Ecobalance of Regenerative Thermal Oxidation regarding the avoidance of Greenhouse Gas Emissions

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Ökoeffizienz der regenerativ thermischen Oxidation (RTO) im Hinblick auf die Vermeidung klimawirksamer Emissionen

Abstract

To assure compliance with valid environmental protection legislation in Germany, it is necessary to treat exhaust air from mechanical-biological treatment plants (MBA) by regenerative-thermal oxidation (RTO). Elimination of organic components in exhaust air by regenerative-thermal oxidation is highly efficient on the one hand, but on the other hand RTO-plants have a high energy consumption.

Based on experience with several installations we examined if there is an effective contribution to climate protection by the use of RTO. The study came to the conclusion that the use of RTO to clean exhaust air with a low concentration of VOC (volatile organic compounds) from MBA is counterproductive, since more greenhouse gases are generated by running the RTO-plant than are avoided by not cleaning the exhaust air. Only on high concentration of VOC in the exhaust air there is a positive contribution to avoid greenhouse gases. In between there is a grey area, that depends on current specific and technical circumstances like composition of the pollutants of the exhaust air and energy-efficiency of the RTO-plant.

Keywords

Waste Storage Ordinance (AbfAblV), 30th Federal Immission Control Ordinance (30. BImSchV), regenerative-thermal oxidation, RTO, ecobalance, greenhouse gas emissions

1 Introduction

According to the requirements of the 30th Federal Immission Control Ordinance (30. BImSchV), MBA-plants must meet very strict demands regarding the residue emissions of organic gas compounds. With the 30th Federal Immission Control Ordinance, emission standards in Germany were adjusted to the requirements for waste incinerations plants. Two substantial reasons led to this regulation:

- reduction of the emission of ecotoxic gases
- reduction of the emission of greenhouse gases

The result of this is that the exhaust air of the MBA-plants cannot be cleaned solely by biolfilters anymore but that it requires distinctly more complex exhaust air treatment systems. For the destruction of the organic compounds only the regenerative-thermal oxidation systems proved suitable so far. In these systems, the exhaust air, which has a temperature of 30°C to 60°C (depending on the plant), is heated until it reaches a temperature of 800°C to 950°C. During the process, most of the organic compounds oxidize. Then, the air is cooled down again to about 60°C to 100°C (25°C to 50°C above the initial temperature) and the heat is stored in heat exchangers made of ceramic stones in the system. Due to an alternating charging of the heat exchanger chambers (2- or 3-chamber-RTO), the major part of the heat is kept in the process. Figure 1 shows the principle. Figure 2 shows an existing plant.

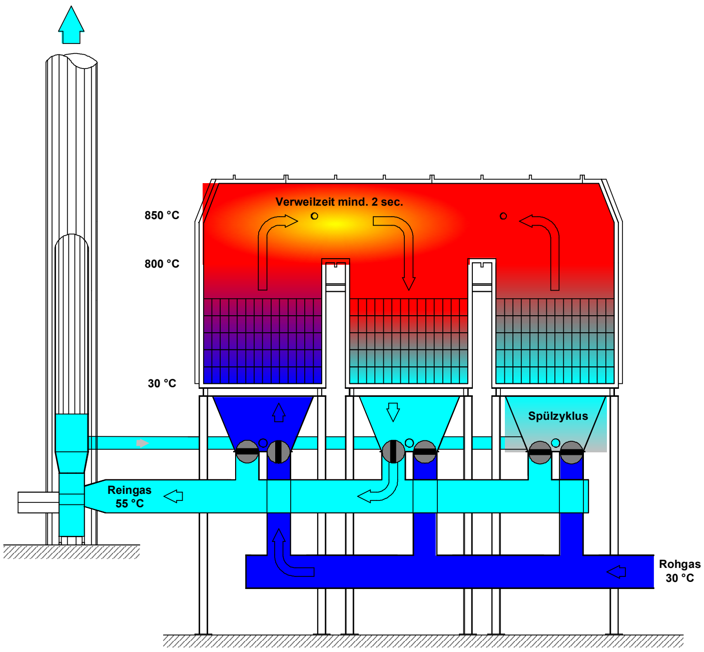


Figure 1 RTO-principle (source: E.I.Tec)

