Proceedings of International Conference on Heat Exchanger Fouling and Cleaning - 2015 (Peer-reviewed)
June 07 - 12, 2015, Enfield (Dublin), Ireland
Editors: M.R. Malayeri, H. Müller-Steinhagen and A.P. Watkinson

Published online
www.heatexchanger-fouling.com

FOULING IN HEAVILY POLLUTED GAS APPLICATIONS – EXPERIENCE, KNOW-HOW, SOPHISTICATED APPROACH

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ABSTRACT

Fouling can be considered an inherent phenomenon occurring in heavily polluted gas applications. Operators then frequently face unexpected fouling-related problems which are sometimes difficult to solve. However, experience and know-how as well as any relevant data obtained in the course of numerous case studies can be utilized to create a knowledge base matching possible issues to their practical solutions.

The present paper aims to provide descriptions of several operating issues reported for heat exchangers employed in units which deal with gaseous media having high fouling propensity – especially flue gas. This fluid contains large amounts of pollutants ranging from fine solid particles sticking to heat exchange surfaces to various compounds forming surface deposits via chemical reactions. Not only that any such layer tends to significantly lower equipment heat duty and increase pressure drop, acidic compounds present therein can also be the primary cause of heat transfer surface corrosion.

Unfortunately, there is no general rule or a prescription as to how heat exchangers should be designed to prevent fouling. The issues presented in this paper which stem from flawed design decisions are accompanied by practical recommendations pertaining to possible fouling mitigation strategies. The impact of flow maldistribution and low flow velocity on fouling is discussed alongside the effect of flow system arrangement and heat exchanger geometry. It is demonstrated how sophisticated computational methods can be utilized in troubleshooting and virtual prototyping, i.e., to mitigate fouling or even prevent it. Additionally, importance of per-case approach and tailor-made solutions to fouling-related issues is emphasized. It is shown that even in the early stage of design all the potential problems associated with fouling have to be taken into consideration.

Approaches discussed in this paper can be utilized by designers to avoid potential problems. Experience from operation and individual cases can then be generalized and a new methodology can be created and utilized.

INTRODUCTION

Fouling in industrial heat exchangers for heat recovery from polluted gaseous streams is still a significant problem and often have major economic impact. This is especially true in power industry where process media usually contain large amounts of small particles which tend to stick to heat transfer surfaces. In such a case the issue is further aggravated if flue gas is wet and higher-coherence lumps of particles sinter into hard layers firmly attached to the surface.

It is obvious that a detailed evaluation of the actual situation is an important pre-requisite of an adequate selection of corrective action. Based on the composition of flue gas we first choose a suitable material and then, according to the kind of fouling, heat exchanger type and its geometry are selected. However, the respective know-how is required in order for these steps to be carried out properly.

In this paper we will discuss via industrial examples the main factors influencing formation of deposits from a polluted flue gas stream and also the measures taken to abate the associated problems.

FACTORS INFLUENCING FOULING

It is not only the composition and properties of foulant and process media that influence the rate of deposition; flow velocity and surface temperature are significant factors as well (Bott, 2001). These two parameters can easily be controlled by the designer of the apparatus via proper selection of heat exchanger geometry. Fig. 1 shows an idealized change of fouling layer thickness in time. In real-life, however, shape of this curve may differ significantly and depends mainly on operating conditions, flow velocity, and surface temperature.

The first step to fouling mitigation is correct thermal-hydraulic design. This means that the designer has to take fouling into account so that it is minimized as much as possible from the start. Also, heat exchanger geometry must permit easy cleaning. In other words, it is much better to minimize fouling in the design stage than deal with it behindhand in the course of equipment operation when the associated costs are much higher.

Flow Velocity

Flow velocity is often governed by the designer's decision on heat exchanger geometry (tube count and pitch, plate dimensions and pitch, etc.). It holds that the higher the flow velocity, the higher the self-cleaning capability and consequently the lower the deposited layer thickness (see Fig. 2). Nonetheless, flow velocity is a major factor

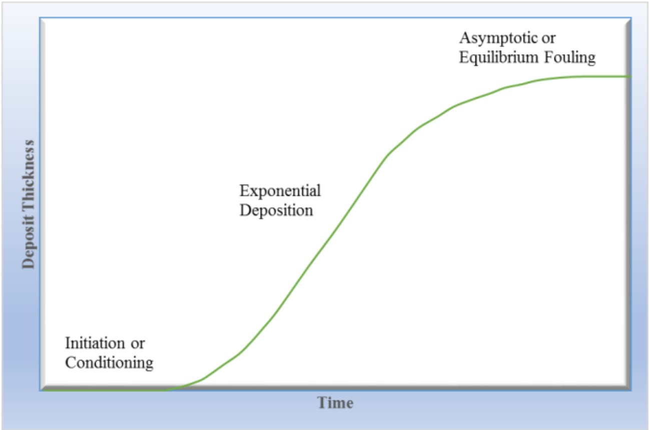

Fig. 1 Idealized change of fouling layer thickness in time (Bott, 2001)

