Improved Analytical Approach for Fuel Demand Re-Evaluation in Liquid and Gaseous Waste Thermal Processing Units

Dr. Zdeněk Jegla, Vít Freisleben, Martin Krňávek

November 2021

RESEARCH GROUP

BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING

EVECO BRNO

Dr. Zdeněk Jegla

Associate professor
Institute of Process Engineering
BUT, Czech Republic

Vít Freisleben

Feasibility study and research
EVECO Brno, Czech Republic

Martin Krňávek

Combustion technology and heat transfer specialist
EVECO Brno, Czech Republic

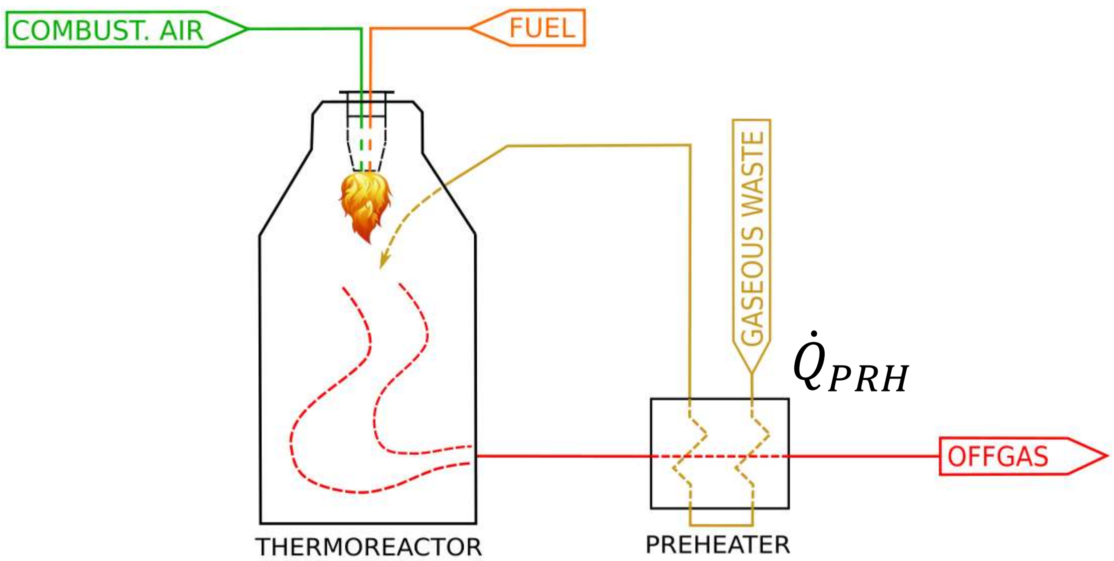
PREZENTATION CONTENT

- **Waste Thermal Processing Units (WTPU) for processing:**
  - **Gaseous waste**
  - **Liquid waste**
- **Existing calculation method for supplemental fuel saving evaluation.**
- **Comparative non-linear (SRK) model.**
- **Improvement of existing calculation procedure**
- **Case studies**

