Modelling of Gasification of Refuse-derived fuel (RDF) based on laboratory experiments

Juma Haydary

Department of Chemical and Biochemical Engineering

Institute of Chemical and Environmental Engineering

Faculty of Chemical and Food Technology

Slovak University of Technology in Bratislava, Slovakia

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Slovak University of Technology in Bratislava

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Institute of Chemical and Environmental Engineering

Reactor Engineering Reaserch Group

- Experimental study and mathematical modeling of fuel thermal processes
- Pyrolysis, gasification and combustion of solid fuels
- Biomass, polymer waste, MSW, and coal thermal and catalytic processing for production energy and materials

National center for research and application of renewable energy sources

Refuse-Derived Fuel (RDF)

MSW

RDF

Biodegradables

Metals

Inorganics

Hazardous wastes

RDF composition

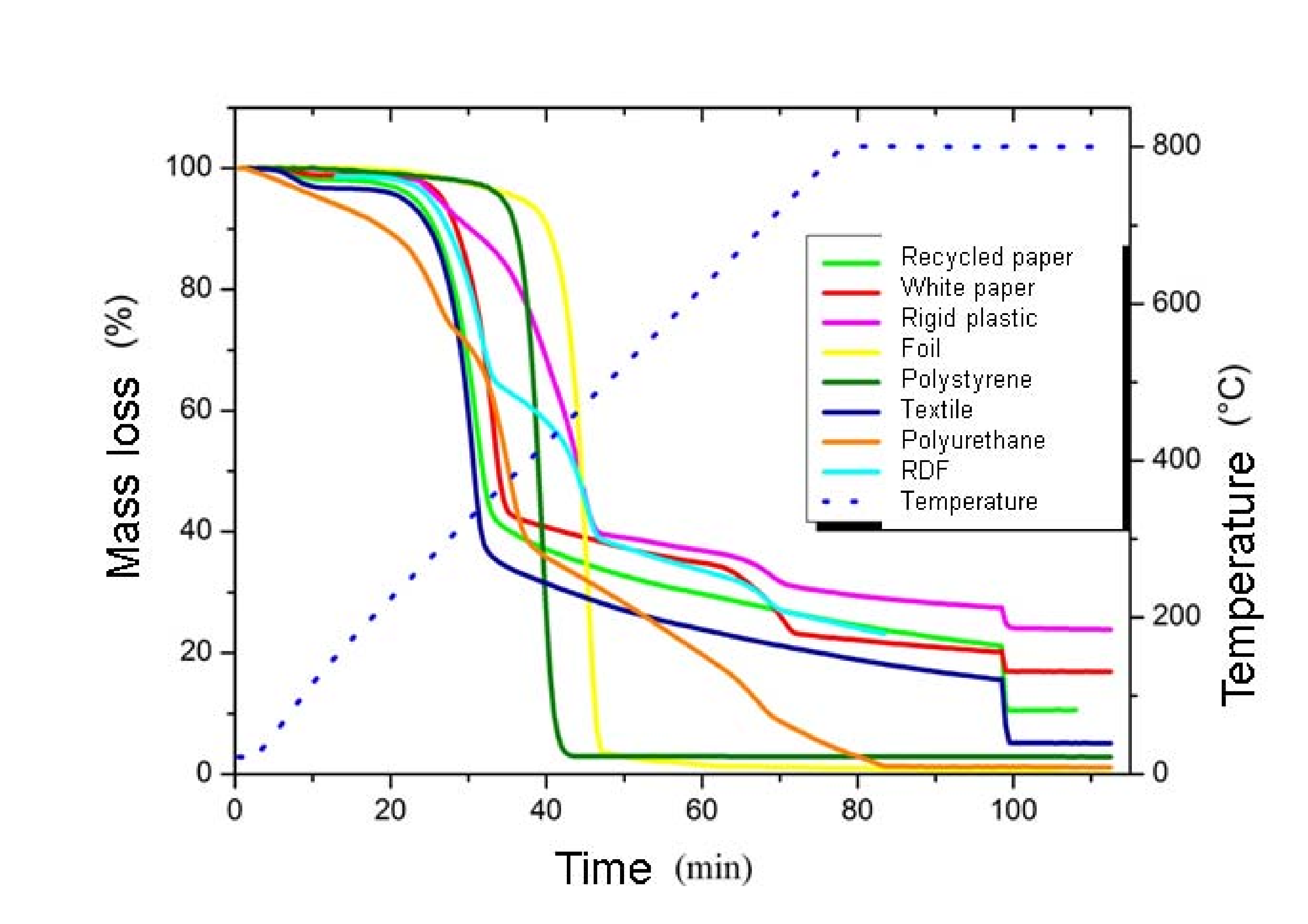
Component	**Material**	**w_i [kg/kg]**
Paper	White paper, recycled paper	0,6317
Foil	LDPE, HDPE	0,1578
Plastics	Rigid plastics, polystyrene, polyurethane	0,1910
Textile	Polyamide, polyester, cotton , wool	0,0194

