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Analysis of Plucking of U-Tubes in Heat Exchanger

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The paper presents issues of thermal and static structural analysis of a special heat exchanger with U-tubes. This heat exchanger serves for preheating of process waste gas (PWG) by flue gas. Operating of this preheater is connected with unexpected difficulties (tubes plucking from a tube sheet). Therefore; the significant part of paper discusses damage causes of heat exchanger tubes and their calculation possibilities. Substantial part of paper is also devoted to discussion of used computational models, boundary conditions and results of applied thermal and structural analyses.

1. Introduction

The analysed preheater of process waste gas (see Figure1) is a part of a unit for thermal disposal of waste gas produced by chemical plant. The main role of the preheater in the plant is to preheat waste gas on the temperature needed for its absolute thermal disposal in a combustion chamber in flame of natural gas. Complications occurring on the preheater (loss of power, tubes plucking from a tube sheet and PWG incursion into flue gas leaving from an incineration plant) have direct influence on the quality of combustion, the running of incineration plant and subsequently emissions of combustion. Because of operating complications the preheater demanding often cleaning and maintenance, it is necessary to put it out of operation as well as the whole incineration plant and consequently the whole chemical production which cannot be kept without secured disposal of produced waste gas. Those facts negatively influence not only life time of the preheater but also many other devices and in addition, they cause considerable economic losses.
As the analysis of operating conditions showed, PWG stream (containing unwanted sticky drops) is a

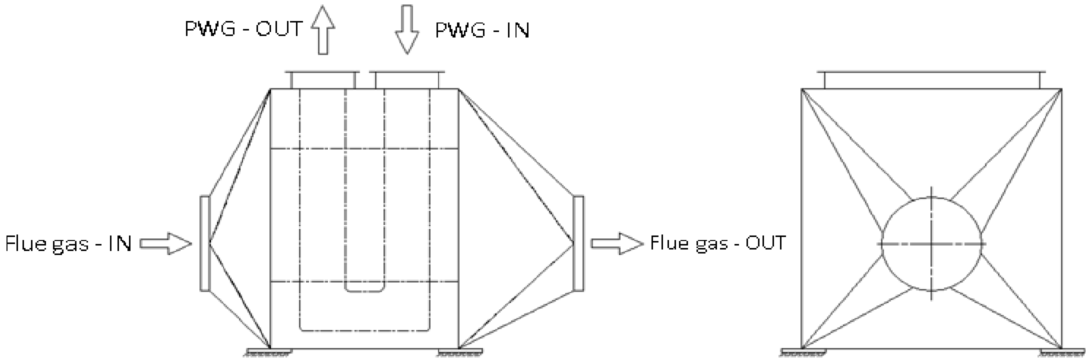

Figure 1: U-tube process waste gas preheater

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cause of total obstruction (clogging) of some preheater´s tubes which are consequently not cooled by entering PWG and they are overheated on the temperature of the flowing flue gas. The current design of the plant and its spatial limitation do not enable to place suitable additional device for separation of liquid particles before it enters the heater. Thus, the main aim of the paper is to analyse ability of the U-tubes bundle, compensate non uniform thermal loading from particular U-tubes and evaluate if those thermal changes cause the current tube bundle´s damage. In order to identify and evaluate causes of damage on tube material compactness, thermal and structural computational models of the preheater were created. The thermal computational model is applied for evaluation of thermal distribution for the most importing operating conditions. The received results were afterwards used as entrance data for computational model of static structural analysis. The analysis takes into consideration stress analysis of particular U-tubes in tubes bundle. The paper describes the principles applied in both computational models and the results obtained. The discussion about the influence of computational presumptions and estimations of unknown parameters on quality of received results is also included.

2. Layout of heater

The PWG stream coming on the incineration plant goes at first trough a drops separator (demister), after that it enters the preheater where it is preheated and lead into the incinerator in order to be thermal liquidated. The PWG preheat in the preheater is arranged by residual heat of combustion products which enter the preheater after they transfer the majority of their heat in waste heat boiler (HRSG). In this preheater occur material coherence damage of tube sheet and tubes in which PWG flows. The preheater´s construction is obvious from the picture above (Figure 1), the scheme of media passage through the tubes bundle is in the Figure 2. The damage of tube sheet and tubes´ coherence occurs on the PWG entrance side in the place of their connection with the tube sheet.

