Operational Experiences and Potential for Optimization of Regenerative Thermal Oxidation Plants in the Field of MBT

Olaf Neese[1], Otto Carlowitz[1,2], Torsten Reindorf[2]

[1]Clausthaler Umwelttechnik-Institut GmbH, Clausthal;
[2]Institut für Umweltwissenschaften der TU Clausthal, Clausthal

Betriebserfahrungen und Optimierungspotenzial von regenerativen thermischen Oxidationsanlagen (RTO) im Anwendungsumfeld der MBA

Abstract

As a consequence of legal regulations with respect to emissions, post-treatment of the exhaust gas streams arising from MBT is necessary. For this purpose thermal post-combustion plants with regenerative pre-heating are widely used. During operation of these plants several problems and outstanding issues arise (e. g. corrosion, deposition growth, compliance with energy demand, that was projected), which are reviewed in this article.

Keywords

Exhaust gas treatment, regenerative-thermal oxidation, MBT, operating problems, corrosion, deposits, fuel consumption

1 Initial situation

The 30th German Federal Immission Control Ordinance (30th BImSchV - Ordinance on plants for the biological treatment of waste) contains regulations on the reduction of gaseous organic emissions. Particularly the limitation of the emission load to 55 $g_{org.C}/Mg_{waste}$ lead to the fact that so called RTO facilities (facilities for regenerative thermal oxidation) were integrated in processes of mechanical-biological treatment (MBT) of residual waste. So far, RTO technology has been available on the German market for about 20 years and proved successful in numerous cases of application in different trades. A variety of operational aspects have to be considered regarding the implementation in MBT plants. Based on the practice as experts as well as on own research and development projects three subjects, recognised as important, are discussed in more detail in this report:

- Prevention and/or limitation of corrosion caused by acidic condensates,
- Treatment of stains and/or adherences within the ceramic storage masses and
- Minimisation of the auxiliary fuel consumption.

In this context, the question for responsibilities is quickly raised, especially between plant operators and constructors, both having different opinions in this respect, of course. However, it should be considered that – despite exemplary pre-studies in the scope of a research project [DOEDENS ET AL. 2002] – all in all a new application area for RTO technology was entered, something that generally bears risks. That is why this contribution is not to be considered as an opinion to one of the two contrary points of view, but rather as an explanation of the as-is state and thus primarily as support to a discussion that should be objective.

2 Operation of RTO plants

Very high degrees of heat are realised within RTO plants, i.e. the exhaust gas mass flow to be treated is strongly preheated and the clean gas arising after the pollutant oxidation is cooled down. This efficient heat recycling allows for example to preheat the exhaust gas to 790 °C with a reaction temperature of 820 °C. The remaining temperature difference of 30 K has to be overcome by means of oxidation of the substances contained in exhaust gas and as is generally the case with MBT plants by means of additional fuel gas (e.g. natural gas, fermentation gas or landfill gas). Figure 1 shows a simplified scheme of a frequently used RTO plant technology. Exhaust gas (air + impurities = exhaust gas) from the decomposition process and treatment halls of the MBT plant, if applicable, firstly proceeds to the regenerator A which generally represents a hot storage mass consisting of ceramic honeycombs and there the exhaust gas is preheated. The oxidation reaction is realised there and in the subsequent combustion chamber D. The pollutants in the form of carbon hydrate compounds mainly react to carbon dioxide and water. According to the composition of the exhaust gas, further oxidation products (e.g. HCl, HF, H_2SO_4) arise in small concentrations. Fuel that is required for the maintenance of the process can be added through burner E (regulation of the combustion chamber temperature to a fixed value). The clean gas formed thereby emits heat when streaming through regenerator B and then leaves the system. At first, regenerator C is not taken into account. This type of procedure takes up a period of about 1…2 minutes. Then, by change-over dampers situated below the regenerators the exhaust gas is conducted to regenerator B, heated up and the again the pollutant oxidation takes place. Now, the clean gas cools down in regenerator A.