Proximate and Elemental Composition of RDF

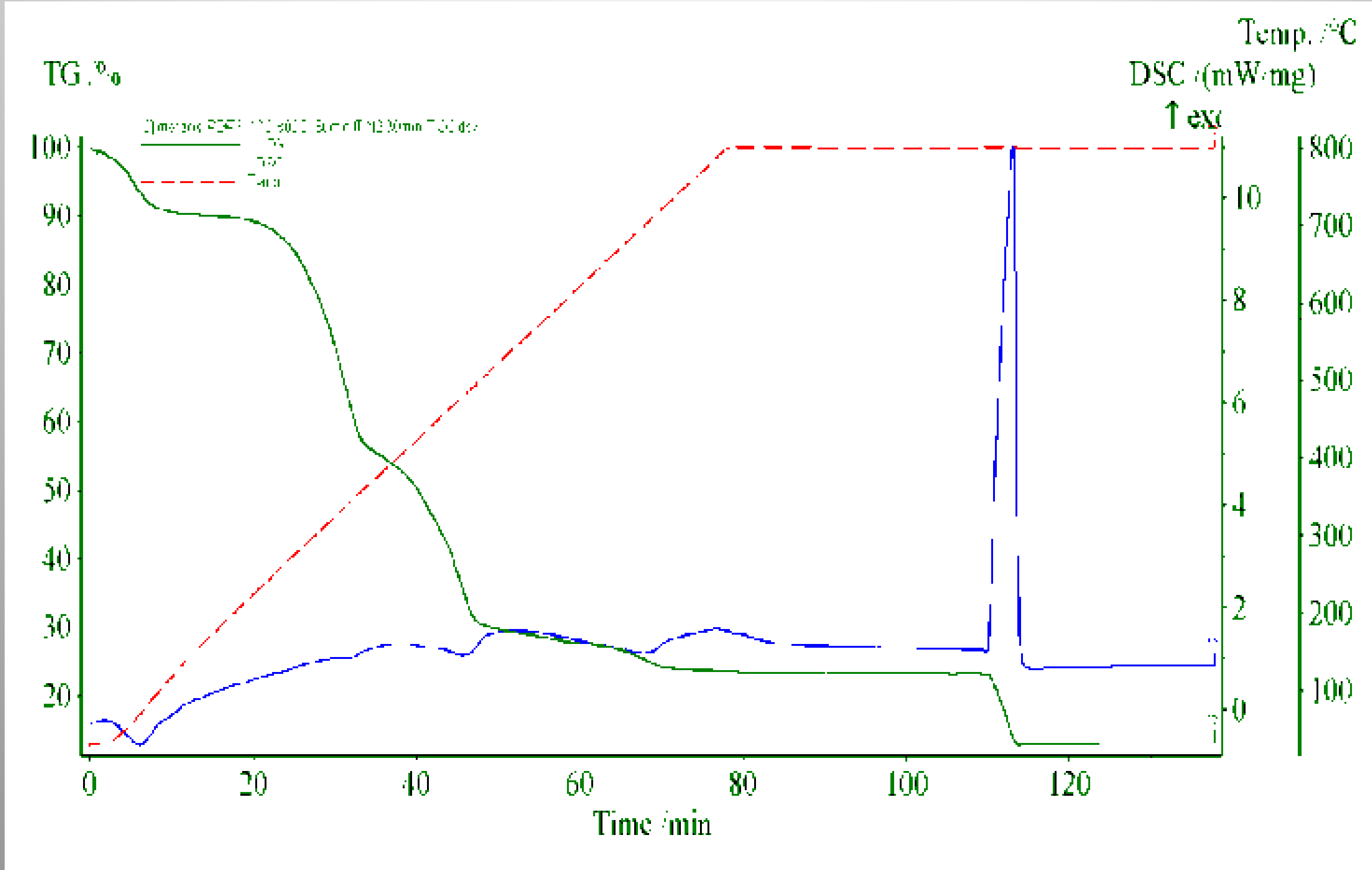
Com.	Mois.	VM*	FC*	ASH*	C	H	N	S	O**
Wt. %	10	75.5	8.9	15.6	51.7	5.9	0.9	0.4	25.5