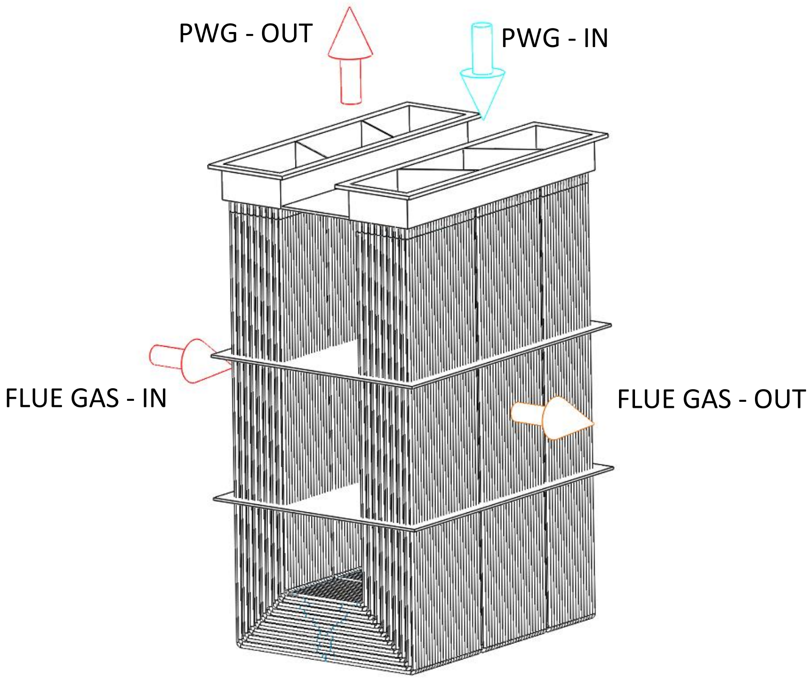

Figure 1: Process streams and layout of supports

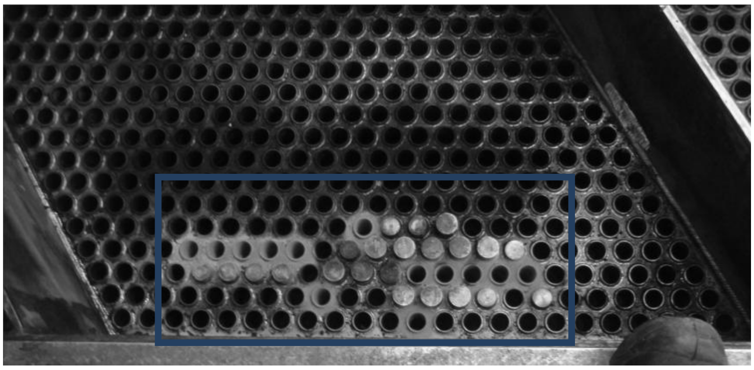

Figure 2: Area of damaged tubes

In the photo of the cleaned preheater in 2011 (see Figure 3) we can see the middle section of the entrance tube sheet and the places where the damage of tubes and tube sheet occurred, the group of already blinded tubes and the highlighted area of the occurrence of new indicated damage in 2012.

3. Discussion about damage of heat exchanger tubes

In chamber on the PWG stream entrance side the fouling of heat exchanger occurs. It’s caused by particles which are contained in the stream (see Figure 4).
Those sediments worsen the preheater´s functionality; in addition, they can also be the cause of the problem situation, which means disruption of material compactness of the tubes. The exchanger´s clogging by sediments causes non uniform thermal stress of the tube bundle whereas clogged tubes begin to overheat by flue gas, which leads to higher thermal dilatation in comparison with the tubes that are clean and permanently cooled by entering PWG. The influence of these thermal dilatations will be discussed below.
As other reasons of the tube bundle´s damage were taken into consideration inappropriate operating conditions, inappropriate manufacturing technology for example inappropriately made weld joints in places of disruption. While making analyses, it has not been found out that they could cause the damage of device. For the lack of data about fracture, it has not been made the analysis based on fracture mechanics. Therefore, attention has been paid to the analysis of the thermal load changes of the exchanger and their influence on the tube bundle.