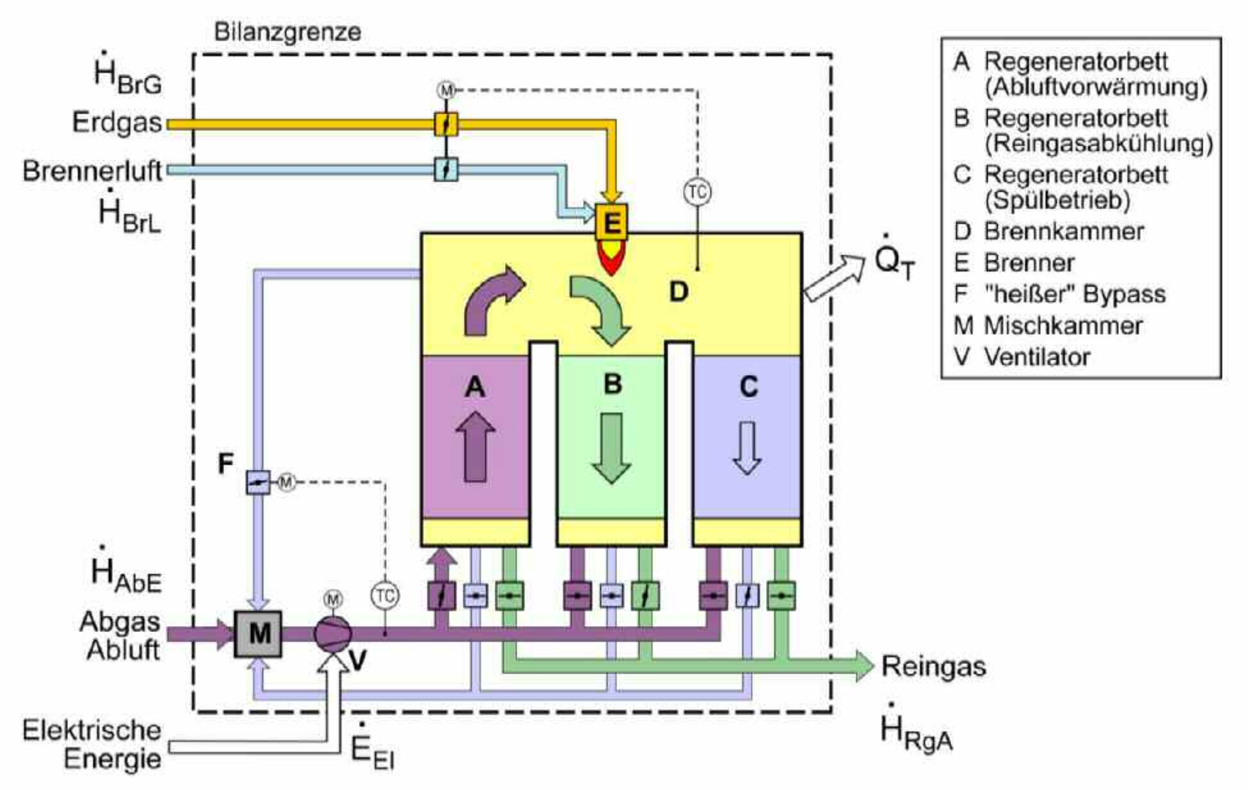


Figure 1 Simplified scheme of an RTO plant with charted balance unit.