*moisture free basis
**calculated to 100%

Behaviour of Thermal decomposition



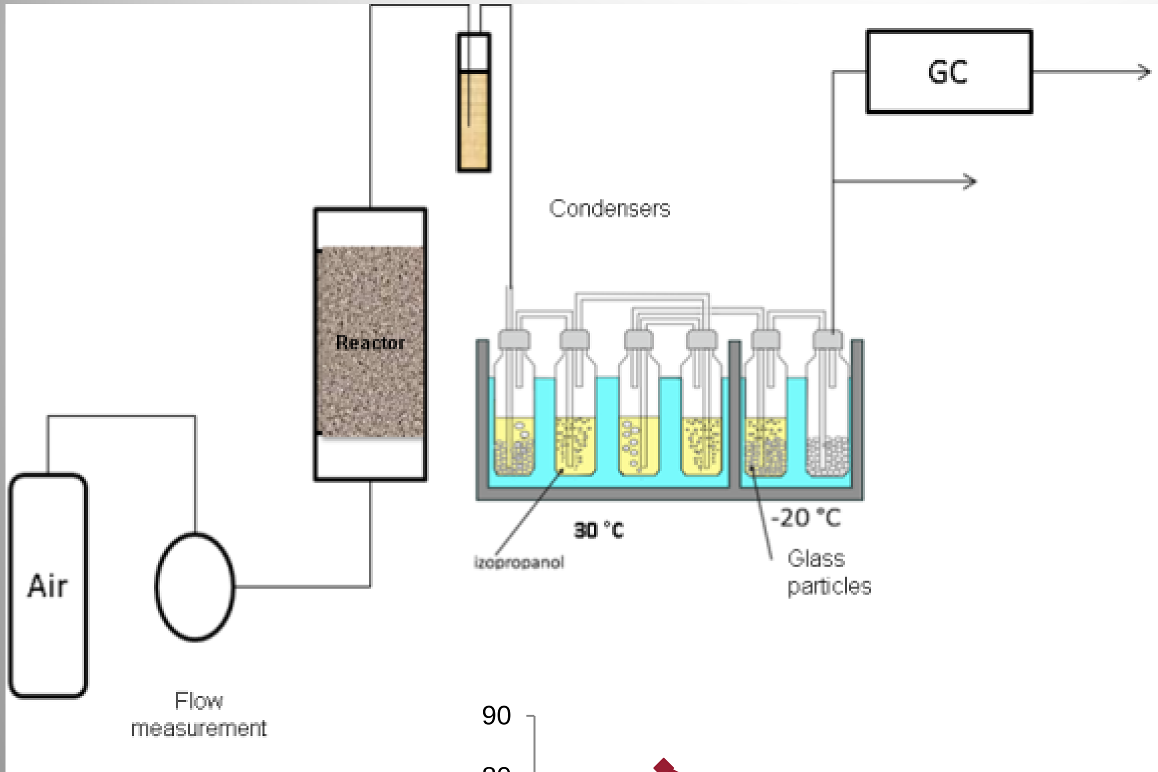
Behaviour of Thermal decomposition

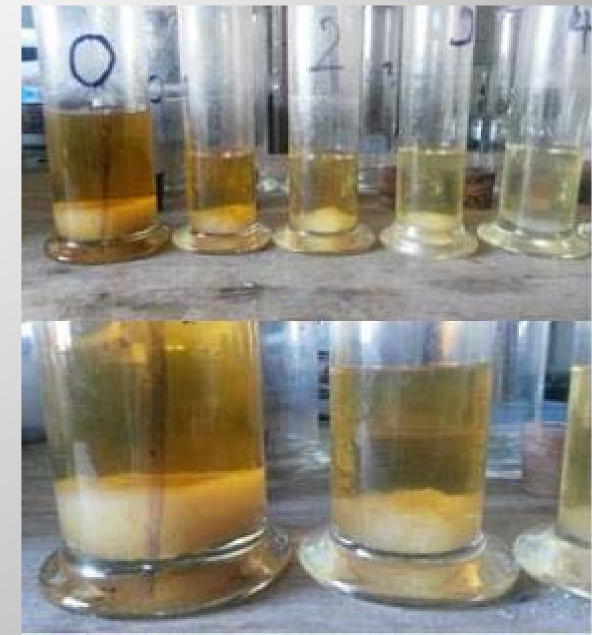


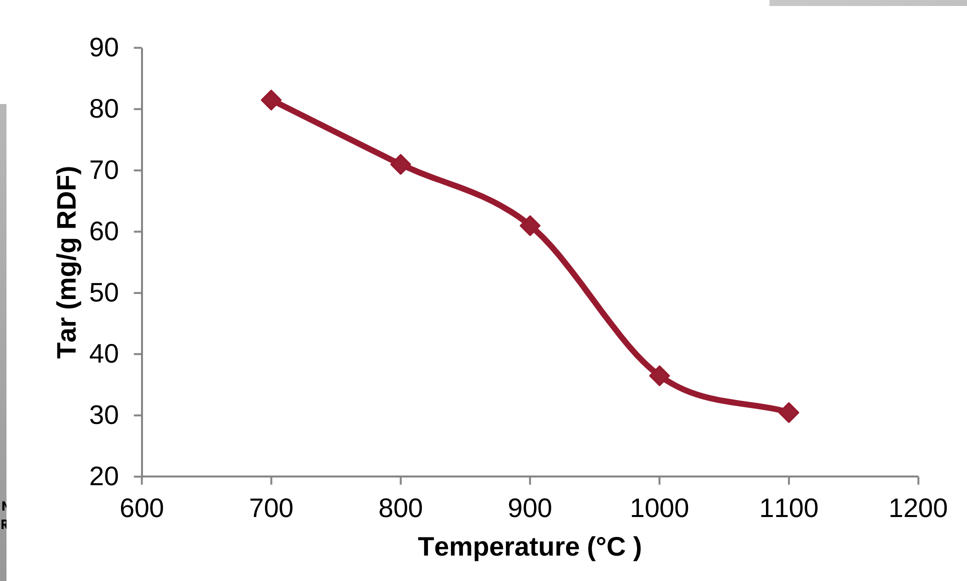
Heating value of RDF

Component	Heating value [kJ/kg]
Paper	13410
Foil	43860
Plastics	33570
Textile	19770
Mixed RDF	20810

Tar content measurement







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Gasification Model

Assumptions:

- **Steady state flow is considered inside the gasifier**
- **No temperature and concentration gradient exist inside the reactor**
- **The residence time is enough long to reach complete decomposition of RDF and unreacted part of RDF is only carbon.**
- **Only the major species are considered in the product gases, i.e CO, CO_2, H_2, CH_4, H_2O, NH_3, H_2S, N_2 and Tar**

Global material balance of RDF gasification

RDF

$$CH_bO_cN_dS_e + x_1O_2 + x_2H_2O \rightarrow x_3CO + x_4CO_2 + x_5H_2 + x_6CH_4 + x_7H_2O$$