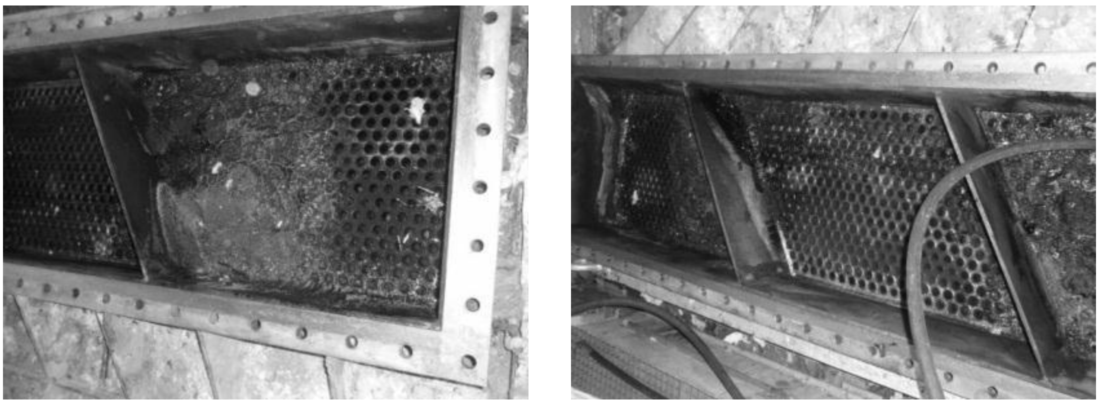

Figure 3: Inlet chamber of PWG with fouled tubes

4. Computational models

In order to discover the damage to the preheater it was made thermal analyses and structural analyses.

4.1 4.1 Thermal analyses

For the purpose of stress analysis it was necessary to realize thermal calculation of the preheater at first which determined the thermal field along the tubes as well as along particular lines of the exchanger. With a view to create such a thermal system, first of all, it has to be made the thermal computational model of the preheater for several operating modes of the exchanger. The first mode concerns the clean heat transfer area of exchanger. It served especially to validation of the computational model by means of comparison of results with measured data at relatively clean preheater. The second mode was related to clogging of 1/3 of tubes; finally the third mode counted with 2/3 of clogged tubes (the extreme case).

The thermal fields were calculated by the help of the thermal computational model and afterwards, such coined detailed thermal system could be used as sufficient entering data for accurate structural analysis.

4.2 4.2. Static structural analysis

Geometry of baffle system of solved preheater in 3D is shown in Figure 5.

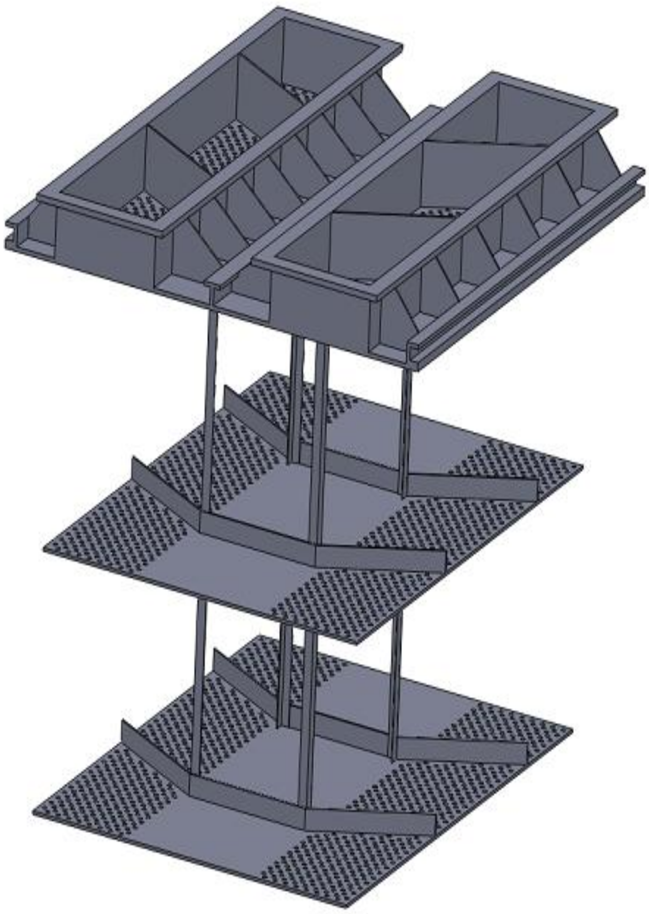

Figure 4: Scheme of a baffle system of preheater

The preheater consists of the U-tubes bundle (see Figure 2), the input and output chamber and baffles, as it is demonstrated in the Figure 5. The dimensions of the input and output chamber are 2500mm x 580mm. The outside diameter of tube is 27.2 mm and the thickness of its wall is 2 mm, the length of the shortest tube is 3,460mm and the longest one 3,757mm.