Figure 2 RTO-plant of MBA Singhofen, acid scrubber at front

Despite the fact that a major part of the heat is kept in the process, RTO-plants have a high energy consumption because an energy source (natural gas, liquid gas, landfill gas, biogas) is constantly required to keep up the process temperature. The so-called autothermic RTO, for which the organic compounds in the exhaust air and their reaction heat in the oxidation is sufficient as an energy supply, is not an option in the MBA-technology as the concentration of organic compounds in the exhaust air is usually too low.

So far, 3 to 5 years of practical experience with RTO-plants in the field of MBA have accumulated. Beside the cleaning capacity, the question of pollution/deposits and corrosion/material resistance played a very important role. Those topics have been discussed several times in the past and during this conference so that in this paper, they are only mentioned for the sake of completeness.

The discussion about the question whether or not the RTO-plants live up to the expectations in terms of emission protection – especially with regard to the reduction of greenhouse gases – has only just started. It is the aim of this paper to contribute to the discussion.

2 Practical Experience

The following practical experience refers to the experience with MBA-plants with RTO (each 2 to 3 blocks, 3-chamber-RTO).

2.1 Cleaning Capacity

The cleaning capacity in the plants proved all in all to live up to the expectations:

- dust
  (limit value: half-hourly average value 30 mg/Nm³, daily average value 10 mg/Nm³):
  the RTO-plants have no cleaning capacity for dust. A preceding scrubber adds to the dust separation so that in the supply air of the RTO the value of < 5 mg/Nm³ is already considerably lower than the limit values of the 30th Federal Immission Control Ordinance. Dust can only lead to a higher pollution in plant components with low local flow rates.

- organic material
  (limit value: half-hourly average value 40 mg/Nm³, daily average value 20 mg/Nm³):
  Generally, RTO-plants can reach a concentration of 4 to 8 mg/Nm³ in the monthly average. The compliance with the concentration limit value is generally no prob-

lem. What may lead to an exceeding of the limit value and especially of the daily average value, though, may be a possible malfunctioning of the combustion systems (temporal failure of the fuel gas, switching from landfill gas to natural gas etc.) or exhaust air volume peaks.

- laughing gas
  (limit value: monthly load of 100 g/Mg input MBA)
  There is no destruction of laughing gas in the RTO. On the contrary, an unsatisfactory ammonia separation in the scrubber may lead to a laughing gas build-up in connection with the production of other nitrogen oxides in the RTO. In 2007, WALLMANN illustrated this phenomenon thoroughly by means of measured values of a dysfunctional scrubber. The safe functioning of the acid scrubbing is, therefore, of utter importance.

2.2 Maintenance – Cleaning – Corrosion

Regarding the maintenance of the RTO-plants, two topics are central:

- interlocking of the heat exchanger stones due to silicon compounds
- corrosion in the dirty gas and clean gas canal

There have been several papers about the problem of the **interlocking of the heat exchanger stones** as a result of the deposits of silicon compounds (see WALLMANN et al. 2007, WALLMANN et al. 2006, NEESE et al. 2006, DACH 2005). Within a range of 0.5 to 3 mg/Nm³, the dirty gas contains silicon in the form of organic silicon compounds. In a plant with an exhaust air stream rate of 50,000 Nm³/h and a dirty gas content of 1 mg/Nm³, those silicon compounds equal 1,200 g/d over all, which in a complete conversion could lead to a strong development of SiO_2.

At present, an effective and economically justifiable technique for the reduction of organic silicon compounds is not available. Against this background it proved sensible to clean at least the surfaces of the heat exchanger chambers (bottom and top) in the RTO-plants in shorter intervals (4 to 10 weeks). Practical experience shows that by doing so the operation of the equipment is clearly stabilized and that critical conditions can be avoided.

