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INNOVATIVE METHOD FOR FUEL SAVING CALCULATION RELATED TO ENERGY RETROFIT OF THERMAL WASTE PROCESSING UNITS

Freisleben V.*, Jegla Z.**

Abstract: *The presented paper introduces a simple systematic method for a fuel saving evaluation achieved by Energy Retrofit of Thermal Waste Processing Unit. Waste thermal treatment and its energy recovery represent a promising energy source, while enabling the ecological waste abatement. However, the waste thermal decomposition is generally an energy intensive process associated with significant external fuel demand. The significant fuel savings could be achieved by the existing unit retrofit in order to improve a waste heat utilization to preheat (or dry) the processed waste. The fuel (and operational) savings achieved by this so-called Energy Retrofit are however associated with high investment costs, which leads to trade-off between achievable fuel and financial savings and investments. To perform the trade-off correctly, the fuel saving evaluation is essential. The developed method enables quick and accurate fuel saving calculation, which does not necessitates using of any professional software or intensive calculation procedures. The method is further applied on model case study of the unit processing waste gas containing Volatile Organic Compounds.*

Keywords: Thermal Waste Processing Unit, Secondary Combustion Chamber, Fuel savings, Waste heat utilization, Heat transfer intensification, Waste gas, Flue gas, Adiabatic Flame Temperature.

1. Introduction

The population growth and live standard increase go hand in hand with waste generation raise. Industry and private sector produce various types of solid, liquid and gaseous waste, which is very often disposed without further processing or utilization. On the other hand, the energy recovery of waste becomes worldwide more and more popular. As an example, the municipal solid waste incineration technology is today discussed as one of possible alternatives to the traditional fossil fuels. The most commonly used method for energy recovery of waste is the thermal processing. In principle, the waste (solid, liquid or gaseous) is thermally decomposed at high temperatures in the Primary Combustion Chamber (PCC) in the Thermal Waste Processing Unit (TWPU) while hot flue gas is produced. Flue gas further continues from PCC to the other part of TWPU, which is Secondary Combustion Chamber (SCC), where the waste thermal oxidation is finished at the prescribed temperatures and residential time. A thermal energy contained in the flue gas is further recovered for heating or power generation purposes.

Due to the high water concentration in waste and/or low energy content, the burner (or set of burners) combusting an energy rich fuel (commonly natural gas) is also ordinarily employed in TWPU in order to support the thermal decomposition of waste and to keep the prescribed temperatures in SCC and therefore ensuring the complete waste thermal oxidation. The thermal processing of waste is hence very energy intensive, which indicates high operating cost. To reduce the amount of external fuel, and thus to improve the TWPU economical aspects, the flue gas heat is often used to preheat the waste streams entering the furnace. In sludge incinerator, for example, the flue gas heat is commonly used for drying the waste stream entering the incinerator, which reduces the external fuel demand. In case of processing the gaseous wastes, the waste gas (WG) could be preheated by the flue gas in heat exchanger. The overview of the

* Ing. Vít Freisleben: Institute of Process Engineering, Brno University of Technology, Technická 2; 616 69, Brno; CZ, vit.freisleben@vutbr.cz

** Assoc. Prof. Ing. Zdeněk Jegla, PhD.: Institute of Process Engineering, Brno University of Technology; Technická 2; 616 69, Brno; CZ, zdenek.jegla@vut.cz

waste processing technology was presented by Stehlik (2009). The principle and simplified technological layout of TWPU is illustrated in Fig. 1.

Commonly, the flue gas cleaning technology is also employed to remove the harmful emissions (e.g. Nitrogen oxides, Sulfur Oxides, Particulate Matter…), however for the purposes of this paper the flue gas cleaning technology is not substantial and therefore is not further discussed.

There is an effort to improve the existing TWPUs in order to reduce the fuel consumption, hence to reduce their operating cost. This could be realized by the intensification of waste stream preheating, which is however connected with investment costs for the unit modification. The retrofit of existing unit therefore becomes a trade-off, where the investment cost, is compared to the potential operational savings reached by the fuel consumption reduction. To perform the modifications correctly, the proper evaluation of fuel saving as a result of existing process intensification is essential.

This paper presents a simple method enabling an evaluation of fuel savings in TWPU associated with waste stream preheating enhancement. The method does not require any professional simulation or calculation software, and therefore it can be widely applied in the initial planning stage for the retrofit of existing TWPU.

