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Analysis of Possibilities of Elimination of Liquid Droplets from Gas Flow for Mitigation of Operating Problems of Gas Preheater

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This study deals with the analysis of possibilities of removing of undesirable sticky liquid droplets contained in process waste gas (PWG) stream before entering o tubes of a tube bank heat exchanger (gas preheater), which is a part of gaseous wastes incineration unit. PWG is being preheated by high-temperature flue gas. Presence of the liquid droplets in the PWG in combination with the specific geometry of existing preheater containing stagnation zones on the entry to tube-side of preheater resulted to extensive fouling of tube-side of preheater by deposits. The aim of the study is to identify suitable way of removing liquid droplets from the PWG stream before preheater and to analyse possibilities of design of suitable separation equipment within the frame of spatial limitations and process and operating potential of the gaseous wastes incineration unit.

1. Introduction

A simplified flow sheet of gaseous wastes incineration unit which is a branch of complex liquid and gaseous wastes incineration unit is pictured in Figure 1.

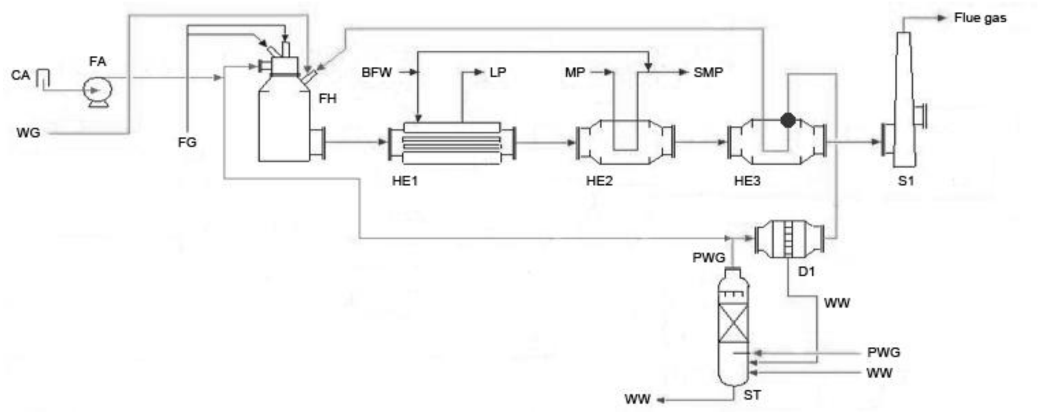

Figure 1: Principal flow sheet of the gaseous waste incineration unit

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It can be seen from lower part of Figure 1 a waste water (WW) stream going into stripping equipment ST where its part is stripped into the PWG stream. The PWG goes into a demister D1 in order to intercept and separate a liquid droplets contained in the PWG stream. The PWG is then led into the heat exchanger HE3 where the PWG is preheated by flue gas flowing on the shell-side of HE3. Finally, the preheated PWG stream goes from HE3 outlet to inlet to furnace FH, where the PWG is thermally disposed.
So, the preheater HE3 plays important role in the disposal of PGW. Main function of the exchanger HE3 role is to utilize waste heat of the flue-gas and to prepare PWG for its reliable thermal incineration in the flame of fuel gas (FG) combusted with combustion air (CA) in the furnace FH. Moreover, furnace FH serves to incineration not only PWG but also to other waste gas (WG) stream as is obvious from Figure 1.