Computational models for structural analysis
Two primary computational models were created. The first one did not contain any baffles regulating vibration of tubes, second one included baffles. ANSYS 12.1 was used to calculate computational models
The computational model was created as a combination of shell elements, pipe elements and of elements forming contact pairs in places of the connection tubes into the tube sheet. SHELL93 was used as a shell element. As pipe element was used PIPE16 with advantage of enter the internal and external temperature. For contact pairs were used elements CONTA174 and TARGE 170.

Loads and boundary condition
The computational model was loaded by thermal fields, which simulated significant states with regard to the operation of the preheater. Following thermal load modes were taken into consideration:

- The preheater is clean, not clogged.
- The middle part of the preheater is clogged, side walls are clean.
- The middle part of the preheater is clean, side walls are clogged.
- The clogged tubes are selected according to the photo documentation provided.

The PWG preheater was also loaded by gravity acceleration; and appropriate mechanical boundary condition were added with respect to real gripping of the tube bundle in the complex of heat exchanger.

Simplifying assumptions
The baffles regulating position of tubes were created as a fixed connection with pipes. This solution was chosen on the basis of extend of the problem and because of insufficient computing power, which would enable create contact set taking into account the separation between tubes and the hole in the baffle at the same time with inclusion of friction. The results of the analysis are supposed to be only qualitative, highlighting places that are potentially dangerous.

5. Estimation of results

Due to different thermal dilatations caused by clogging of tubes ‘parts lead to the situation in which the hot, more dilating tubes transfer this movement on other cooler tubes which are not clogged and pull them down and into sides. Cold tubes are then plucking. Apparently the area, which is considered during calculation as functional and not clogged, significantly exceeds allowed values of mechanical stress, thus it is likely that there occur tubes´ failure. It was necessary to cover some simplification into calculation. In the real situation, it is expected stress redistribution caused by movement of tubes in baffles. The results of the analysis made for the case without any baffles demonstrated that there will not occur any problems, tubes can freely dilate and they are not tied up to each other. The places of the tube bundle, which appear to be dangers according to the analysis results, comply with the location of places where damage occurred indeed (see Figure 3).
The results confirm that the most effective solution to the problems of PWG preheater will be modification of the preheater´ s entering conical (distributional) part of the exchanger on PWG entry into the preheater, which leads to flow balancing, as well as it will not cause flow slowing in dead corners on the entrance tube sheet, which causes cleaving of clogging particles on the tube sheet and tubes.
Another possibility is to remove of antivibration baffles from the tube bundle, which subsequently causes plucking the tubes. By suitable adjustment it is possible to eliminate the current situation, when warmer tubes transmit loads to the cooler ones. However, this modification is necessary to realize with the greatest accuracy, since baffles have important function in the preheater. It is prevention from tubes vibrations caused by karman vortex street during combustion products´ flow. By total removal of baffles or their inadequate modification would cause those vibrations and there would be a risk of high cycle fatigue on all tubes. The suitable constructional modification of current baffles has to be included in another research.

Another option is to reconsider the possibility of installing pretreatment of stream PWG. Thanks to this intervention the stream would no longer contains particles that fouled tubes, in addition, there would not be any differences in the thermal dilatation; therefore, no other additional design adjustment would be required

6. Conclusion

The results of the study carried out by static thermal and structural analysis of the special tubular heat exchanger with U-tubes for preheating PWG enable definitely to identify and confirm the mechanism of damage to the U-tubes in the preheater. The results show that the damage to the heat exchanger is caused by different thermal dilatations of tubes (resulting from unequal tube fouling) and also by transfer of this displacement over the baffles to another tubes. Without implementation of design changes of the preheater or without upstream devices on the PWG stream, the preheater will be still damaged with impact on a growing part of tube bundle

The results of executed study also showed that the most effective solution to problems of damage of preheater´s tubes will be installation of suitable equipment for more efficient pre-treatment of waste gas (PWG) before it comes to preheater, together with geometry modification of input chamber of PWG into the preheater to ensure equal current distribution PWG into U-tubes of the tube bundle.

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