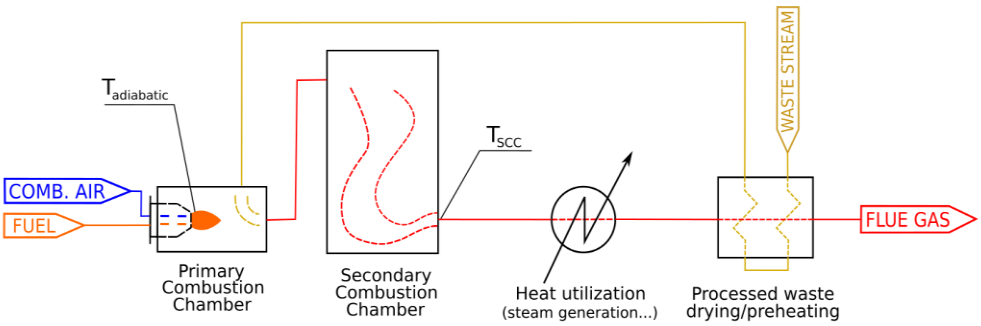

Fig. 1: Standard waste gas thermal oxidation unit.

2. Methods

The developed method is in the paragraphs bellow described in more detail and basic relations are presented. Further, it is applied to the case study of model unit processing waste gas containing Volatile Organic Compounds, where the method results are compared to the non-linear model results to verify the method accuracy.

2.1. The developed method description

The fuel energy content is commonly evaluated by using of Lower Heating Value (LHV), which is defined as the amount of energy released during the combustion of certain amount of fuel from the initial fuel (and oxidizer) temperature, while the produced hot flue gas is cooled down back to the initial temperature of the fuel (and oxidizer) without consideration of the water condensation. Further, the flame produced by the fuel combustion in TWPU burner is considered as adiabatic (i.e. all the heat of combustion is released to the combustion products – the flue gas), therefore the produced flue gas is at the adiabatic flame temperature. In other words, the LHV could be also evaluated as the amount of heat released by the produced flue gas being cooled down from adiabatic flame temperature to the fuel/oxidizer initial temperature. The theory of combustion processes, where this is discussed in more detail, is summarized e.g. in publication of Glassman and Yetter (2008).

In the TWPU the heat from the fuel combustion is primarily used to heat up the waste and to keep the temperature in SCC (T_{SCC} – see Fig. 1) constant to ensure the complete waste thermal oxidation. The amount of useful heat to keep the T_{SCC} stable therefore covers only the burner flue gas temperature range between the adiabatic flame temperature ($T_{adiabatic}$) and T_{SCC}. The linear interpolation could be used to evaluate the fuel approximate energy content FHV_{SCC}, utilizable for the waste thermal decomposition – see equation (1). In this model the value of specific heat capacity is assumed to be constant (i.e. not dependent on the flue gas temperature), which decreases the model accuracy significantly. The flue gas temperature dependence is therefore included by the correction factor n_C = 1.07-1.09 implementation. The given n_C value was obtained by the burner combustion non-linear simulations performed in educational version of software CHEMCAD (in the version CHEMCAD 7 from Chemstations, Inc.) and is generally valid for hydrocarbon gaseous fuels used to keep the temperature in SCC in range 700-900 °C.

The calculation of the Fuel Heating Value related to keep the T_{SCC} constant is then performed according equation (2).

$$\frac{LHV}{T_{adiabatic}-T_{initial}} = \frac{FHV_{SCC}}{T_{adiabatic}-T_{SCC}} \quad (1)$$

$$FHV_{SCC} = n_C \cdot LHV \cdot \frac{T_{adiabatic}-T_{SCC}}{T_{adiabatic}-T_{initial}} \quad (2)$$

As it is mentioned in the Introduction, the fuel savings in the existing TWPU could be reached by the intensification (or introduction) of the waste stream preheating or drying. If the value of increased heat transfer $\Delta Q_{preheat}$ to the waste stream is known, the fuel saving Δf_s can be calculated according the equation (3).

$$\Delta f_s = \Delta Q_{preheat}/FHV_{SCC} \quad (3)$$

In summary, the developed method calculation procedure consists of the following steps:

- The evaluation of achievable heat transfer enhancement of waste stream preheating $\Delta Q_{preheat}$. This is dependent on the existing TWPU design, available intensification technology, investment limits and other parameters.
- The adiabatic flame temperature assessment. It could be calculated or provided by the fuel supplier.
- The potential fuel saving calculation according to the equation (2) and (3).

2.2. Case study

The accuracy of the developed method is now verified by its application to the model case study of the industrial unit processing the waste gas containing Volatile Organic Compounds (VOC). The waste gas process specifications are summarized in the Table 1.

Tab. 1: Model waste gas process specifications.

Temperature [°C]	Flowrate [Nm^3/h]	Waste gas composition [$\%_{vol}$]				
		N_2	H_2O	O_2	CO_2	VOC*
64	14 000	67.00	23.00	8.00	1.61	0.39

* The VOC content is modeled as a mixture of ethane, propane and butane

The technological layout of the existing unit is similar to the one illustrated in Figure 1, but it does not employ any WG preheating. The simulation is performed with 5 kinds of fuel with varying LHV, where the rich fuel is modeled as pure methane (CH_4) and LHV decrease is performed by mixing CH_4 with nitrogen (N_2). This way it is possible to verify the method reliability for a wide range of gas fuels with various energy content. The fuel is combusted with dry air at the initial temperature $T_{initial}$ = 20 °C and with air excess 5 %. The thermal oxidation of VOC according Warahena et. al (2009) usually takes place at the temperatures between 730-850 °C, thus the value of oxidation temperature is set as T_{SCC} = 800 °C.