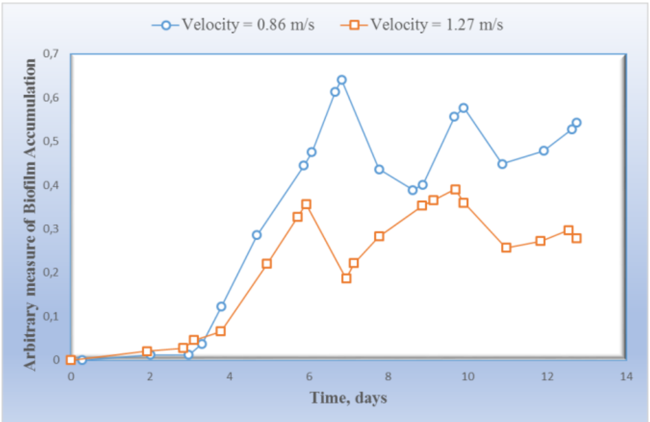

Fig. 2 The effect of flow velocity upon the actual thickness of fouling layer in time (Bott, 2001)

influencing heat transfer coefficient and pressure drop and as such it is necessary to find its optimum value with the resulting pressure drop being close to the allowed limit.

Surface Temperature

Increase in surface temperature can lead to increased corrosion rate and increased rate of chemical reactions, thus causing increased build-up of fouling layers. Lower surface temperature is therefore preferred.

INDUSTRIAL EXAMPLES

In this section we will discuss several industrial cases that we encountered. In many of these cases the existing heat exchangers had to be modified or even replaced by a new tailor-made apparatus due to unacceptable fouling rate.

Case 1

Here we dealt with an air preheater employed in a municipal solid waste incinerator. The exchanger itself consisted of three stages with a cleaning chamber being present between the first and the second stage. Individual stages were vertical plain tube bundles with staggered tubes. The exchanger suffered from excessive fouling due to the presence of particulate matter in the flue gas stream which resulted in significant deposition on the tube surfaces and, consequently, in decrease in heat duty and increase in pressure drop of the entire unit. Cleaning of neither all tube rows in each stage of the air preheater nor the process stream itself was economically feasible and as such the requirement of the operator was to replace the unit with another one featuring identical built-up area. Similarly, all the inlet and outlet nozzles of the new exchanger had to be approximately in the same locations as in case of the old apparatus.

The operator also required that the tube arrangement was changed to inline which then led to a bundle consisting of a larger number of tubes. Our aim was to make pressure drop of the new apparatus as close to the allowed value as possible while keeping it acceptable even with an average-thickness fouling layer being present on the tube surfaces. Additionally, flow velocity was increased via narrowing the flow channel which, in the end, resulted in lower overall fouling rate.

The newly designed air preheater has been operated for almost two years now and so far no issues occurred and no unplanned shutdowns were necessary.

Case 2

Sludge produced in waste water treatment plants is often dried and incinerated which necessitates presence of a waste heat utilization system. In this case, thermal oil was used as the second process medium. The heat exchanger we dealt with was a recuperative one with cross-flow arrangement and consisted of two identical tube bank modules. Tube bundles therein were horizontal with inline tube arrangement while flue gas flew across them upwards. The main issue was heavy particulate fouling of tube surfaces of the lower tube bank module – fine particles stuck to the surfaces together with ammonium sulfate, a byproduct of selective non-catalytic reduction of NO_x. As a result, brittle crusts were formed which significantly hindered heat transfer and increased pressure drop. Moreover, shutdowns were often necessary. Two corrective measures were thus proposed:

1. installation of a sonic sootblower;
2. installation of shell-side inserts designed using computational fluid dynamics simulations.

More on this problem and the steps taken to improve the situation can be found in (Stehlík et al., 2011).

Case 3

In this case we dealt with a reheater placed in a vertical flue gas duct. The exchanger consisted of a cross-flow, staggered tube bundle of several rows of finned tubes and its purpose was to heat up the flue gas stream after it exited a wet scrubber. Flue gas flew upwards and – even though it passed through a series of demisters beforehand – it still contained significant amounts of water droplets, moisture, and solid particles.

Presence of water in the stream was eventually determined to be the main reason that stood behind formation of fouling layers. Abrupt increase in temperature of the flue gas stream above its dew point before it entered the reheater was therefore chosen. This was achieved by placing an additional exchanger just before the reheater.