Corrosion especially affects the raw air post-scrubber pipelines, in which the exhaust air is moist and contains acid components. Models made of coated plain steel are just as affected as models made of refined steel. In order to solve the problem, active as well as passive measures will have to be taken in many plants:

- passive protective measures against corrosion

- application of more valuable refined steels/alloys and/or application of more valuable and more temperature resistant special coats
- optimization of the condensate emission in the field of feeding pipelines and canals

- active measures
  - optimization of the drop separation for the reduction of the water entry
  - drying of the exhaust air by pre-warming before entering the RTO-plant

2.3 Application of Landfill Gas and Biogas

At the beginning, the application of landfill gas led to problems with the adjustment of the burner and flameless injections. This can be explained with the fact that landfill gas is moist and may vary in quality and that it has a lower calorific value than natural or liquid gas. After a learning period, though, it was possible to run RTO-plants with landfill and biogas safely and permanently.

In the plants evaluated in this paper, the landfill gas is cleaned by an activated carbon adsorption (reduction of sulphur and silicon oxides) and dried by warming before the feeding. From everything we know so far, however, it can be concluded that the greater share of the load of silicon compounds, which may lead to problems in the RTO-plant, does not derive from the landfill gas but from the exhaust air so that with an activated carbon adsorption in the landfill gas flow alone, the problem cannot be avoided.

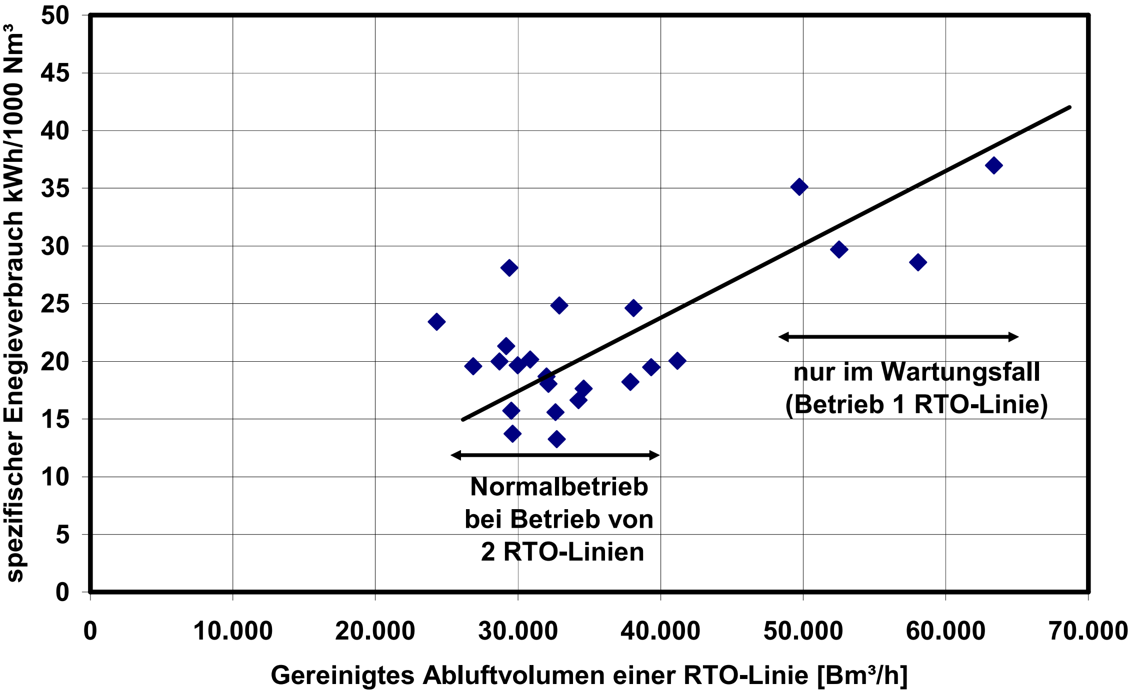
2.4 Energy Consumption

The energy consumption of the RTO depends on a number of factors. Above all, they are:

- design of the RTO, size of the heat exchanger, retention time
- exhaust air volume flow
- raw air temperature
- organics content; calorific value in the raw air
- condition of maintenance; pollution

Experience from the two rotting plants MBA Singhofen and Linkenbach shows that with a raw air temperature in the range of 40°C to 50°C, water vapour saturation and VOC-contents in the raw air in the range of 100 to 200 mg/m³, the specific energy consumption in form of fuel gas is in the range of 12 to 25 kWh/1,000 Nm³. Only with very high exhaust air volume flows (e.g. in case of repair or maintenance), the consumption values are higher.

