On Sewage Sludge Gasification – Modeling and Tests

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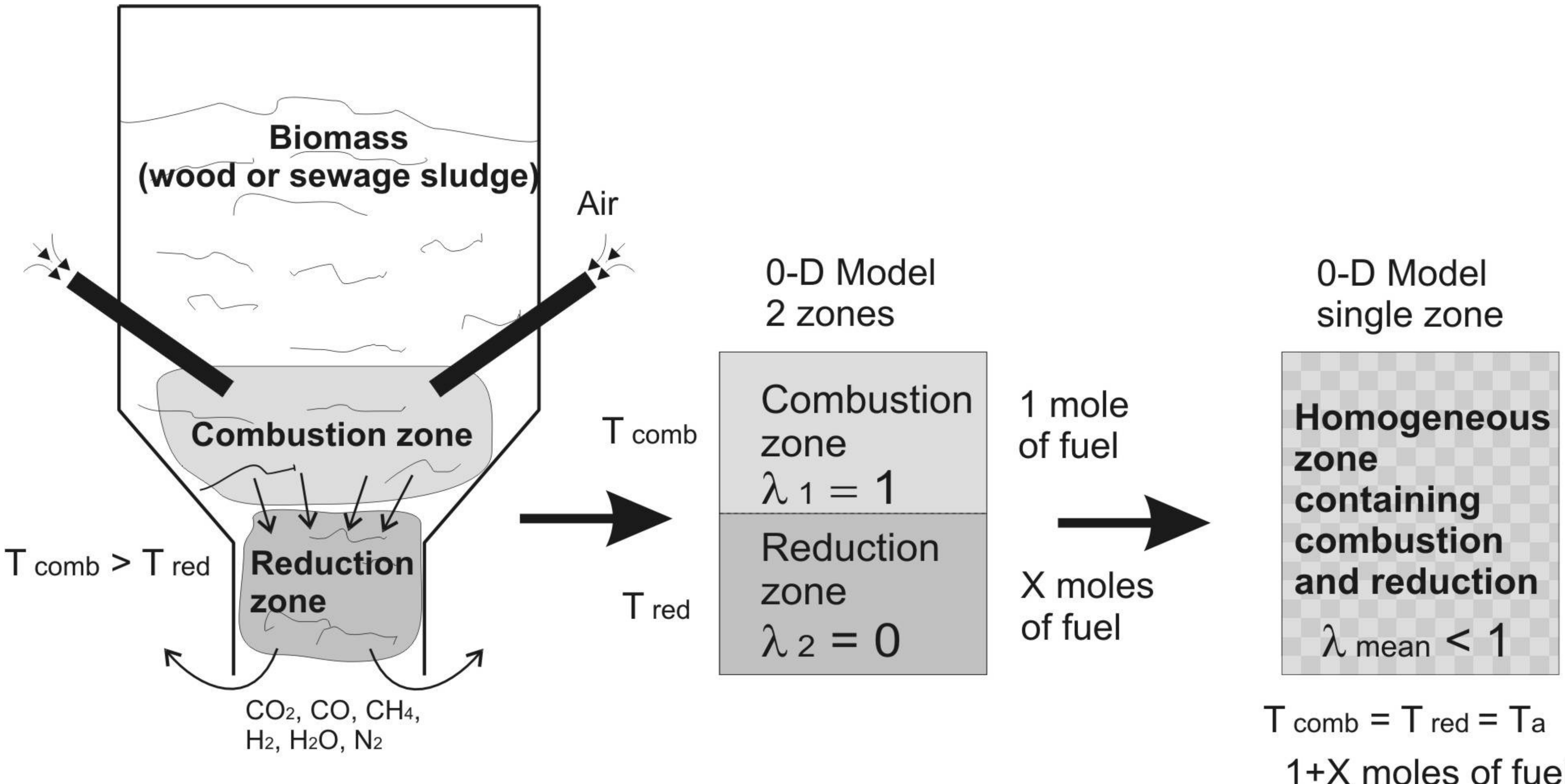
Heat Engines and Environmental Protection 2011