Case 4

The exchanger in question was a part of a liquid and gaseous wastes incineration unit in an acrylic monomer production plant. Flue gas produced via incineration of a process waste gas (PWG) flew across a staggered U-tube bundle in which the same PWG was being preheated.

Although the PWG passed through a demister before entering the preheater, there still remained a large amount of sticky droplets. This then caused formation of thick jelly-like layers on the inlet tube sheet which resulted in partial or even complete blockages of tubes and thus decrease in heat duty. Additionally, increased mechanical loading of the tube bundle due to improperly designed partition plates caused cracking of the blocked tubes just below the inlet tube sheet and, consequently, PWG leaked into the flue gas stream (photographs can be found in Stehlík et al., 2013).

Based on thermal-hydraulic and mechanical analyses and simulations it was determined that although presence of droplets was the main cause, flow maldistribution was aggravating the issue even further. Addition of a demister or cyclone before the preheater was therefore proposed in combination with flue gas injection into the PWG stream to evaporate/solidify as many droplets as possible. For more information please refer to (Pačíska et al., 2012). Also, an optimized inlet transition piece was designed to improve flow distribution (see Turek et al., 2012).

Case 5

Here we dealt with a cross-flow toluene evaporator with the heating medium being flue gas from straw incineration. This stream contained a non-negligible amount of water. What was more, fine solid particles present therein covered heat transfer surfaces with a thick layer, predominantly on the top of each of the tubes. An acoustic cleaning system and special chains were added to the apparatus, however, neither of these was particularly efficient given the character of the deposited layers.

A new evaporator with a lower number of tubes per row was therefore designed. This way we achieved higher flow velocities while meeting the maximum allowed pressure drop. The increase in flow velocity also acted as an abating factor considering deposition of the particles and, moreover, it improved the apparatus self-cleaning capability. Additionally, zeolite injection was proposed to decrease water content in the flue gas.

KNOWLEDGE BASE

Table 1 lists the general recommendations based on the actual character of fouling as was discussed via the industrial cases in the previous section. Nonetheless, dealing with such problems in engineering practice is often much more complex and one must therefore approach each problem individually. Still, any such general knowledge base would be of tremendous help to equipment designers.

CONCLUSIONS

1. The importance of taking fouling into account as early as in the equipment design stage has been emphasized.
2. The main factors influencing fouling that can be easily controlled by the designer were discussed.
3. Five industrial examples were briefly presented alongside the resulting fouling mitigation measures. From these it is obvious that such problems must be dealt with on a per-case basis.

ACKNOWLEDGMENT

The authors gratefully acknowledge financial support provided by Technology Agency of the Czech Republic within the research project No. TE02000236 “Waste-to-Energy (WtE) Competence Centre”.

REFERENCES

Bott, T.R., 2001, To foul or not to foul – that is the question, *Chem. Eng. Prog.*, Vol. 97, pp. 30–37.

Pačíska, T., Jegla, Z., Reppich, M., 2012, Analysis of possibilities of elimination of liquid droplets from gas flow for mitigation of operating problems of gas preheater, *Chem. Eng. Trans.*, Vol. 29, pp. 1339–1344.

Stehlík, P., Jegla, Z., and Kilkovský, B., 2013, Application of complex approach to troubleshooting related to waste gas preheater fouling, in *Proc. Heat Exchanger Fouling and Cleaning 2013 Conference, June 9–14 2013, Budapest, Hungary.*

Stehlík, P., Puchýř, R., and Jegla, Z., 2011, Fouling of heat exchangers in difficult “polluted flue gas applications” – experience, know-how, modeling, in *Proc. Heat Exchanger Fouling and Cleaning 2011 Conference, June 5–10 2011, Crete, Greece.*

Turek, V., Bělohradský, P., and Jegla, Z., 2012, Geometry optimization of a gas preheater – a case study, *Chem. Eng. Trans.*, Vol. 29, pp. 1339–1344.

Table 1. Recommendations on fouling mitigation for the discussed industrial cases

	Case 1	Case 2	Case 3	Case 4	Case 5
Character of fouling	gaseous medium containing fine solid particles	flue gas with fine solid particles and ammonium sulfate	wet flue gas containing fly ash	sticky droplets present in flue gas	sticky solid particles present in flue gas
The result	hard-to-clean deposits	brittle crusts	crusts	tube blockages, cracked tubes	sticky deposits
Fouling mitigation approach	inline tube arrangement, narrower channel	tube inserts added	additional flue gas reheating	demister/cyclone added, improved flow distribution	modified geometry, changes in technology