On top of that, there is an electric energy consumption in the range of 1.5 to 2.5 kWh/1,000 Nm³. Figure 3 shows the experience values for the gas consumption of the RTO in the MBA Singhofen.



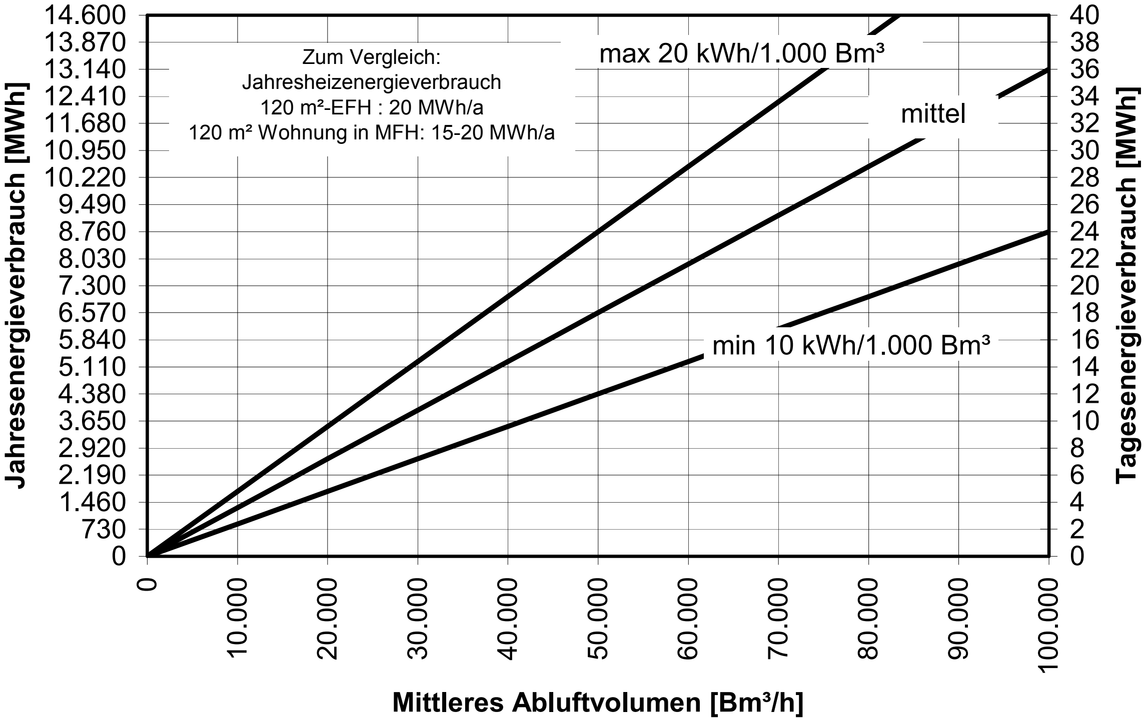
spezifischer Energieverbrauch	*specific energy consumption*
Gereinigtes Abluftvolumen einer RTO-Linie	*cleaned exhaust air volume of an RTO-line*
Normalbetrieb bei Betrieb von 2 RTO-Linien	*normal operation with operation of 2 RTO-lines*
nur im Wartungfall (Betrieb 1 RTO-Linie)	*only in case of maintenance (operation 1 RTO-line)*

Figure 3 Specific energy consumption of RTO-line as a function of exhaust air volume – MBA Singhofen (each daily average values)

In reference to the moist exhaust air volume flow (at 40°C to 50°C and water vapour saturation) to be cleaned, 12 to 25 kWh/1,000 Nm³ (standard cubic metre) equal approx. 10 to 20 kWh/1,000 Bm³ (operating cubic metre). A medium-sized RTO-plant that cleans a medium exhaust air volume of 60,000 Bm³/h, has a daily energy consumption in the range of 14 to 28 MWh/d or an annual energy consumption of 5,000 to 10,000 MWh/a of gaseous energy sources.