Combustion zone

$$(x_1 \cdot C + x_2 \cdot H + x_3 \cdot O)_{org.} + (x_4 \cdot SiO_2)_{incomb.} + x_5 \cdot S + x_6 \cdot (air) =$$
$$= x_1 \cdot CO_2 + x_2 / 2 \cdot H_2O + x_4 \cdot SiO_2 + x_5 \cdot SO_2 + x_6 \cdot 3.76 N_2$$

Reduction zone

$$X \cdot \left[(x_1 \cdot C + x_2 \cdot H + x_3 \cdot O)_{org.} + (x_4 \cdot SiO_2)_{incomb.}\right] +$$
$$+ \left[x_1 \cdot CO_2 + x_2 / 2 \cdot H_2O + x_4 \cdot SiO_2 + x_5 \cdot SO_2 + x_6 \cdot 3.76 N_2\right] =$$
$$= y_1 \cdot C + y_2 \cdot CO + y_3 \cdot H_2 + y_4 \cdot CH_4 + y_5 \cdot CO_2 + y_6 \cdot H_2O + x_4 \cdot SiO_2 + x_5 \cdot SO_2 + x_6 \cdot 3.76 N_2$$

Adiabatic process temperature T_a

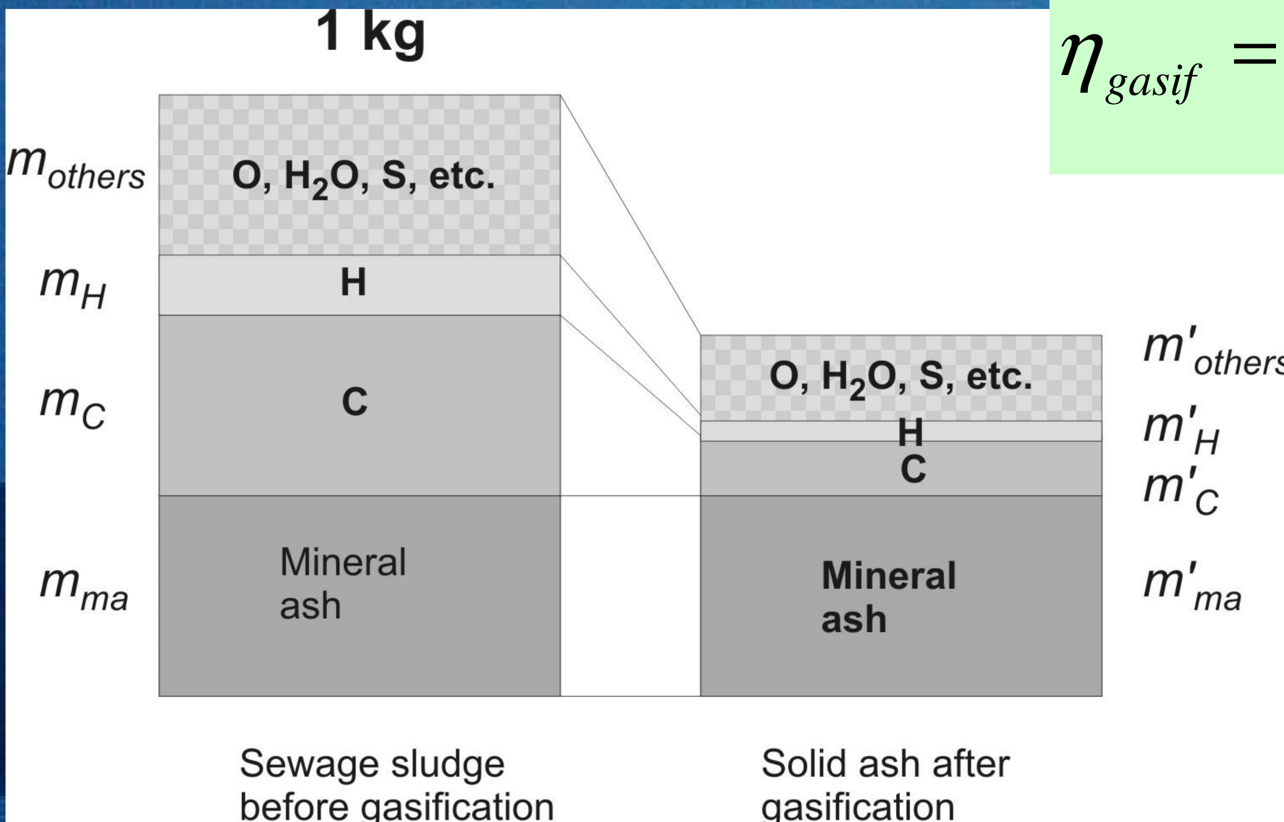
$$H_{prod}(T_a) = H_{reac}(T_1)$$

$$\sum_i n_i \left(h^0_{i(reac)} + \int_{T0}^{T1} c_{p,i}(T)\,dT \right) = \sum_j n_j \left(h^0_{j(prod)} + \int_{T0}^{Ta} c_{p,j}(T)\,dT \right)$$

Heat of combustion Q

$$Q = \sum_j n_j h^0_{j(prod)} - \sum_i n_i h^0_{i(reac)} = \sum_j n_j h^0_{j(prod)}$$

Gasification efficiency η_{gasif}