A Regenerator bed (exhaust air preheating); B Regenerator bed (clean gas cool-down); C Regenerator bed (Scavenging); D Combustion chamber; E Burner; F „Hot by-pass";M Mixing chamber; V Ventilator

Bilanzgrenze – Envelope boundary; Erdgas – Natural gas; Brennerluft – Burner air; Abgas/Abluft – Exhaust gas/air; Elektrische Energie – Electrical energy; Reingas – Clean gas

This cycle repeats itself but is imperfect in one point in terms of processing and environmental technology. For example, when regenerator A is changed over from exhaust gas preheating to clean gas cool-down the exhaust gas volume contained therein is discharged with the clean gas. This is evidenced in form of a peak of concentration of hydrocarbon in the clean gas. To avoid this, a third regenerator C is necessary so that prior to change-over scavenging is realised. This is done by sucking clean gas in form of an ECB (emission cut back) through regenerator C, then this scavenging gas is added to the exhaust gas from the mixing chamber M. Furthermore, some RTO plants of the described application area are equipped with a "hot by-pass" F. A clean gas partial flow is removed from the combustion chamber and mingled with the exhaust gas in order to increase the temperature with the aim to prevent condensation in the subsequent guidance system.

3 Corrosion prevention

Already after ca. 1…2 years of operation, massive corrosion damages occurred with many plants. Above all, the cold parts of the plant are affected thereof. Figure 2 gives an insight into the problems that arose in many plants of different manufacturers. It can be observed that also austenitic steels (e.g. W1.4571) display corrosion damages in form of pittings in the exhaust gas guidance system of the RTO plants. In the case of ferritic steels corrosion occurs in a rather laminar form.

a) Dirty gas channel (pitting)

b) Pitting detail

c) Flow distribution chamber

d) Wall of combustion chamber (inside)

Figure 2 Corrosion damages with RTO plants for treatment of MBT exhaust gas.

The exhaust air or gas from the rot processes exhibits a share of water vapour close to the saturation limit, especially when the gas passes a scrubber for ammonia removal prior to entry into the RTO plant. This can cause condensation in the dirty gas and/or exhaust gas pipes. Since all water-soluble exhaust gas and/or dirty gas matter are contained therein, partially including acids and acid formers, and since the vaporisation of the condensate leads to local concentrations, corrosion in these areas is benefited. Basically no corrosion damages or none at all occur in those units of the plant where no condensates arise.

Actions that reduce corrosion generally can be implemented on the basis of optimisation approaches in terms of materials and processing technology.

Materials-related measures

As there is a great series of substances in the MBT exhaust gas causing corrosion, checks and/or limitations of the input material are not possible in most cases so that measures in terms of materials technology are clearly limited, unless wanting to choose the way of an expensive complete substitution of the affected parts of the plant with a high-quality material (e.g. nickel alloys). Even the subsequent application of alloys seems not to fulfil its aim, because this has to be done in an absolutely perfect manner. Additionally, the material has to be endowed with a sufficient resistance in accordance with the alternating stress in mechanical and thermal terms so as to exclude that condensates emerge. Furthermore, it has to be observed that the related warranties mostly go along with limitations concerning the arising substances and operational conditions.

Process-related measures

The aim of these measures has to be the prevention of condensates within RTO plants and particularly on components that get into contact with the clean gas. For this purpose a heating of the dirty gas to temperatures of ca. 90…110°C (according to water vapour and acid content) is favourable. The heating causes additional expenses for equipment but also means a high level of protection against corrosion. With the increased entry temperature, the clean gas discharges temperature increments as well so that all parts of the plant that are affected by this medium are operated off the condensation point, insofar as sufficient heat insulation is provided for (prevention of heat bridges!).

The following measures are available for the instrumental implementation:

- Direct heating up of the exhaust gas with burners, heated heat transfer media or a hot by-pass.
- Indirect heating up of the exhaust gas by using the clean gas enthalpy at the stack by means of a preceding recuperator.

Though heating up the exhaust gas directly requires less efforts instrumentally speaking, it bears the disadvantage that in case of an increase in temperature by 50…60 K, for instance, the fuel demand is more than twice as high and this results in unsuitably high operational costs. Furthermore, in the case of the hot by-pass possibly further acid formers (oxidation products) are added, which support corrosion. The same risk arises with the scavenging of the regenerators with clean gas, a method that is widely applied.