$$+ x_8NH_3 + x_9H_2S + x_{10}CH_{b1}O_{c1}N_{d1}S_{e1}$$

TAR

Reactions:

$$C + 0,5O_2 \longrightarrow CO$$
$$CO + 0,5O_2 \longrightarrow CO_2$$
$$H_2 + 0,5O_2 \longrightarrow H_2O$$
$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

$$C + H_2O \longleftrightarrow H_2 + CO$$
$$C + CO_2 \longleftrightarrow 2CO$$
$$CH_4 + H_2O \longleftrightarrow 3H_2 + CO$$
$$C + 2H_2 \longrightarrow CH_4$$
$$CO + H_2O \longleftrightarrow CO_2 + H_2$$

Equilibrium constant:

$$K_a = \left(\frac{P}{P^0}\right)^{\sum \nu_i} \prod \phi_i^{\nu_i} \prod x_i^{\nu_i}$$

$$K_a^{298} = e^{\frac{-\Delta_r G^{298}}{RT}}, \quad \Delta_r G^{298} = \Delta_r H^{298} - T\Delta_r S^{298}$$

$$\Delta_r H^{298} = \sum \nu_i \Delta_f H_i^{298} \qquad \Delta_r S^{298} = \sum \nu_i \Delta_f S_i^{298}$$

$$\Delta_r H = \Delta_r H^{298} + \sum \nu_i c_{pi} \cdot (T - 298) \qquad \Delta_r S = \Delta_r S^{298} + \sum \nu_i c_{pi} \cdot \ln\frac{T}{298}$$