$$\eta_{gasif} = 1 - \frac{m'_C + m'_H}{m_C + m_H}$$

$$\eta_{gasif} = 1 - \frac{0{,}201 + 0{,}0153}{0{,}322 + 0{,}0406} = 0{,}40$$

Table 2. Chemical composition of the sewage sludge and the solid ash

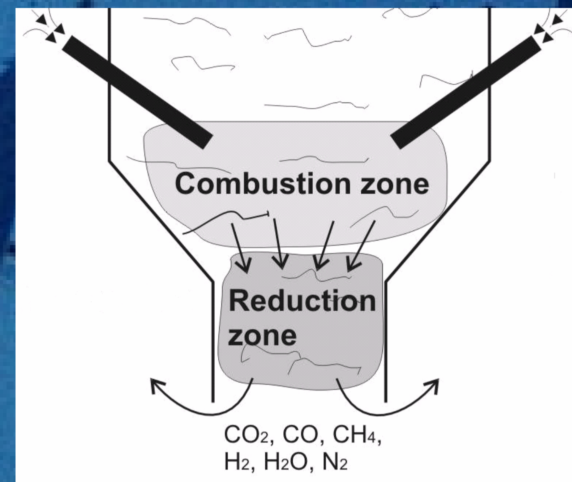
Sludge composition		% by mass	Mass fraction	Solid ash composition		% by mass	Mass fracton
		%	kg/kg of sludge			%	kg/kg of sludge
Carbon	m_C	32.2	0.322	Carbon	m'_C	28.5	0.201
Hydrogen	m_H	4.06	0.0406	Hydrogen	m'_H	2.15	0.0153
Oxygen	m_O	17.14	0.171	Oxygen	m'_O	7.12	0.0501
Nitrogen	m_N	3.5	0.035	Nitrogen	m'_N	2.88	0.0203
Water	m_{H2O}	3.8	0.038	Water	m'_{H2O}	3.9	0.0274
Sulphur	m_S	1.5	0.015	Sulphur	m'_S	1.75	0.0123
Ash (mineral)	m_{ma}	37.8	0.378	Ash (mineral)	m'_{ma}	53.7	0.378
Total	m_c	100	1	Total	m'_c	100	0.704

Reduction to combustion ratio *X*

$$X = \frac{n_{sludge\ \ at\ reduction}}{n_{sludge\ \ at\ combustion}\ (\lambda = 1)} = \frac{m_{sludge\ \ at\ reduction}}{m_{sludge\ \ at\ combustion}\ (\lambda = 1)} \left[\frac{mol}{mol}\ or\ \frac{kg}{kg} \right]$$