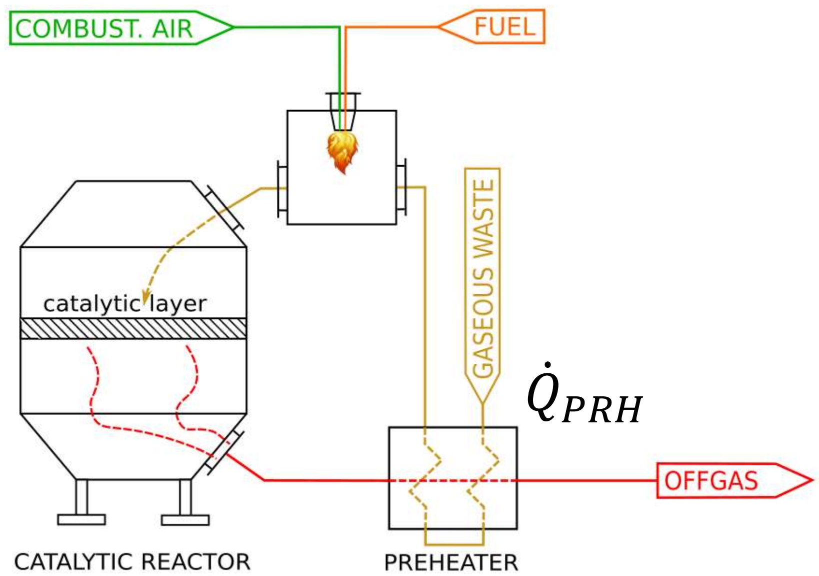
WASTE THERMAL PROCESSING UNITS

Gaseous waste processing

Thermal decomposition

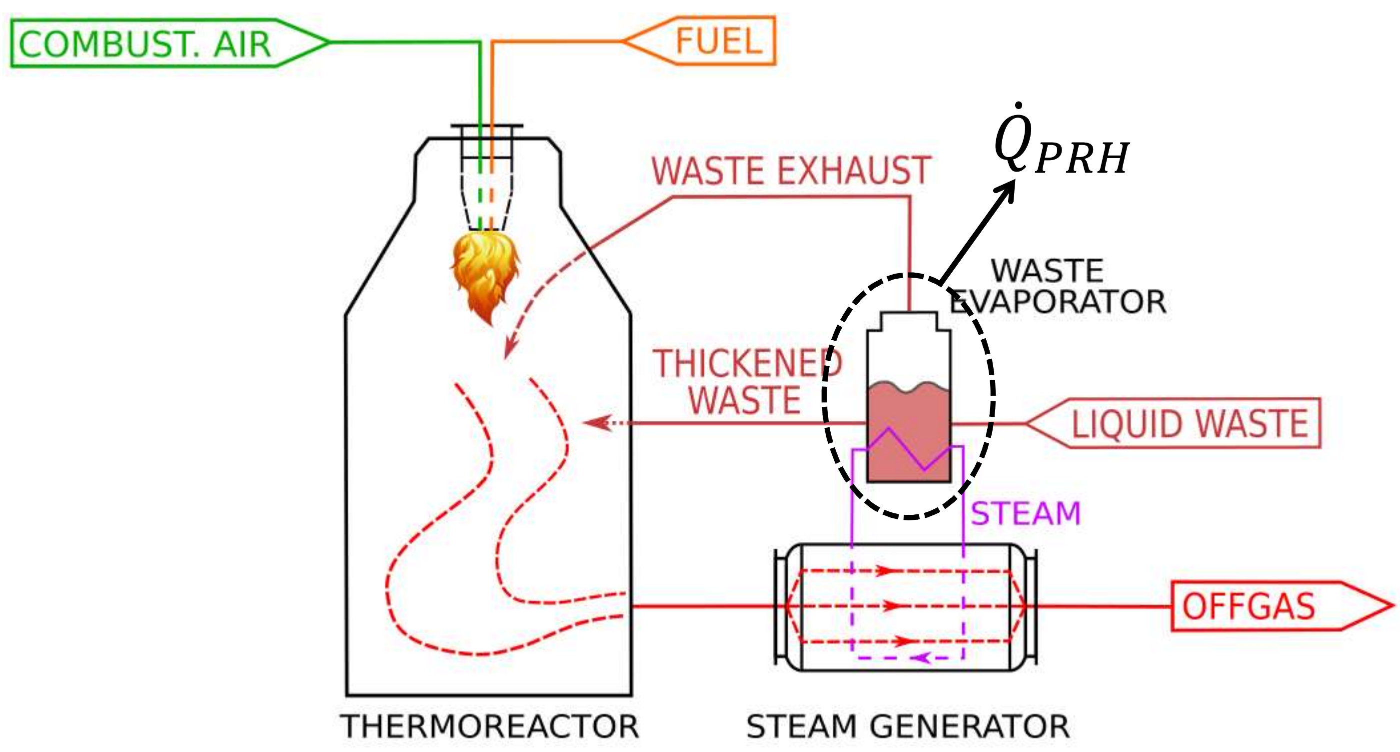


Catalytic decomposition



WASTE THERMAL PROCESSING UNITS

Liquid waste processing



SUPPLEMENTAL FUEL SAVING EVALUATION

Previous research

V. Freisleben and Z. Jegla, ‘Innovative Method for Fuel Saving Calculation Related to Energy Retrofit of Thermal Waste Processing Units‘, in *Proceedings of the 26th Conference Eng. Mech.*, Svratka, 2020, vol. 10, pp. 142–145.

$$\Delta f_s = \dot{Q}_{PRH} / FHV_{CC}$$

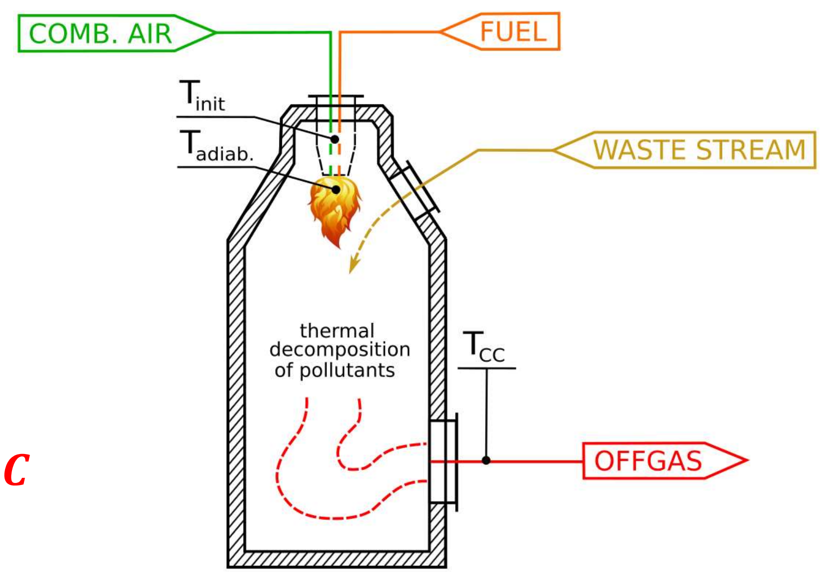
$$FHV_{CC} = LHV \cdot n_c \cdot \frac{T_{adiab} - T_{CC}}{T_{adiab} - T_{init}}$$