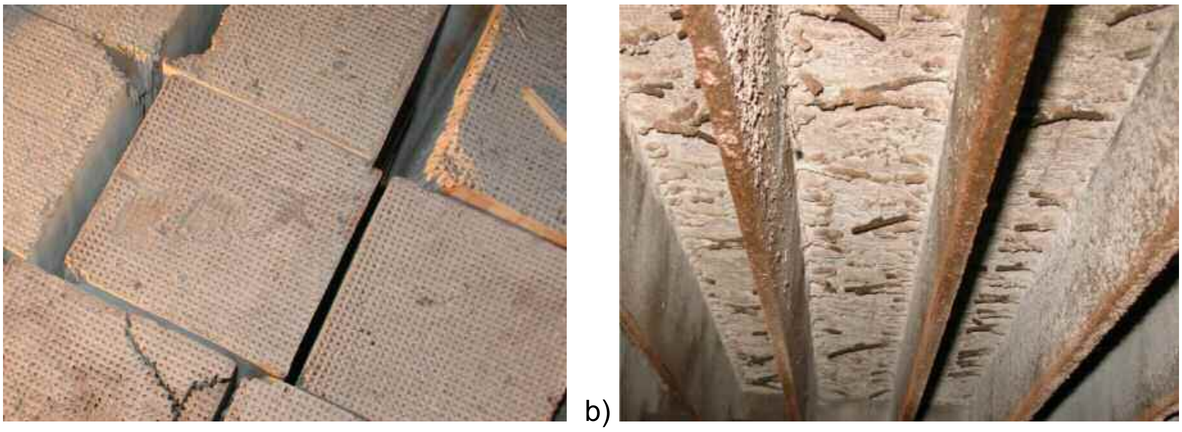
Using the clean gas enthalpy at the stack by means of a preceding recuperator also by interposing a heat transfer medium (e.g. thermal oil), if applicable, bears the great advantage that by the additionally inserted heat transfer area no additional heat demand arises. The temperature level at the chimney remains hardly unaltered, while the exhaust gas and clean gas conducting systems (ventilator, distributor, flaps) of the RTO plant work at notably higher temperatures. However, the selection of materials for the heat transfer device is to be carried out with diligence and an additional loss of pressure has to be overcome (slightly increased energy power requirements).

This solution for the prevention of (materially different) condensates already has been successfully applied in sections of the manufacturing industry.

Further is to be noted that RTO plants should have an outer insulation in the area of the regenerators and the combustion chamber. Since the inner insulation of ceramic fibre is not impermeable to gaseous diffusion, condensates at the cold insides of the equipment walls can be the result. With the aid of an outer insulation the dropping below dew point is avoided at these spots.

4 Formation of stains from the oxidation products

The formation of stains within the ceramic storage masses is another problem that was not predictable to this extent before the implementation of the RTO plants for mechanical-biological waste treatment.



a) b)

Figure 3 Stains on honeycombs of RTO plants for the treatment of MBT exhaust gas: a) in the combustion chamber, b) in the lower stream area.

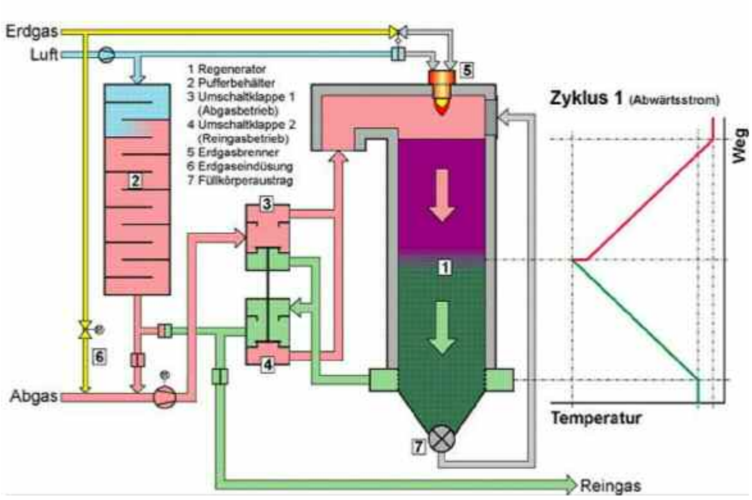
Figure 3 shows one of the two most frequently occurring forms of stain. In the combustion chambers of RTO plants (Figure 3a), the honeycombs are covered with amorphous silica (SiO_2) which is formed as oxidation product from silicon organic compounds that are contained in the exhaust gas to a small extent. It is expected that such compounds (e.g. silanes, siloxanes) arise during the biological degradation process of the contained substances from the disposed products (crèmes, shampoos) or from packaging residues. Since, according to the manufacturer of silanes and siloxanes, these basic substances are increasingly applied it can be expected that the problem will aggravate.