On top of that comes the electricity consumption. At a specific electricity consumption of 1.5 kWh/1,000 Bm³, it amounts to about 2.2 MWh/d or 800 MWh/a with an exhaust air volume flow of 60,000 Bm³/h.

Figure 4 shows the range of the daily and annual energy consumptions of gaseous energy sources in dependence of the exhaust air volume flow and the specific energy consumption.



Jahresenergieverbrauch	*annual energy consumption*
Mittleres Abluftvolumen	*medium exhaust air volume*
Tagesenergieverbrauch	*daily energy consumption*
Zum Vergleich: Jahresheizenergieverbrauch *120m²-EFH: 20 MWh/a* *120m²-Wohnung in MFH: 15-20 MWh/a*	*for comparison: annual heating energy cunsumption* *120m² detached house: 20 MWh/a* *120m² flat in a block of flats: 15-20 MWh/a*

Figure 4 Range of daily and annual energy consumption of RTO (according to experience in rotting plants)

With an average energy consumption for the heating of a detached house of about 20 MWh/a, this amount equals the consumption of 250 to 500 detached houses.

3 Greenhouse Gas Emissions Balance

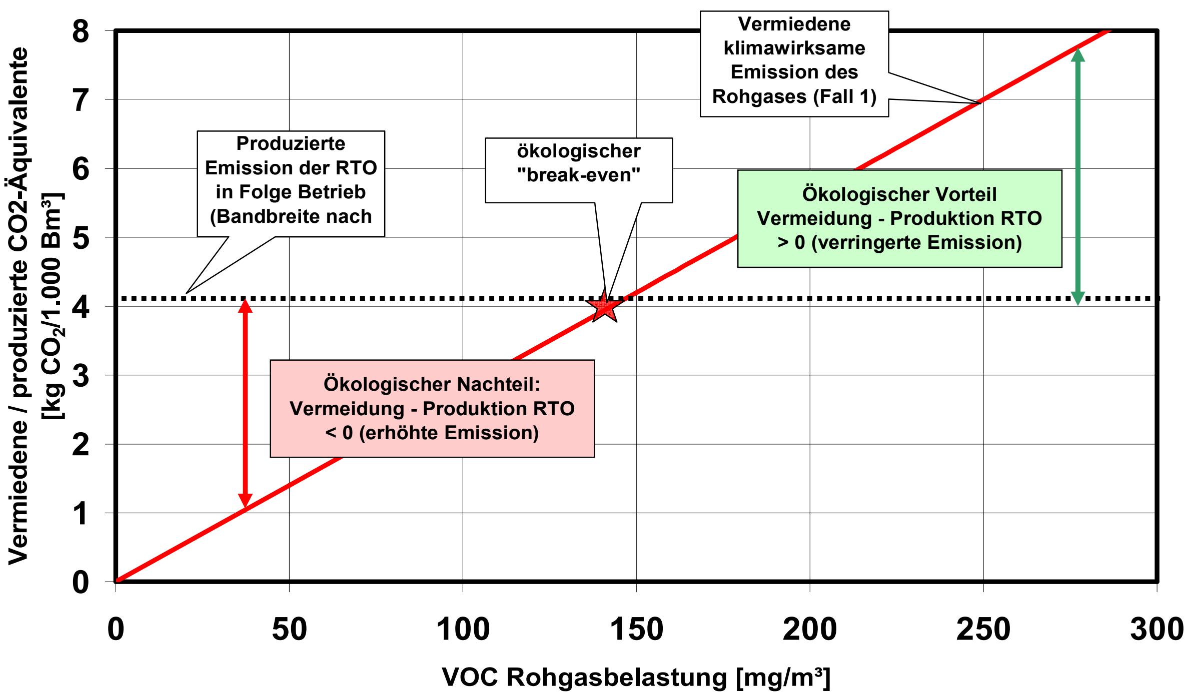
Considering the high energy and gas consumption, which are necessary for the operation of an RTO-plant, the question is whether or not a contribution is made to the protection of the emission at all times. This question is especially important in the field of greenhouse gas emissions. On the one hand, greenhouse gas emissions are avoided by the cleaning of the exhaust air and by the destruction of rotting and waste-derived organic material. On the other hand, more greenhouse gas emissions are generated through the high energy consumption. What is the ratio of those two effects?