$$n_c = (1.07; 1.09)$$

Gaseous waste processing units retrofit

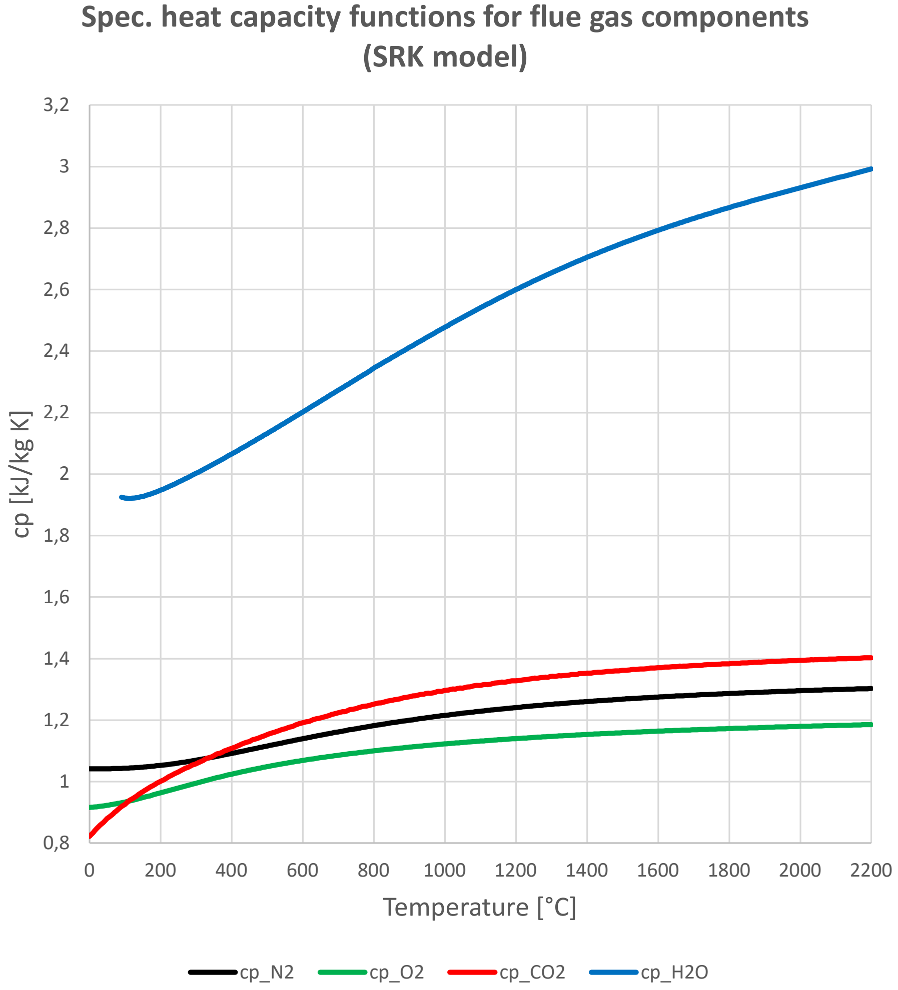
V. Freisleben and Z. Jegla, „Conceptual Design Method for Energy Retrofit of Waste Gas-to-Energy Units", *J. sustain. dev. energy water environ. syst.*, vol. 10, 2021, (in press).

Reliable relationship only for $T_{CC} \approx 800\ °C$ and $T_{init} \approx 20\ °C$



Goal: finding relationship for reliable Δf_s calculation in wider temperature range, i.e. for any WTPU

FLUE GAS PROPERTIES - SRK MODEL



Soave–Redlich–Kwong (SRK) model:

$$c_p = a \cdot T^4 + b \cdot T^3 + c \cdot T^2 + d \cdot T + e$$

H_2O:

$a = 9.44 \cdot 10^{-14}$
$b = -5.05 \cdot 10^{-10}$
$c = 7.79 \cdot 10^{-7}$
$d = 2.29 \cdot 10^{-4}$
$e = 1.8791$

CO_2:

$a = -3.71 \cdot 10^{-1}$
$b = 2.44 \cdot 10^{-10}$
$c = -6.52 \cdot 10^{-7}$
$d = 9.01 \cdot 10^{-4}$
$e = 0.8389$

N_2:

$a = 4.82 \cdot 10^{-14}$
$b = -2.27 \cdot 10^{-10}$
$c = 2.91 \cdot 10^{-7}$
$d = 0.69 \cdot 10^{-4}$
$e = 1.0334$

O_2:

$a = -6.75 \cdot 10^{-16}$
$b = 0.37 \cdot 10^{-10}$
$c = -1.88 \cdot 10^{-7}$
$d = 3.74 \cdot 10^{-4}$
$e = 0.9014$