Salting (e.g. ammonia salts) prevails in the relatively cold stream area below the regenerators (Figure 3). These are also reaction products that are formed in the oxidation process of the substances contained in the exhaust gas; but due to their specific properties, these substances only desublimate in colder plant areas. Since these salts reciprocally evaporate at relatively low temperatures (around 200…300 °C) the stains can be removed pretty easily (burn-out operation).

So far, all efforts to prevent the multiple amorphous adherences of silica in the combustion chamber or to alleviate the effect thereof have not been of the expected success. Currently, a plant concept adequate for silicon organic compounds with regenerative preheating of the exhaust gas is not available. As a makeshift, the deposits are periodically submitted to suction or, for instance, steam cleaned after dissembling the ceramic honeycombs.

Against this background, in the scope of a research project promoted by the Deutschen Bundesstiftung Umwelt (DBU) – a large foundation that promotes innovative and exemplary environmental projects – a new plant technology was initiated with the basic idea consisting in the fact that the arising stains are to be accepted at first, but that the ceramic regenerator mass would be removed, cleaned and reinserted automatically on a regular basis (e.g. monthly). Project partners were the companies LTB (Lufttechnik Bayreuth), Goldkronach as plant constructors, the CUTEC-Institut GmbH, Clausthal as research institute as well as the company ALBIS Plastic, Hamburg as (first) operator.

A particular challenge was to realise all three cycles (preheating of dirty gas, cooling down of clean gas and scavenging regenerator), which are characteristic for RNV units (thermal exhaust gas purification units with regenerative exhaust air preheating) within a plant with one tower, whereas heating up should take place by means of a conventional burner system. Figure 4 displays a principle drawing of the plant design (a) and the pilot plant in the field testing at the site of an industrial operator (b). The realisation of this plant concept/design has already been explained in detail at some other point, e.g. [CARLOWITZ 2005, REINDORF 2005, REINDORF 2006].

a) 

b) 

Figure 4 New technology distribution: a) Principle of functioning, b) Pilot plant operating at a plastics processing plant (Albis Plastic GmbH, Hamburg).

Erdgas – Natural gas; Luft – Air; Abgas – Exhaust gas; Reingas – Clean gas; Temperatur – Temperature; Weg – Travel; Zyklus 1 (Abwärtsstrom) – Cycle 1 (downstream);

1 Regenerator; 2 buffer container; 3 Change-over flap (Exhaust gas operation); 4 Change-over flap (Clean gas operation); 5 Natural gas burner; 6 Natural gas injection; 7 Packing output

After submission to extensive testing at the pilot plant's station, the pilot plant has been finished and submitted to a ca. six months field testing with an industrial operator (ALBIS Plastic, Hamburg). The results of the studies carried out are positive so that the second phase of the project can now start, within which the main construction is to be designed and realised. Furthermore it is provided to operate the pilot plant with other potential operators in different trades.

