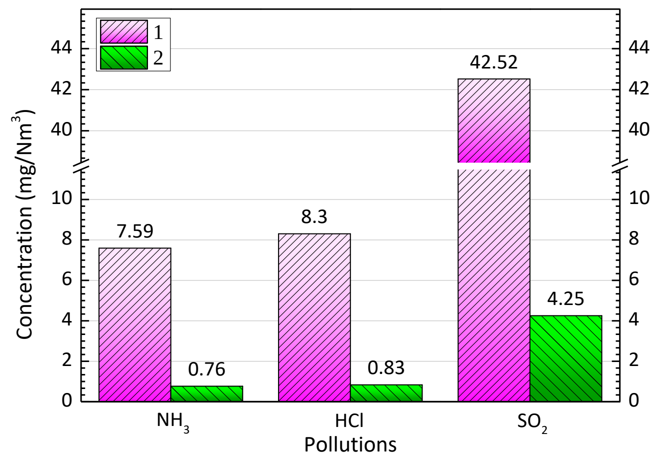


Fig. 2 Pollutions concentration in flue gas (1 and 2) without FGQ

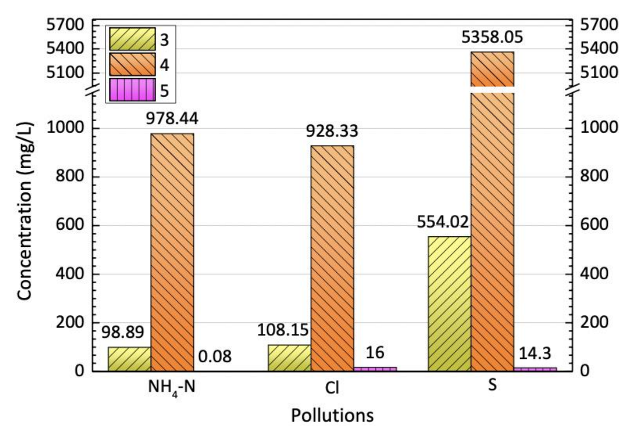


Fig. 3 Pollutions concentration in process water (3, 4 and 5) without FGQ

Case 2: with FGQ and FGC

The function of FGQ is illustrated in Fig. 4 and Fig.5. For the flue gas, after FGQ (6-7) and FGC (7-14), the concentrations of $NH_3$, HCl and $SO_2$ sent to the stack were as low as 0.88, 0.33 and 0.43 mg/Nm$^3$, respectively. For the process water, the pollutions concentration in outlet of WWTP (11) decreased obviously compared with Case 1. Meanwhile, most of pollutions were collected in FGQ water, which is send the boiler instead of the MWWTP.

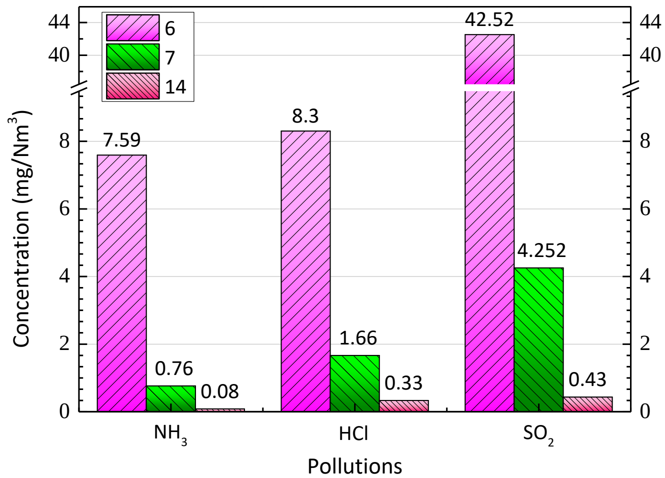


Fig. 4 Pollutions concentration in flue gas (6, 7 and 14) with FGQ

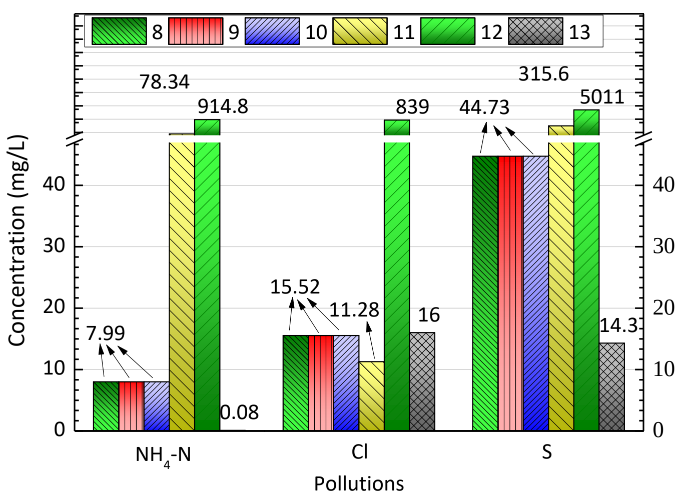


Fig. 5 Pollutions concentration in process water (8, 9, 10, 11, 12 and 13) with FGQ

### *3.2 Potential load reduction on MWWTP*

The comparative results between system with FGQ and without FGQ show a significant reduction in wastewater that needs to be treated at the municipal waste water treatment plant, i.e. the system without FGQ requires about 74 tonnes per day of wastewater load (with 980 mg/l of NH4-N, 930 mg/l of Cl, and 5358 mg/l of S) on the municipal water treatment plant from the CHP plant. Whereas, in system with FGQ, nearly identical amount of waste water from internal WWTP is used as injection water to the FGQ and the rejection water from the FGQ is further introduced to the boiler. Moreover, the concentrations of contaminants are also substantially lower in the system with FGQ as compared to the system without FGQ, i.e. the injection water to the FGQ contains about 78 mg/l of NH4-N, 11 mg/l of Cl, and 315 mg/l of S).

### *3.3 Potential reduction in fresh water use*

The internal wastewater treatment at the CHP plants cleans the condensate from the FGC and the clean water can be available for further internal use. Within the system without FGQ, the conventional load on the internal wastewater treatment is about 727 tonnes per day and the treatment facility produces 654 tonnes per day of clean water. In comparison, with FGQ, the load on the internal wastewater treatment is about 791 tonnes per day and the treatment facility can produce 712 tonnes per day of clean water. This implies that nearly 58 tonnes per day of more clean water available to use internally within FGQ system resulting in less burden on the external fresh water use.

## 4. CONCLUSIONS

In this study, a comparative analysis is presented between the CHP system with and without flue gas quench (FGQ) in terms of pollutant and energy load on the municipal wastewater treatment plant together with possible difference in fresh water withdrawal externally. The comparative analysis concludes that:

(i) The system with FGQ puts less wastewater load (about 74 tonnes/day) together with less pollutant load (in terms of NH4-N, Cl and S) on the municipal wastewater treatment plant than the system without FGQ.

(ii) There is relatively more clean water available to use internally within FGQ system resulting in less burden on the external fresh water use.


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