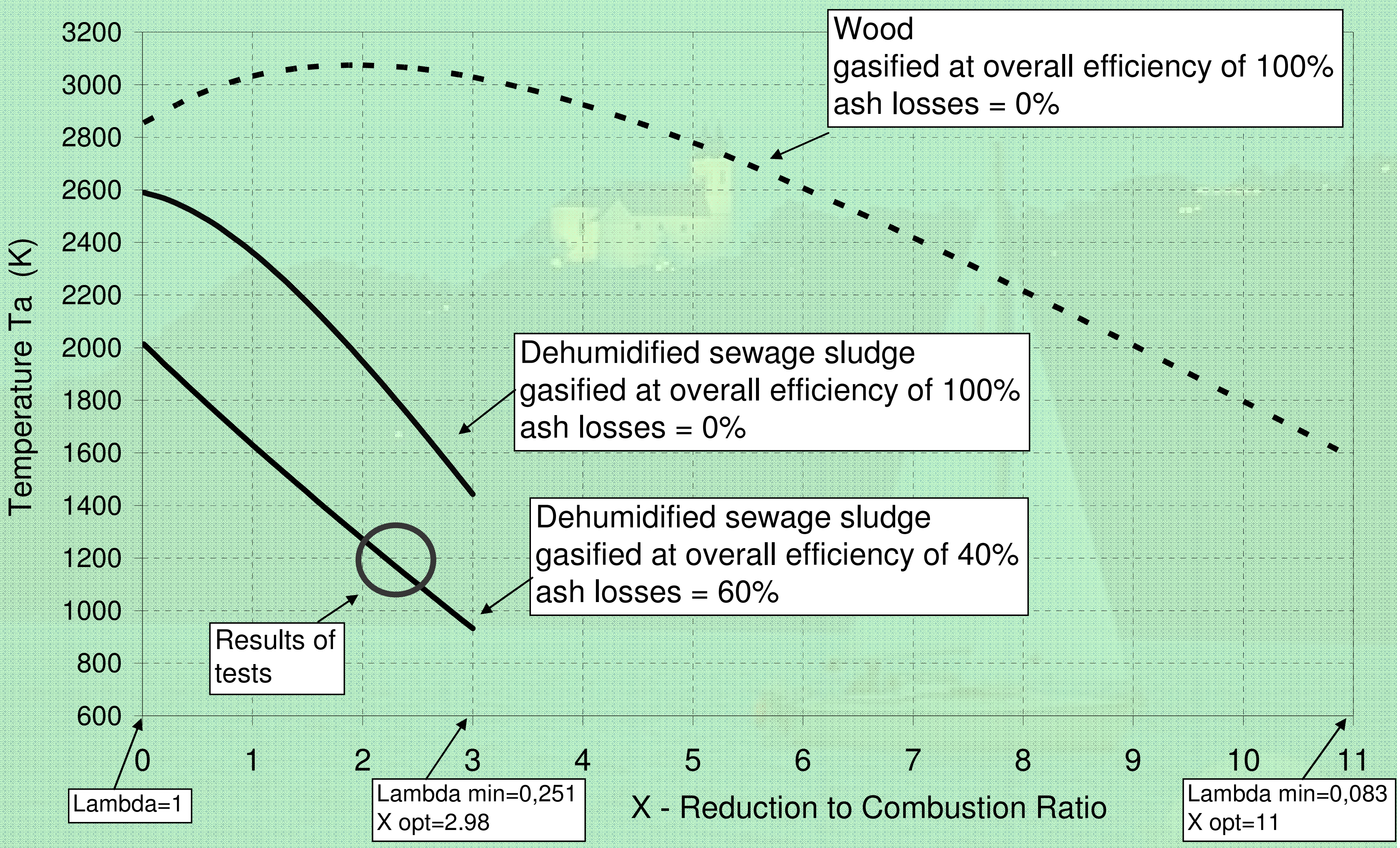
Table 3. λ_{min} and X_{opt} for wood and sludge

Gasifier charge	λ_{min}	X_{opt}
Wood (cellulosis)	0.083	11
Dehumidified sewage sludge	0.251	2.98



Proportion between the reduction and the combustion zone (*X) depends on*:
- temperature *Ta*,
- heat released rate at these zones,
- heat losses transferred to the environment.