5 Realisation of a minimal auxiliary fuel demand

An energy and mass balance at the (almost) stationary operating regenerator system generate the following equations according to Figure 1

$$\dot{H}_{BrG} = \dot{Q}_T + \dot{H}_{RgA} - \dot{E}_{El} - \dot{H}_{AbE} - \dot{H}_{BrL} \quad (1)$$

$$\dot{m}_{RgA} = \dot{m}_{BrG} + \dot{m}_{BrL} + \dot{m}_{AbE} \quad (2)$$

with $\dot{E}_{El}$ Electric energy
$\dot{H}$ Enthalpy flow
$\dot{m}$ Mass flow
$\dot{Q}_T$ Transmission heat loss

Indexes: *Br* Brenner – *burner*, *Ab* Abluft - *exhaust gas*, *Rg* Reingas – *clean gas*, *G* Gas - *gas*,
L Luft - *air*, *A* Austritt –*outlet*, *E* Eintritt - *inlet*

Often, the so called exhaust air preheating efficiency ηv is formed [VDI2442 2006] as factor to evaluate the exhaust gas preheating process and the fuel consumption thereof. This factor represents the efficiency of the exhaust air preheating process, whereas the actually used energy flow for the preheating process is related to the maximum of efficiency. The necessary heat transfer medium area is derived from this planning factor. With some assumptions and simplifications [NEESE ET AL. 2006], the proportionality between the preheating efficiency and the heat transfer area is calculated thereof:

$$A_{WÜ} \sim \left[\frac{\eta_V}{1-\eta_V}\right] \quad (3)$$

Equation (3) and its graphic depiction in Figure 5 make clear that the heat transfer area extremely increases $A_{WÜ}$ for the exhaust air preheating efficiency η_V striving for the value one.

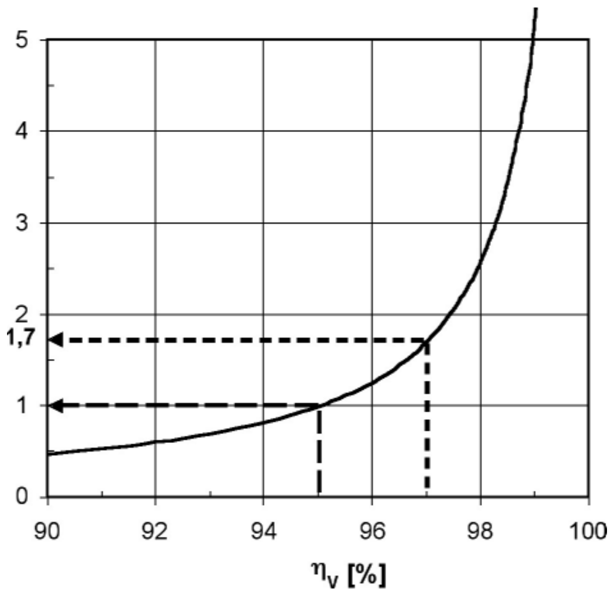


Figure 5 Dependency of the heat transfer area from the preheating efficiency (standardized to the area of the exhaust air preheating efficiency of 95 %).

Today, in practice RTO-plants are mainly designed for exhaust air preheating efficiency of 95 %, whereas η_V is generally established as guarantee value. If the exhaust gas was not containing fuels, the remaining 5 % would have to be added by auxiliary fuels. In the event that a plant “only” reaches η_V = 93 %, this would be the same as an excess consumption of fuels of (maximum) 40 %. The instrumental effort for an increase of the exhaust air preheating efficiency from, for instance, 95 % to 97 % is considerable, according to equation 3. The required heat transfer area is multiplied by 1.7 which is equal to an increase of the regenerator beds by 70 % at the same flow area (empty) (cf. Figure 5).

Against this background, it is of particular importance to assure the conservation of the used heat transfer area in the RTO plants; this heat transfer area can decrease drastically due to stains.