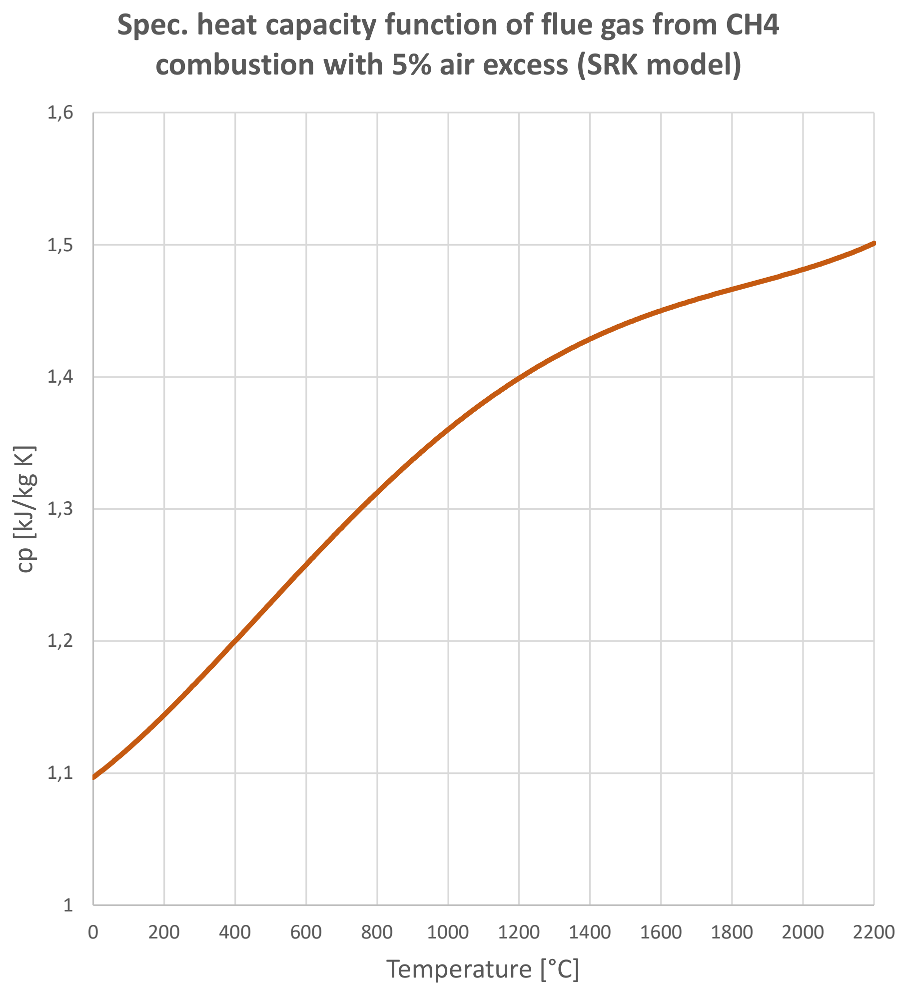
FLUE GAS PROPERTIES - SRK MODEL

$$c_{p\,FlueGas} = \sum_{comp.} w_i \cdot c_{p\,i}$$

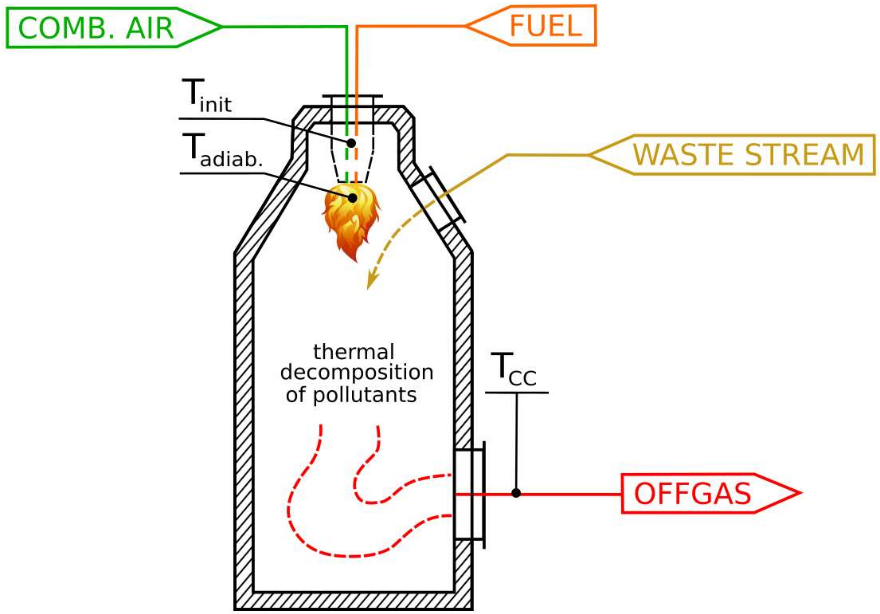
$$= w_{H_2O} \cdot c_{p\,H_2O} + w_{CO_2} \cdot c_{p\,CO_2} + w_{N_2} \cdot c_{p\,N_2} + w_{O_2} \cdot c_{p\,O_2}$$

w_i - weight fraction of component in flue gas

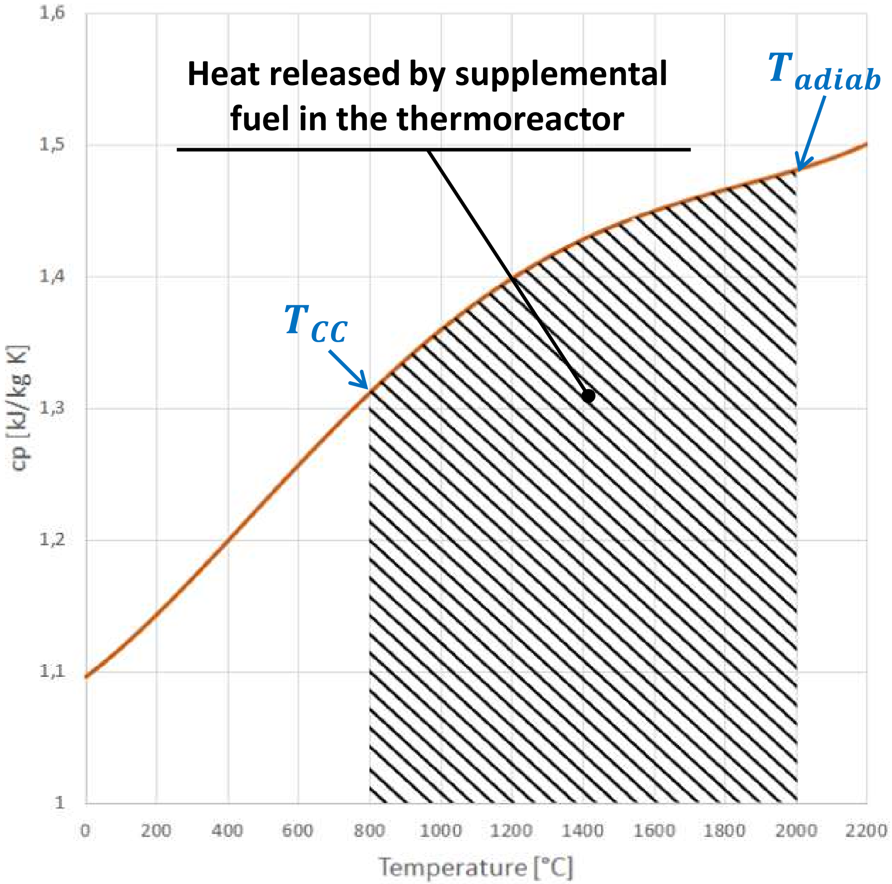
$c_{p\,i}$ - spec. heat capacity of component in flue gas



FUEL´S HEAT CONTENT IN THERMOREACTOR



Spec. heat capacity function of flue gas from CH4 combustion with 5% air excess (SRK model)



LINEAR APPROXIMATION OF SRK MODEL

Initial problem

$$n_{c\_nonlin} = \frac{T_{adiab} - T_{init}}{T_{adiab} - T_{CC}} \cdot \frac{\int_{T_{CC}}^{T_{adiab}} c_{p_{FlueGas}} dT}{\int_{T_{init}}^{T_{adiab}} c_{p_{FlueGas}} dT}$$

$$n_{c\_lin} = K_1 \cdot T_{CC} + K_2 \cdot T_{init} + K_3 \cdot T_{adiab} + K_4$$