For the consideration of an answer to the question a model calculation was conducted on the basis of experience gained in existing plants. The calculation is based on the following assumptions:

- emission due to energy demand of the RTO
  - an RTO-plant with a specific energy consumption of 10 to 20 kWh/1,000 Bm³ is being analysed. The energy demand is met by methane (e.g. from landfill gas).
  - the fuel gas (e.g. methane) has a calorific value of 50 MJ/kg, respectively 13.9 kWh/kg. If converted, this equals a methane consumption of 0.7 to 1.4 kg/1,000 Bm³.
  - during the combustion of the fuel gas CH_4, mainly CO_2 (and water) is released, with stoichiometry of CH_4 and CO_2 being 1:2.75. This amounts to a CO_2-emission of 2 to 4 kg CO_2/1,000 Bm³ exhaust air to be cleaned.
  - due to the power consumption of the plant, further emissions of the power station of approx. 0.67 kg CO_2-equivalents/kWh are emitted ("Strommix Deutschland", data base WALLMANN 1999). At an energy demand of 1.2 to 2.1 kWh/1,000 Bm³ (1.5 to 2.5 kWh/1,000 Nm³, see above), this equals a converted 0.8 to 1.4 kg CO_2-equivalents/1,000 Bm³ of exhaust air which is produced by the power consumption and needs cleaning.
  - in total, 2.8 to 5.4 kg CO_2-equivalents/1,000 Bm³ (average approx. 4.1 kg CO_2-equivalents/1,000 Bm³) are produced due to the energy consumption of the RTO.
- avoided emission due to cleaning of exhaust air
  - the pollution of the raw air varies between 0 and 300 mg VOC/Bm³ (expectation and experience values in rotting plants).
  - regarding the greenhouse potential of the pollutant compounds in the raw gas, two cases can be considered:
  - case 1: it is assumed that the entire organic raw air pollution VOC consists a 100 % of greenhouse effective methane (equivalence factor to CO_2 = 21). At a VOC of 100 mg/Bm³, about 2.8 kg CO_2-equivalents/1,000 Bm³ would be emitted if the exhaust air was released uncleaned into the environment.

- case 2: it is assumed that the organic raw air pollution consists a 30 % of greenhouse effective methane (equivalence factor CO_2 = 21) and a 70 % of NMVOC (equivalence factor CO_2 = 11, see WALLMANN, 1999). At a VOC of 100 mg/Bm³, about 2.2 kg CO_2-equivalents/1,000 Bm³ would be emitted, if the exhaust air was released uncleaned into the environment.
- the cleaning capacity of the RTO is assumed a 100 % for the sake of simplicity (real values 93 to 97 %).

If the greenhouse effective CO_2-emission caused by the energy consumption is opposed to the CH_4-emission caused by the cleaning of the exhaust air (converted to CO_2-equivalents factor 21), the following picture comes up for case 1 and an RTO with medium energy consumption:

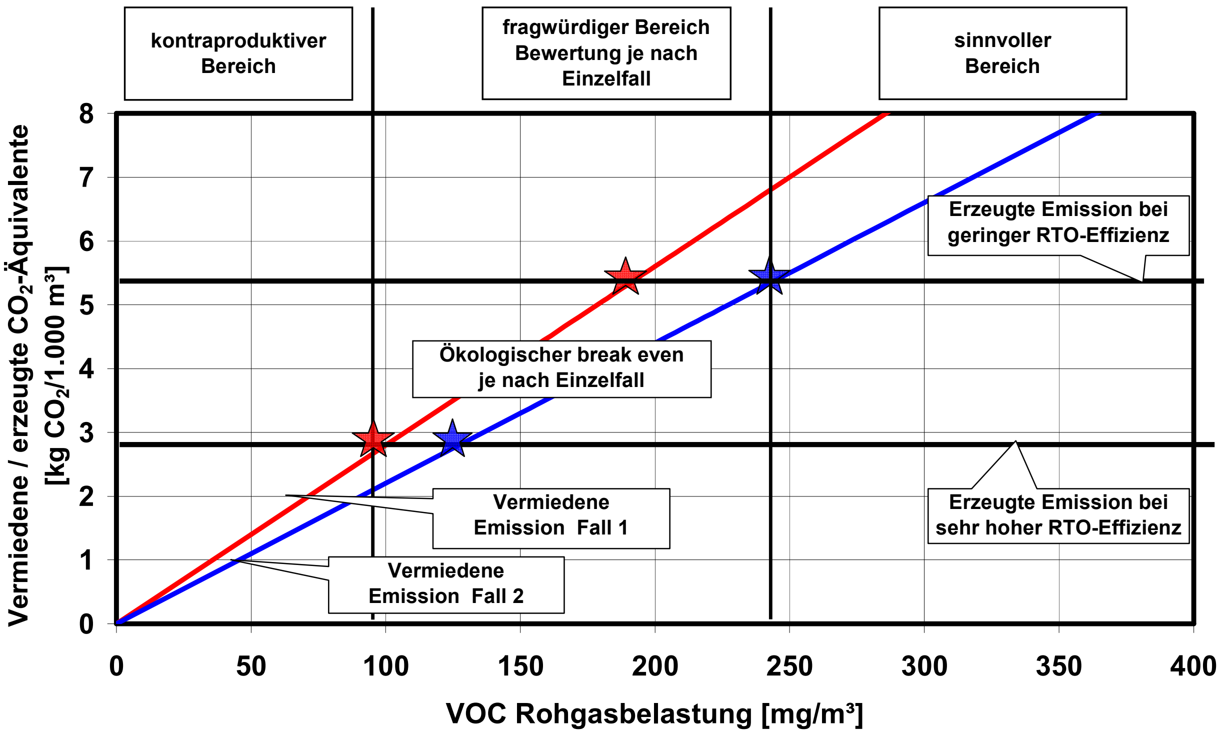


Vermiedene / produzierte CO2-Äquivalente	*avoided / produced CO2-equivalents*
VOC Rohgasbelastung	*VOC dirty gas pollution*
Produzierte Emission der RTO in Folge Betrieb (Bandbreite nach	*produced emission of the RTO due to operation (range according*
Ökologischer Nachteil: Vermeidung – Produktion RTO < 0 (erhöhte Emission)	*ecological disadvantage: avoidance – production RTO < 0 (higher emission)*
ökologischer "break-even"	*ecological "break-even"*
Ökologischer Vorteil: Vermeidung – Produktion RTO > 0 (verringerte Emission)	*ecological advantage: avoidance – production RTO > 0 (reduced emission)*
Vermiedene klimawirksame Emission des Rohgases (Fall 1)	*avoided greenhouse gas emission of the dirty gases (case 1)*

Figure 5 Balance of the additionally produced and maximally saved greenhouse gas emissions as a function of the VOC-content of the dirty gas (medium RTO and case 1: VOC = 100 % methane)

Regarding greenhouse gas emission, there is an ecological disadvantage if the dirty gas pollution is too low because the produced emissions are higher than the avoided emissions. With a high dirty gas pollution, there is an advantage. The ecological "break-even" in this case would be at around 140 mg/m³ VOC dirty gas pollution.

Figure 6 shows the range of what is expected in practice in different plants and with different constellations (high/medium efficiency of the RTO, high/medium methane share in the dirty gas).