2. Operating troubles of PWG preheater

During operation of gaseous wastes incineration unit the important decreasing of thermal duty of preheater HE3 was observed. This fact means substantially worse PWG incineration indicated by not acceptable flue gas emissions measured in flue gas. This observation resulted in substantial reduction of capacity of main plants producing chemical products for reduction of production of amount of PWG and thus in substantial economic losses of producer. Analysis of operating troubles of HE3 shown that source of troubles is the demister D1 which work with low efficiency, i.e. important part of liquid droplets going in the PWG from D1 to the preheater HE3. Presence of the liquid droplets in the PWG in combination with the specific geometry of existing preheater containing stagnation zones on the entry to tube-side of preheater resulted to extensive fouling of tube-side of preheater by deposits and to mentioned reduction of preheater thermal duty.
The black dot on HE3 in the Figure 1 denotes the critical point of the preheater where the fouling within the process takes place. The fouling results in clogging of some tubes (see Figure 2 left) and thereby decrease in heat output and also increase a mechanical stresses of the heat exchanger – it has already resulted in breaking several tubes and thereby also undesirable leaking of the PWG into flue-gas (see Figure 2 right). This led to mentioned failure of function of incinerator, because the PWG waste stream leaked into both shell side of flue-gas stream and stack S1. The remaining liquid droplets entering the tubes solidify due to increased temperature and subsequently stick to the inner tubes surfaces.

Figure 2: Fouling of the heat exchanger HE3 – tube side (left), shell side (right)

Thus, the aim of the study is to identify the efficient and suitable way of removing liquid droplets from the PWG stream before preheater HE3 and to analyse possibilities of design of selected suitable separation equipment within the frame of spatial limitations and process and operating potential of the gaseous wastes incineration unit.

3. Analysis of possibilities of liquid droplets elimination from gas flow

The initial point of solution is the analysis of input data and actual operating data and operating regimes and composition of PWG stream leaving stripping equipment ST (see Figure 1).

3.1 Input data analysis

Composition of PWG stream was successfully completed and known. Main operating data provided by plant operator are presented in Table 1. In the left column of the Table 1 operating conditions are shown and the corresponding degree of evaporation according to the operating company. The degree of evaporation is according to this data equal to one, which would mean that the PWG stream does not contain any liquid droplets. However, based on the fact that the existing demister D1 continuously intercepts 20 – 30 L/h of liquid droplets can be stated that the data are not in accordance with actual incineration operating. So, it was necessary to carry out a simulation to analyse the actual state of the PWG stream. The simulation results show that the degree of evaporation that is according to the operating company equal to one is theoretically correct.

Table 1: Operating conditions according to the plant operator versus the results of simulation

Parameter PWG	Plant operator	Simulation
Degree of evaporation, -	1	0,9968
Temperature, °C	70	70
Absolute pressure, kPa	110	112
Amount of liquid droplets intercepted by the droplet separator D1, L/h	20 – 30	
Amount of the liquid droplets, L/h	0	57

The explanation is given by the dew point curve (see Figure 3) obtained on the basis of known composition of the PWG stream and the operating conditions; from Table 1. From dew point curve can be seen that operating temperature (70 °C) and operating pressure (110 kPa) of PWG is very close to the dew point. The explanation lies in standard fluctuation in operating conditions (for example, pressure fluctuate approx. ± 2 kPa). The consequence of the fluctuation in operating conditions monitored during operation is under these circumstances repeated crossing of the dew point.

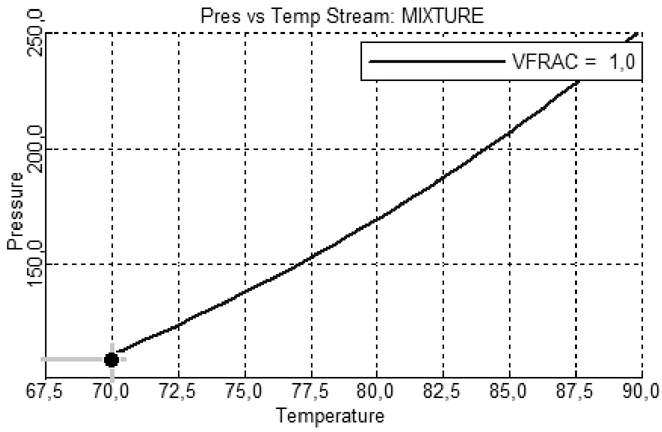

Figure 3: Dew point curve of the PWG stream

This piece of knowledge led to a new simulation task in which the intended operating pressure is 2 kPa higher (the influence of the fluctuation during the operation) than the one given by the operating company (nominal data). The results of this simulation can be seen in the right column of the Table 1.