$(500; 1100)°C$ $(0; 400)°C$ $(1800; 2200)°C$

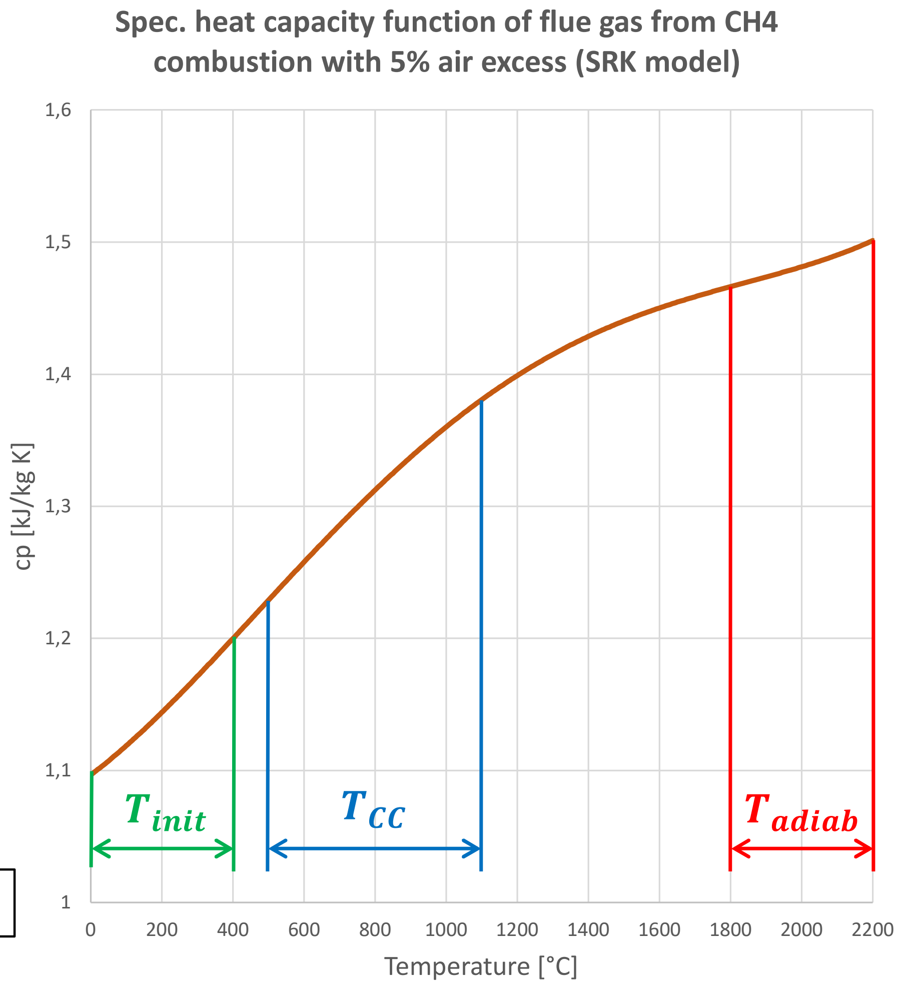
$$objective \rightarrow min\{|n_{c\_nonlin} - n_{c\_lin}|\}$$

Process

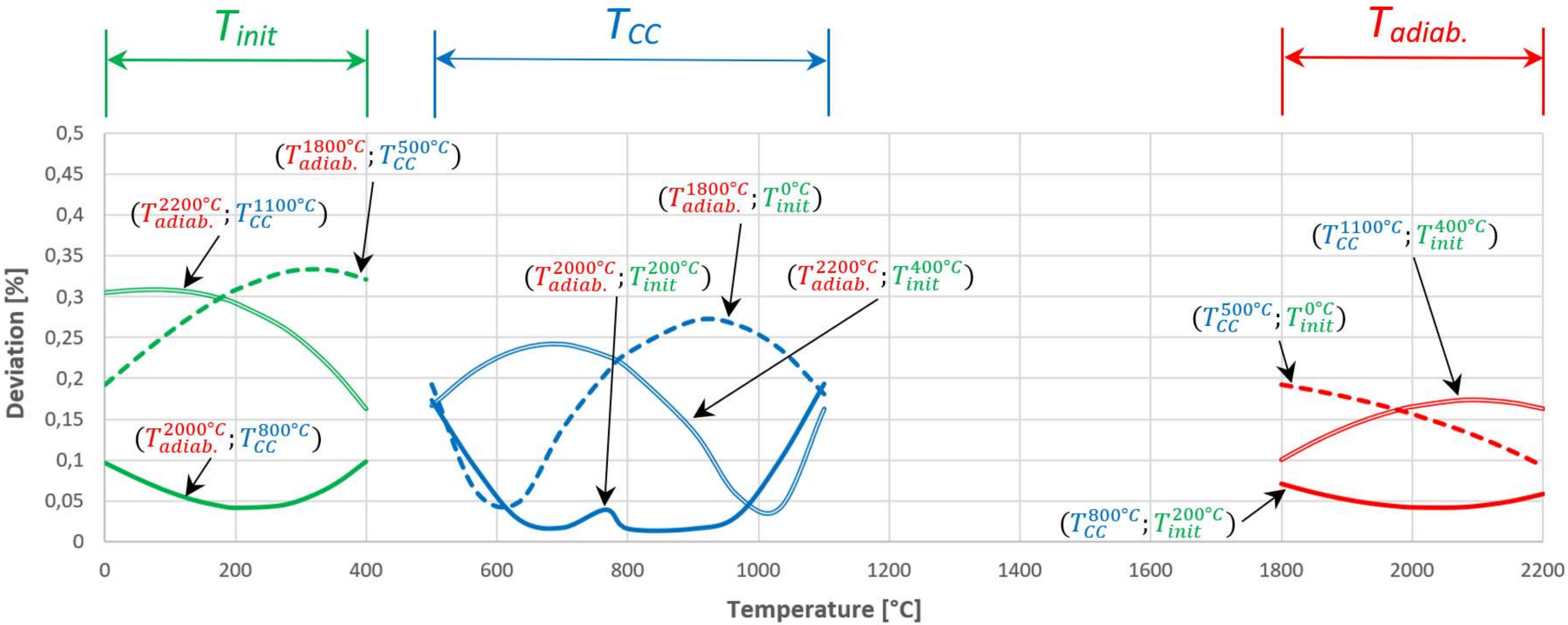
Optimization of the values K_1, K_2, K_3 and K_4 to find the best linear approximation of SRK model