Irregular flow of the storage mass

The fuel consumption is also increased by an irregular flow of the heat storage mass which can occur in the case of unfavourable stream conditions and blocking of parts of the flow area. The impact of this phenomenon is made clear in Figure 6. In the scope of a model calculation according to [NEESE ET AL. 2006], the efficiency of a regenerator was determined, with one half (B) being less streamed through than the other half (A). Depending on the mass flow ratio

$$\xi = \frac{\dot{m}_A}{\dot{m}_B} \quad \text{with} \quad \dot{m} = \dot{m}_A + \dot{m}_B = \text{const.}, \tag{4}$$

the result is reduction of the efficiency and additional fuel consumption as consequence of irregular flow ($\xi > 1$) according to Figure 6. Considering a system with an exhaust air preheating efficiency of $\eta_V \approx 0{,}95$, losses of the preheating efficiency of up to 1.8 percent (in case of entire blocking of an half of the regenerator) has to be accepted. This corresponds to an additional fuel consumption of 31 %. In this diagram, the decrease of the heat transfer medium area, e.g. due to blocking, which leads to a further increase of the fuel consumption, is not considered.

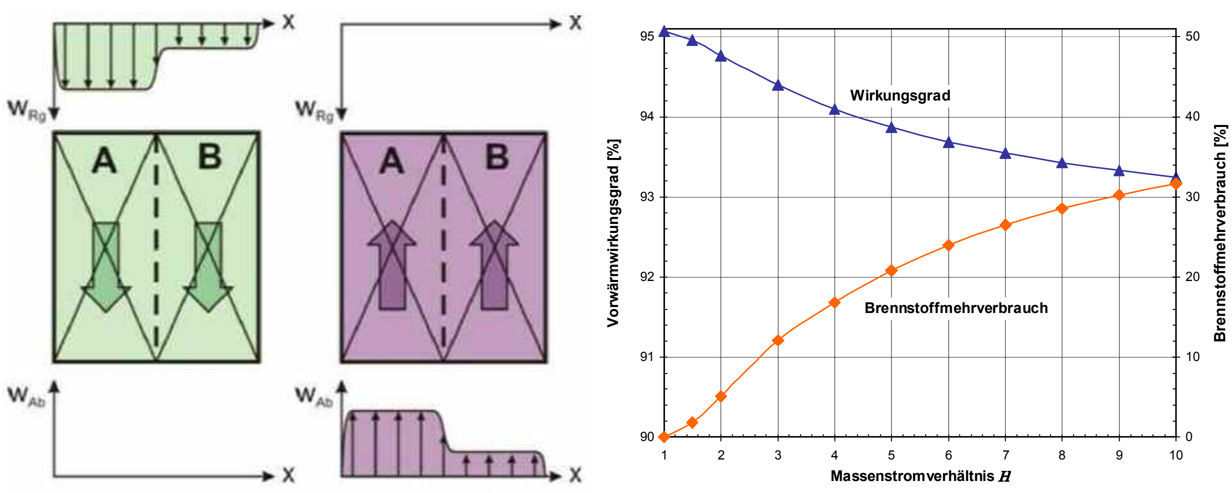


Figure 6 Influence of the irregular regenerator flow through on the exhaust air preheating efficiency.

Wirkungsgrad – Efficiency; Vorwärmwirkungsgrad - Preheating efficiency; Brennstoffmehrverbrauch - Additional fuel consumption; Massenstromverhältnis - mass flow ratio

Liquid droplets in the exhaust gas

In the previous chapter, it was mentioned that the degree of humidity of the exhaust gas can be considerable and lead to corrosion. Since the post-incinerators generally operate at a slight overpressure and the respective ventilator positioned in the exhaust gas, the exhaust gas tends to additionally form droplets before entering the RTO system. These water particles evaporate in the regenerator beds and post-incinerator. So, the vaporisation heat has to be accounted for which also increments the fuel demand. Liquid droplets of 10 g/m^3_n in the exhaust gas at usual exhaust air preheating efficiency can already cause up to 30 % more auxiliary fuel.