At first, a non-linear simulation of the current unit (i.e. no WG preheating is employed) was performed in CHEMCAD to estimate the fuel consumption for every observed kind of fuel. The initial parameters, in terms of fuel consumption (f_{base}), are therefore specified.

Then the calculation procedure of the developed method was applied to determine the fuel savings (Δf_{FHV_SCC}) that could be reached by the WG slight preheat ($Q_{WG\_preheat}$ = 1 000 kW) and very intensive preheat introduction ($Q_{WG\_preheat}$ = 2 500 kW). The method reliability is hence observed in relation to the WG preheating enhancement extend. The same WG preheating heat duties are then applied in the non-linear model to obtain the fuel savings (Δf_{NLP}), which are considered as accurate. The results of described experiment are summarized in the Table 2.

The results confirm that the developed method provides very accurate evaluation of the fuel savings related to the TWPU energy retrofit, where the comparison to the non-linear model results showed no difference greater than 0.4 %. The method is hence summarized as a simple procedure enabling fast

TWPU achievable fuel saving evaluation in relation to the waste preheating enhancement without the need for intensive calculations and professional software employment. It could be used as a valuable tool for the existing TWPU owners during the unit energy retrofit planning.

Tab. 2: The summary of the case study results – the developed method accuracy verification.

Fuel	CH_4-100%$_{vol}$ N_2-0%$_{vol}$	CH_4-80%$_{vol}$ N_2-20%$_{vol}$	CH_4-60%$_{vol}$ N_2-40%$_{vol}$	CH_4-40%$_{vol}$ N_2-60%$_{vol}$	CH_4-20%$_{vol}$ N_2-80%$_{vol}$
$T_{adiabatic}$ [°C]*	1 909	1 877	1 825	1 730	1 499
LHV [kJ/kg_{fuel}]	50 000.0	34 805.7	23 104.0	13 814.9	6 261.9
FHV_{SCC} [kJ/kg_{fuel}]**	31 408.9	21 599.2	14 038.4	8 039.3	3 166.7
	CURRENT UNIT – NO WASTE GAS PREHEATING				
f_{base} [kg/h]***	328.8	478.0	734.8	497.20	1 258.70
	WASTE GAS IS SLIGTLY PREHEATED – **$Q_{WG\_preheat}$ = 1 000 kW**				
Δf_{FHV_SCC} [kg/h]**	114.6	166.7	256.4	447.8	1 136.8
Δf_{NLP} [kg/h]***	115.0	167.3	257.0	448.3	1 136.0
Fuel sav. deviation [%]	**-0.33**	**-0.37**	**-0.21**	**-0.11**	**0.07**
	WASTE GAS IS INTENSIVELY PREHEATED – **$Q_{WG\_preheat}$ = 2 500 kW**				
Δf_{FHV_SCC} [kg/h]**	286.5	416.7	641.1	1 119.5	2 842.1
Δf_{NLP} [kg/h]***	287.5	418.0	642.6	1 120.8	2 838.5
Fuel sav. deviation [%]	**-0.33**	**-0.32**	**-0.23**	**-0.12**	**0.13**

* $T_{adiabatic}$ calculation procedure was performed according to Glassman and Yetter (2008).
** Equations (2) and (3) were used to calculate FHV_{SCC} and Δf_{FHV_SCC}. Correction factor n_C = 1.07 was used.
*** Initial fuel consumption (f_{base}) and fuel savings (Δf_{NLP}) were obtained by the process non-linear simulation in CHEMCAD.

3. Conclusions

In this paper, the method for the fuel saving calculation related to the waste preheating system enhancement of the units for thermal processing of waste (solid, liquid or gaseous) was presented. A new parameter FHV_{SCC} was established to determine the fuel energy content utilizable for the waste thermal decomposition by using the data commonly provided by the fuel supplier, like Lower Heating Value (LHV) or Adiabatic Flame Temperature ($T_{adiabatic}$). The accuracy of the developed calculation approach was proven by its application to the model case study of the unit processing waste gas containing VOC, while the results were compared to the outcome of professional non-linear simulation. The procedure can be used to quick and simple fuel saving assessment, so it can be a very useful tool during the existing waste processing unit Energy Retrofit.

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References

Stehlík, P. (2009) Contribution to advances in waste-to-energy technologies. Journal of Cleaner Production, 17(10), pp. 919-931.

Glassman, I. and Yetter, R.A. (2008) Combustion, 4th edition. Elsevier Science, London.

Warahena, Aruna S.K., Chuah K.Y. (2009) Energy Recovery Efficiency and Cost Analysis of VOC Thermal Oxidation Pollution Control Technology. Environmental science & technology, 43, pp. 6101-6105.