Result

$$n_{c\_lin} = (6,462 \cdot T_{CC} - 8,969 \cdot T_{init} - 1,467 \cdot T_{adiab}) \cdot 10^{-5} + 1,0416$$



LINEAR/NON-LINEAR MODEL COMPARISON



CASE STUDIES

The developed calculation procedure is applied on both, the gaseous waste processing units and liquid waste processing units. In all studies, the supplemental fuel is natural gas combusted in the burner with 5% excess of combustion air. The results are compared to the non-linear simulation based on the SRK model.

Linear model

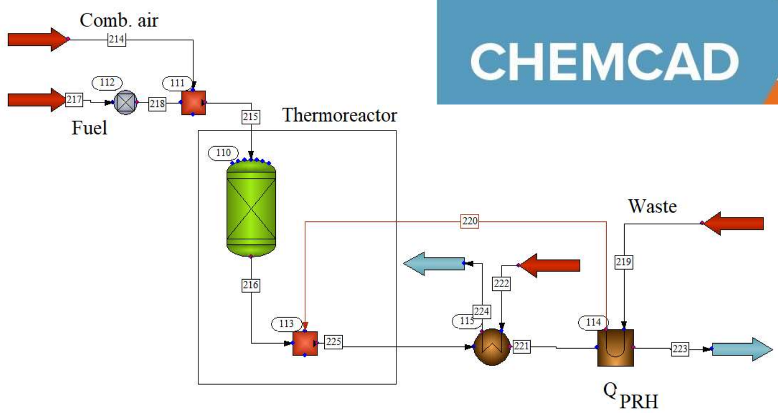
$$\Delta f_s = \dot{Q}_{PRH} / FHV_{CC}$$

$$FHV_{CC} = LHV \cdot n_c \cdot \frac{T_{adiab} - T_{CC}}{T_{adiab} - T_{init}}$$

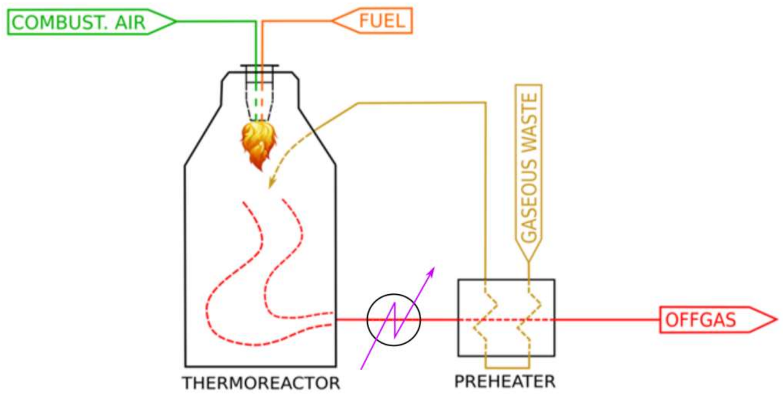
$$n_c = (6,462 \cdot T_{CC} - 8,969 \cdot T_{init} - 1,467 \cdot T_{adiab}) \cdot 10^{-5} + 1,0416$$