Burner air, mass flow of scavenging gas and clean gas decoupling

In [VDI2442 2006] it is also shown with examples that fresh burner air in the post-incinerators causes a notable rise of additional fuel consumption, insofar as the exhaust gas or air contains enough oxygen for the oxidation of exhaust gas pollutants and auxiliary fuel. If the burner is correctly adjusted and operates at air excess above the overall required control range (this also has to be sufficiently calculated regarding the lower limit, because otherwise with small exhaust gas quantities excess temperatures in the burners can occur) of no more than 20 %, the use of fresh burner air has to be calculated with the usual exhaust air preheating efficiency around η_V = 95 % and an additional fuel consumption of 15…25 %. In this context, it makes sense to directly and exclusively feed the combustion chamber with the fuel gas.

The mass flow of scavenging gas and a decoupled hot gas mass flow (cf. by-pass F in Figure 1) increment the total gas mass flow put through the plant as well as the temperature level of inlet into the regenerator system. The two effects augment the auxiliary fuel consumption.

6 Summary and outlook

In the context of the above mentioned versions possible, approaches have been outlined for solving selected problems with exhaust gas purification by means of RTO within mechanical-biological waste treatment plants. Three subjects have been predominant in this respect:

- Prevention of corrosion.

  Main cause of corrosion is the arising of watery condensates containing acidic clean gas substances (e.g. HCl, HF, H_2SO_4). A safe way to prevent these condensates is most effectively achieved with the raise of the temperature level of the clean gas inlet. Since a direct heating up goes along with a drastic rise in fuel consumption, the use of clean gas enthalpy at the plant outlet by means of an additional recuperator system is beneficial. Furthermore, the RTO plant should be endowed with an outer insulation in order to, especially in the cold season, prevent that condensates are formed at the sheet metal walls of the inside of the regenerator.

- Stains on regenerators.

  Currently, the blockings of the regenerator honeycombs, caused by amorphous silica, have to be accepted. They have to be removed manually in regular periods. However at present, a regenerator system based on ceramic balls is developed which allows a periodical and automatic withdrawal of the storage mass and thus facilitating the removal of the SiO_2-adherences. Deposits of salts can be removed by means of a burn-out operation.

- Reduction of the fuel consumption.

  It has become clear that high exhaust air preheating efficiency and thus lower fuel demands require extremely large regenerators from ceramic storage masses. Furthermore, irregular flow conditions can decrease the preheating efficiency. If there are water droplets in the exhaust gas, the respective vaporisation heat has to be compensated in form of auxiliary fuels. Fresh burner air should be done without as far as possible, because it also leads to a remarkable rise in fuel demand. Decoupling the hot gas of a clean gas partial flow from the combustion chamber and the corresponding adding thereof to raise the temperature level of the exhaust gas with the aim to prevent condensation causes an increase of the fuel demand. The fuel demand also rises with a scavenging gas mass flow that has not been optimised.

Finally, it should be expressly emphasized that MBT plants are a relatively new application area for RTO technology and that everyone involved should, with a sense of proportion, try to find feasible solutions for the problems occurred.

7 Literature

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Authors' addresses

Dipl.-Ing. Olaf Neese
Clausthaler Umwelttechnik-Institut GmbH
Leibnizstr. 21+23
D-38678 Clausthal-Zellerfeld
Phone: +49 5323 933-203
Email: olaf.neese@cutec.de
Website: www.cutec.de

Univ.-Prof. Dr.-Ing. Otto Carlowitz
Clausthaler Umwelttechnik-Institut GmbH
Leibnizstr. 21+23
D-38678 Clausthal-Zellerfeld
Phone: +49 5323 933-120
Email: otto.carlowitz@cutec.de
Website: www.cutec.de

Dipl.-Ing. Torsten Reindorf
Institut für Umweltwissenschaften der TU Clausthal
Leibnizstr. 21+23
D-38678 Clausthal-Zellerfeld
Phone: +49 5323 933-234
Email: torsten.reindorf@tu-clausthal.de
Website: www.iuw.tu-clausthal.de