This data correspond to the monitored actual stated accurately enough. Therefore these data were used as input data for further solution.

3.2 Strategy of solution

Through a discussion with the plant operator it was decided to use ways of liquid droplets intercepting based on cyclones as best possible way of solution. This type of equipment can be designed directly to intercept liquid droplets. However, in terms of reliable design computing possibilities seems unreliable. Therefore, a two-stage treatment of the PWG stream solution consisting of a) solidifying liquid droplets and b) their subsequent separation in cyclone appears suitable.

In terms of minimization of investment and operating costs it is suitable to use technological potential of the incineration unit to solidify liquid droplets. In this case, this can be carried out by direct injection of a certain amount of flue-gas into the PWG stream. The amount of flue-gas needed for injection is the subject of the balance calculation. Flue-gas for injection to PWG can be removed from flue-gas line from two possible places: a) before gas preheater b) behind gas preheater. Possibilities are schematically shown on modified flow sheet in Figure 4. First possible way is to remove flue-gas before HE3 – see line A in Figure 4. Second possible way is to remove flue-gas behind HE3 – see line B in Figure 4.

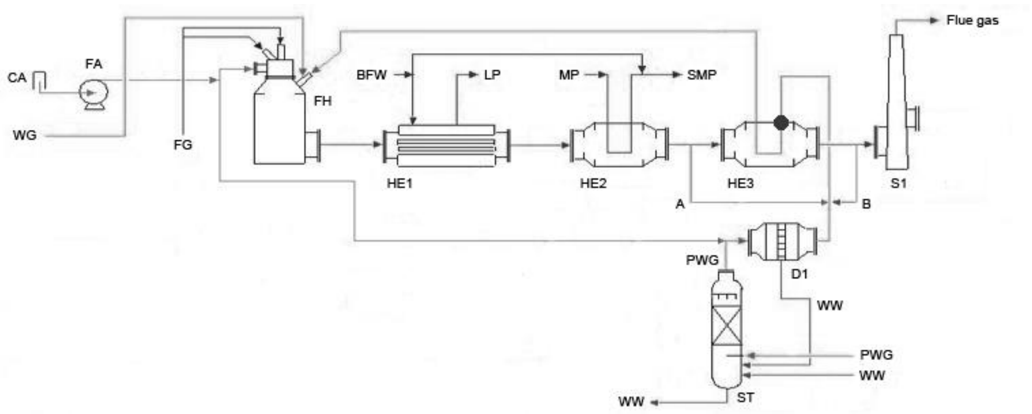

Figure 4: Flow sheet of the incineration unit with possible flue-gas injecting lines A and B

4. Solution results

The input parameter of the balance calculations is the temperature on which the PWG stream should be heated up. According to Figure 3, the targeting temperature was determined to 85 °C, therefore heating from 70 to 85 °C. It was necessary to carry out two balance computations. Each one corresponded to a given way of injection of the flue-gas (A or B from Figure 4), since the flue-gas can be taken away either in front of (see Figure 5 left) or behind the heat exchanger HE3 (see Figure 5 right).

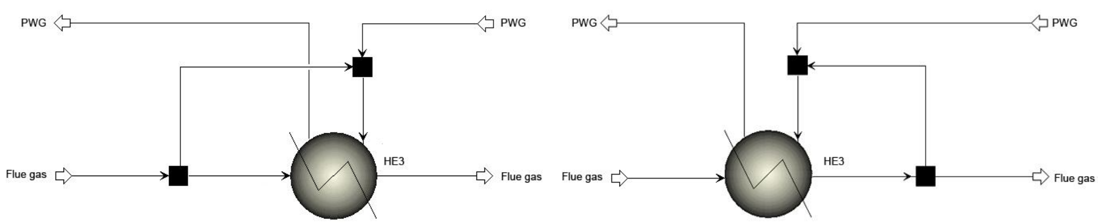

Figure 5: The schemes of calculation models of possible alternatives of flue-gas injection into the PWG stream

The position of flue-gas sampling point influences the amount of flue-gas (hot stream) needed to achieve the intended temperature and with that the total amount of PWG (cold stream). Both of these streams enter the preheater HE3 as heat transfer mediums. In both cases the thermal-hydraulic properties of HE3 are affected. The main results of calculations are presented in Tables 2 and 3. The total amount of the PWG (or PWG and flue-gas) has an influence on the design of the separating equipment – cyclone.