Vermiedene / erzeugte CO2-Äquivalente	*avoided / produced CO2-equivalents*
VOC Rohgasbelastung	*VOC dirty gas pollution*
kontraproduktiver Bereich	*couterproductive range*
Vermiedene Emission Fall 1	*avoided emission case 1*
Vermiedene Emission Fall 2	*avoided emission case 2*
fragwürdiger Bereich Bewertung je nach Einzelfall	*questionable range assessment according to individual case*
Ökologischer break even je nach Einzelfall	*ecological break-even according to individual case*
sinnvoller Bereich	*reasonable range*
erzeugte Emission bei geringer RTO-Effizienz	*produced emission with low RTO-efficiency*
erzeugte Emission bei sehr hoher RTO-Effizienz	*produced emission with very high RTO-efficiency*

Figure 6 Balance of additionally produced and maximally saved greenhouse gas emissions as a function of the VOC-content in the dirty gas (range of high and medium efficiency of the RTO as well as high methane share = case 1 and medium methane share = case 2 in the dirty gas)

Different intersections derive between the produced emissions of the RTO (horizontal line) and the emissions avoided by the cleaning of the pollutants (curves, lines). Those intersections each constitute the "ecological break-even", a point, from which more emissions are avoided than produced. The following conclusions can be drawn from the diagram:

- case 1: the VOC in the dirty gas consists a 100 % of methane and therefore has a high (maximal) greenhouse gas potential (borderline case)
    - greenhouse gas emissions in a highly efficient RTO can only be avoided effectively with a VOC-concentration of at least 100 mg VOC/m³.
    - greenhouse gas emissions in a medium efficient RTO can only be avoided effectively with a VOC-concentration of at least 180 mg VOC/m³.
- case 2: the VOC in the dirty gas consists 30 % of methane and 70 % of other components and therefore has a low greenhouse gas potential (realistic case).
    - greenhouse gas emissions in a highly efficient RTO can only be avoided effectively with a VOC-concentration of at least 130 mg VOC/m³.
    - greenhouse gas emissions in a medium efficient RTO can only be avoided effectively with a VOC-concentration of at least 240 mg VOC/m³.

This means that through the RTO – especially in the field of low dirty gas concentrations and/or of a medium efficiency of an RTO – more greenhouse gases are emitted than destroyed in the dirty gas. The inversion of this conclusion is that with a raw air pollution of less than 100 mg/m³ the ecological effect regarding the greenhouse gas emissions is counterproductive. At higher concentrations, the "ecological break-even" depends on the composition of the VOC and the efficiency of the RTO.

4 Future Application of RTO-Plants in the Waste Industry

Considering the discussed problem that RTO-plants do not only have positive effects due to their destruction of ecotoxic and greenhouse effective organic pollutant compounds, but add themselves considerably and in certain cases unjustifiably strongly to the greenhouse effect, the technology and its field of application should be analysed critically:

Organically polluted exhaust air can be found in many plants in the waste industry, especially in the bio and green waste treatment plants. MBA-plants show as of the 3rd rotting week, after the waste-derived organic pollutants have been stripped, a comparable range of organic pollutants to those of the before-mentioned plants. Two conclusions can be derived from this:

- for bio and green waste treatment plants and possibly other plants in the waste industry similarly strict limit values would have to be set, which would lead to an extensive retrofitting and increase of costs.
- for MBA-plants the limit values of the 30th Federal Immission Control Ordinance should be reconsidered and questioned. It seems reasonable to regulate emissions from the first couple of treatment weeks (high concentrations, high emissions of waste-derived pollutants) differently than the treatment of lightly polluted exhaust air and exhaust air from late rotting phases.

Furthermore, there is the task of optimizing RTO-plants energetically. As these plants are in themselves technically mature and only experienced difficulties when a new field of application was introduced, the potential, however, is going to be limited.

It would be desirable to find alternatives to the RTO-technology. At present, however, there are no ideas that could be put into practice in the short term.

For an efficient ambient air protection, it would be important to re-analyse the existing plants with regard to their ecoefficiency (greenhouse gas compounds in the dirty and clean gas, energy consumption) and then reconsider the demands. In view of energy consumption and greenhouse gas potential, sufficient data is available. In terms of eco-efficiency in the reducing of ecotoxic emissions, complementary investigations will be necessary.

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