Adiabatic temperature T_a of total gasification process of the sludge vs the X



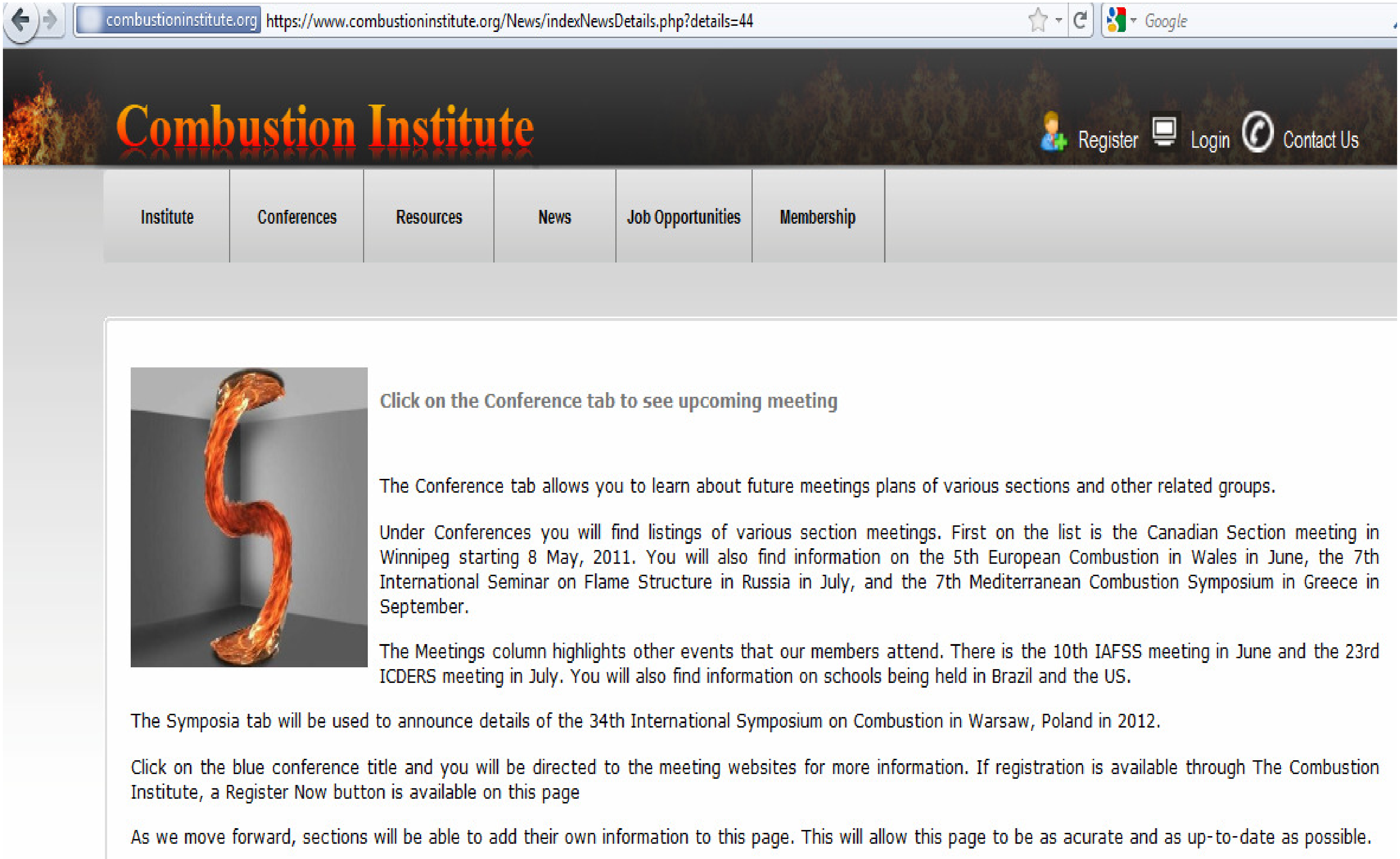
CONCLUSIONS

- 0-D model of the gasification is useful for preliminary estimation of quality of the gasification process, however, temperature T_a cannot be identified as temperature of combustion or reduction zone.

- The *Ta* and the *Xopt* are the parameters which characterize the ideal gasification process.

Measures to increase the temperature T_a and to expand the reduction zone (the X):

- Minimizing heat losses from the reactor bed to the environment.
- Applying pure oxygen instead of air.
- Co-combustion of the dried sewage sludge and fuel with high LHV (eg. coal, wood).
- Optimizing the reactor bed geometry.



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Köszönöm
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