Non-linear model

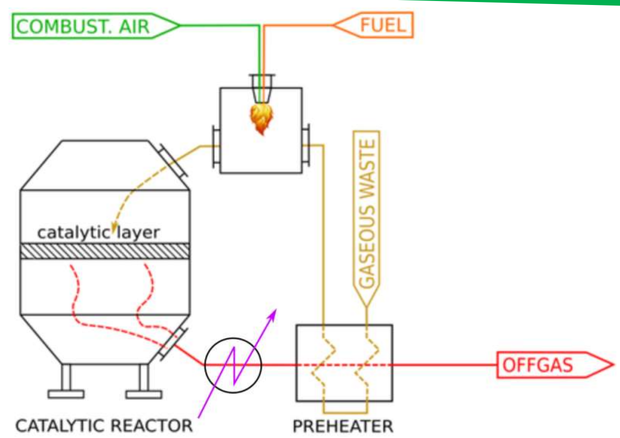
CHEMCAD 7



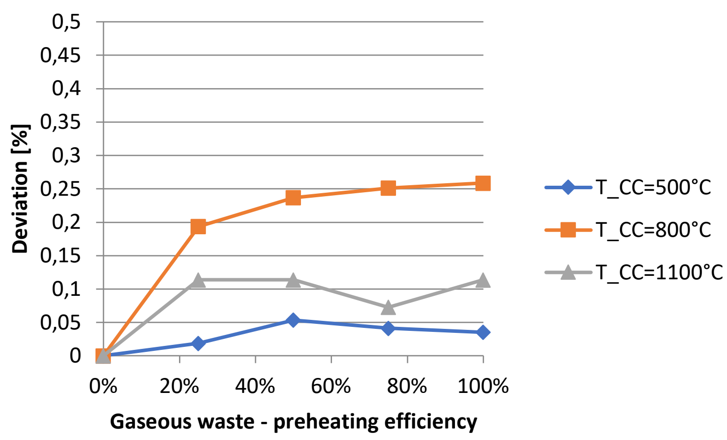
CASE STUDY 1: WTPU – GASEOUS WASTE

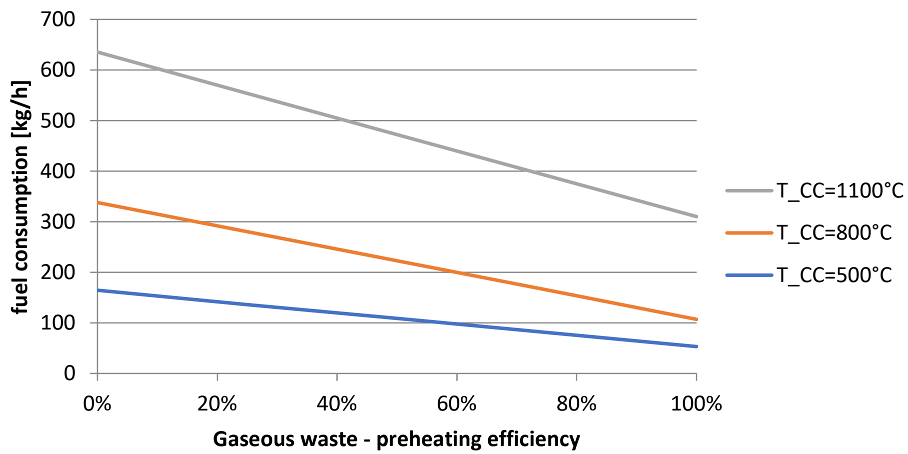


+

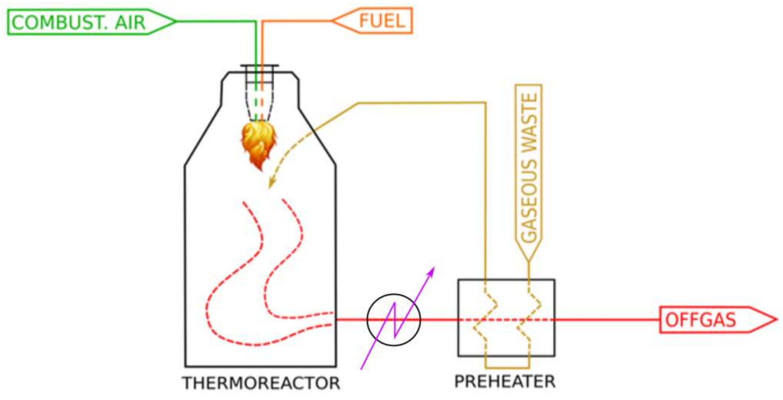


Variables: T_{CC} and Q_{PRH} (in terms of HE´s efficiency)