Table 2: The main results of the case of the flue-gas injection to PWG taken before HE3

Parameter	Value	Unit
Temperature of the withdrawn flue-gas	431	°C
Amount of the withdrawn flue-gas	945	kg/h
Amount of PWG and flue-gas	18075	kg/h

Table 3: The main results of the case of the flue-gas injection to PWG taken behind HE3

Parameter	Value	Unit
Temperature of the withdrawn flue-gas	229	°C
Amount of the withdrawn flue-gas	2323	kg/h
Amount of PWG and flue-gas	19453	kg/h

The subsequent design of cyclone was carried out with regard to spatial limitations of the incineration unit. The height and the diameter of the cyclone are considered as parameters to be dominantly limited by spatial limitations. Cyclone was designed by method that is described by Green and Perry, (2008) and using equations from Stephan et al., (2010). The results of the basic geometric characteristics of designed cyclones for both possibilities of flue-gas injection are presented in Table 4.

Table 4: The basic geometric parameters of cyclones designed for possible alternatives of flue-gas injection to PWG

Parameter	Symbol	Alt. 1	Alt. 2	Unit
Cyclone (barrel) diameter	D_C	1.58	1.64	m
Cyclone (overall) height	H_C	3.69	3.83	m
Vortex finder diameter	D_P	0.64	0.66	m
Vortex finder length	H_P	0.90	0.93	m
Barrel height	H_V	1.03	1.06	m
Inlet height	H_E	0.77	0.80	m
Inlet width	B_E	0.42	0.44	m
Dust exit diameter	D_K	0.64	0.66	m

Note: Alt. 1 – flue-gas injection to PWG before HE3; Alt. 2 – flue-gas injection to PWG behind HE3

From the results is obvious that smaller cyclone is obtained in alternative 1 where flue-gas for injecting to PWG is removed from flue-gas line before preheater HE3. A simplified scheme of this cyclone with matching main geometric characteristics is presented in Figure 6.

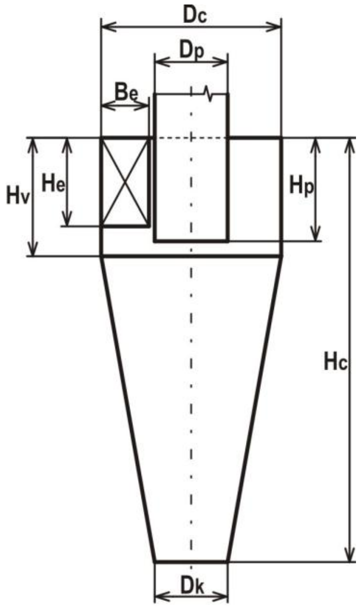

Figure 6: the scheme of cyclone with main geometrical parameters

5. Conclusion

For given industrial problem and according to requirements of plant operator it was identified suitable way of removing liquid droplets from the PWG stream before inlet to preheater. It was performed analysis of possibilities and alternative designs of suitable separation equipment within the frame of spatial limitations and process and operating potential of the gaseous wastes incineration unit. The smaller equipment was recommended as optimum solution for existing operating situation, requirements, constraints and limitations.

A competitive solution of problem of elimination of liquid droplets which was also presented to plant operator to consideration is to integrate another demister of the same type as equipment D1. The separation ability would be strengthened importantly by this way. When the results of the simulation are taken into account it can be said that the current equipment D1 works with an approximate efficiency of droplets separation about 50 %. By implementation of another one a sufficient total separating efficiency would be reached with minimum investment and operating costs. In combination with an suitable adjustment of the PWG inlet section of preheater for improvement of the PWG stream distribution in the preheater the elimination of operational problems is expected.

Acknowledgement

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