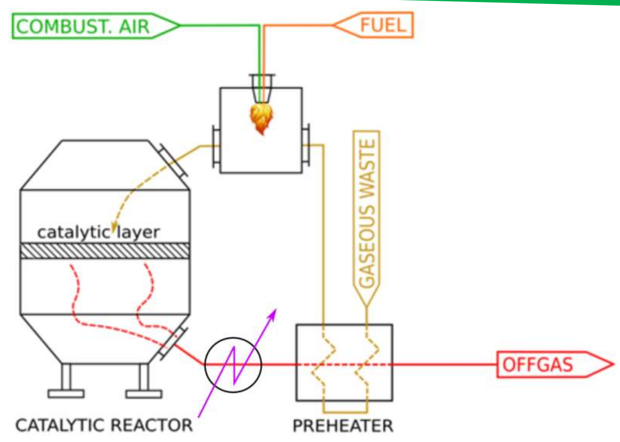




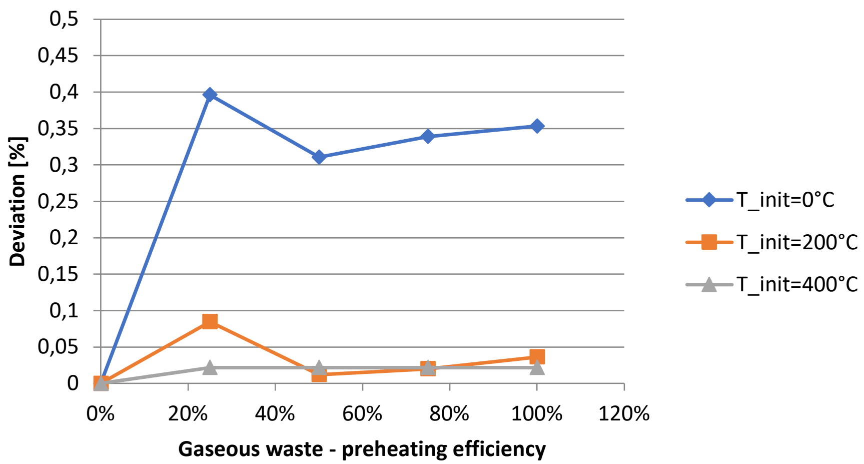
CASE STUDY 1: WTPU – GASEOUS WASTE

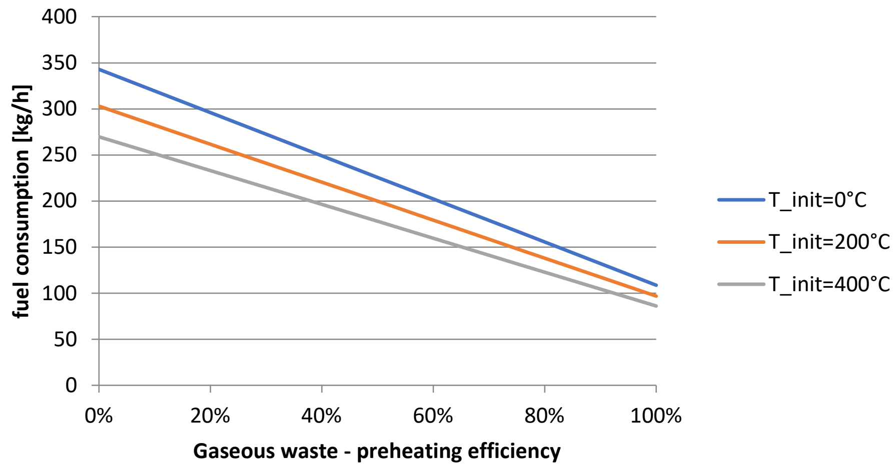


+

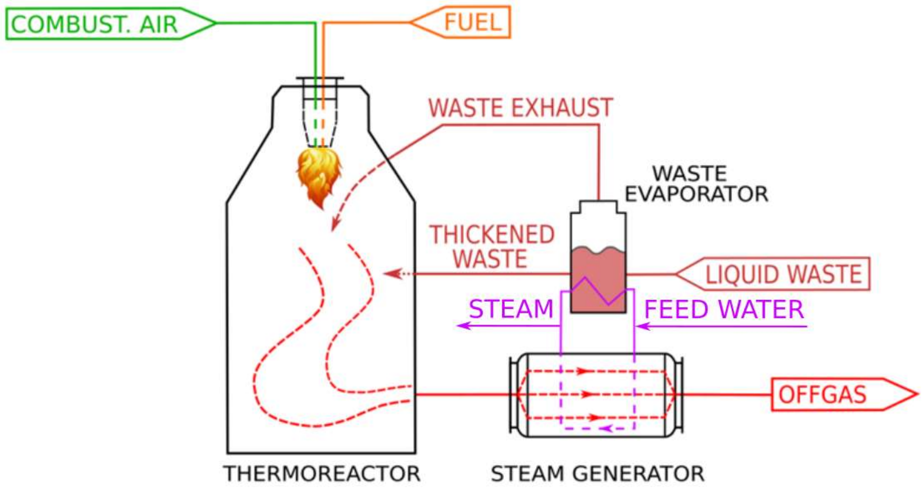


Variables: T_{init} and Q_{PRH} (in terms of HE´s efficiency)

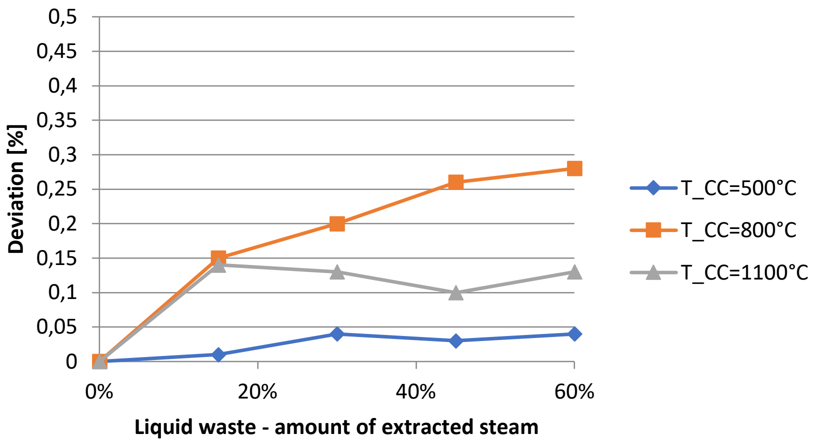




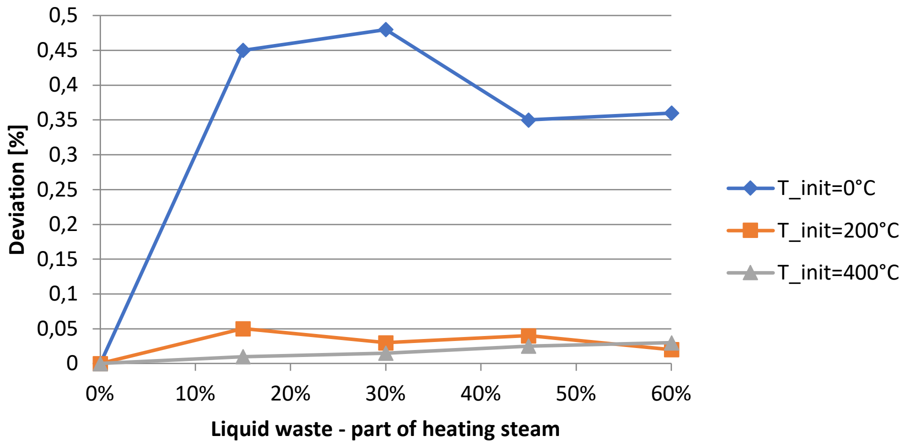
CASE STUDY 2: WTPU – LIQUID WASTE



Variables: T_{CC} and Q_{PRH} (amount of heating steam)



Variables: T_{init} and Q_{PRH}



CONCLUSION AND FUTURE WORK

- **Within this research, a reliable and simple calculation procedure was proposed in order to describe the relationship between the waste thermal pre-treatment, and consequent supplemental fuel saving. The procedure is applicable to any WTPU with similar technology arrangement, as presented here. The results´ accuracy is not dependent on the heating intensity, so the developed procedure can be applied to the WTPU of any size or preheating efficiency.**
- **In the future work, the developed procedure will be implemented to the, co-called, CDM (Conceptual Design Method) in order to extend the CDM´s applicability to the retrofit of WTPUs processing liquid wastes, and catalytic WTPUs processing gaseous wastes.**

SUPPORTING PROJECTS

- **CZ.02.1.01/0.0/0.0/16_026/0008413 – „ Strategic Partnership for Environmental Technologies and Energy Production “**

EUROPEAN UNION
European Structural and Investment Funds
Operational Programme Research,
Development and Education

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

- **LTACH19033 – „Transmission Enhancement and Energy Optimised Integration of Heat Exchangers in Petrochemical Industry Waste Heat Utilisation “**

INTER-EXCELLENCE

MINISTRY OF EDUCATION,
YOUTH AND SPORTS

THANK YOU!

Dr. Zdeněk Jegla, Vít Freisleben, Martin Krňávek

November 2021