Enthalpy balance:

$$H_{RDF} + H_{O2(air)} + H_{steam} + Q_R = H_{gas} + H_{ash} + H_C + Q_{loss}$$

$$Q_R = m_{RDF} \sum w_i Q_i - \sum (-\Delta_c H_i) n_i$$

IF, $T_{air} = T_{RDF} = T_{ref}$, then $H_{RDF} = 0$, $H_{O2(air)} = 0$

$$T = T_{ref} + \frac{m_{RDF} \sum w_i Q_i - \left(\sum (-\Delta_c H_i) n_i \right) - Q_{loss}}{\left(\sum n_i c_{pi} \right) + m_C \bar{c}_{pC} + m_{ash} \bar{c}_{pash} - m_{steam} \bar{c}_{steam}}$$

Q_R – heat of reaction [*J*],
H_{RDF} – enthalpy of RDF feed [*J*],
$H_{O2(air)}$ – enthalpy of oxygen and air respectively [*J*],
H_{steam} – enthalpy of water steam [*J*],
H_{gas} – enthalpy of gas [*J*],
H_{ash} – enthalpy of ash [*J*],
H_C – enthalpy of unreacted carbon [*J*],
Q_{loss} – heat losses from the reactor [*J*]

m_{RDF} *– mass flow of RDF feed [kg]*

n_i *– mole flow of component i in the products [kmol]*

w_i – maas fraction of component *i* in the feed (paper, foil, plastics, textil

Q_i – lower heating value of component *i* in the feed (paper, foil, plastics, textile) [Jkg^{-1}],

$\Delta_c H_i$ - heat of combustion of component *i* in the products [$Jkmol^{-1}$]

m_{ash} *– mass flow of ash [kg]*

m_{ash} *– mass flow of remaining carbon [kg]*

m_{steam} *– mass flow of steam [kg]*

$\bar{c}_{pash}$ *– specific heat capacity of ash [*$Jkg^{-1}K^{-1}$*]*

$\bar{c}_{pC}$ *– specific heat capacity of remaining carbon [*$Jkg^{-1}K^{-1}$*]*

$\bar{c}_{psteam}$ *– specific heat capacity of steam [Jkg-1*K^{-1}*]*

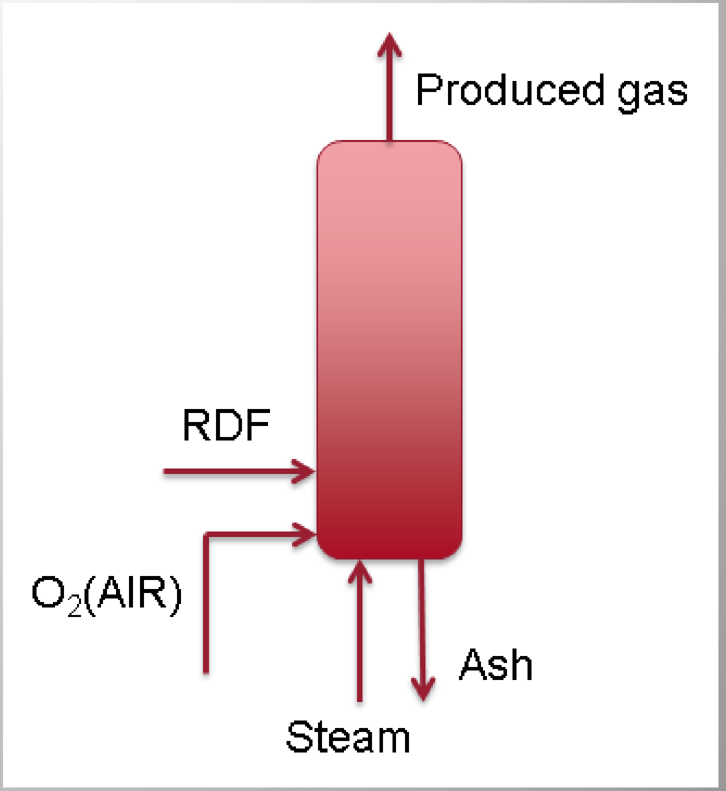
Results of modelling RDF gasification

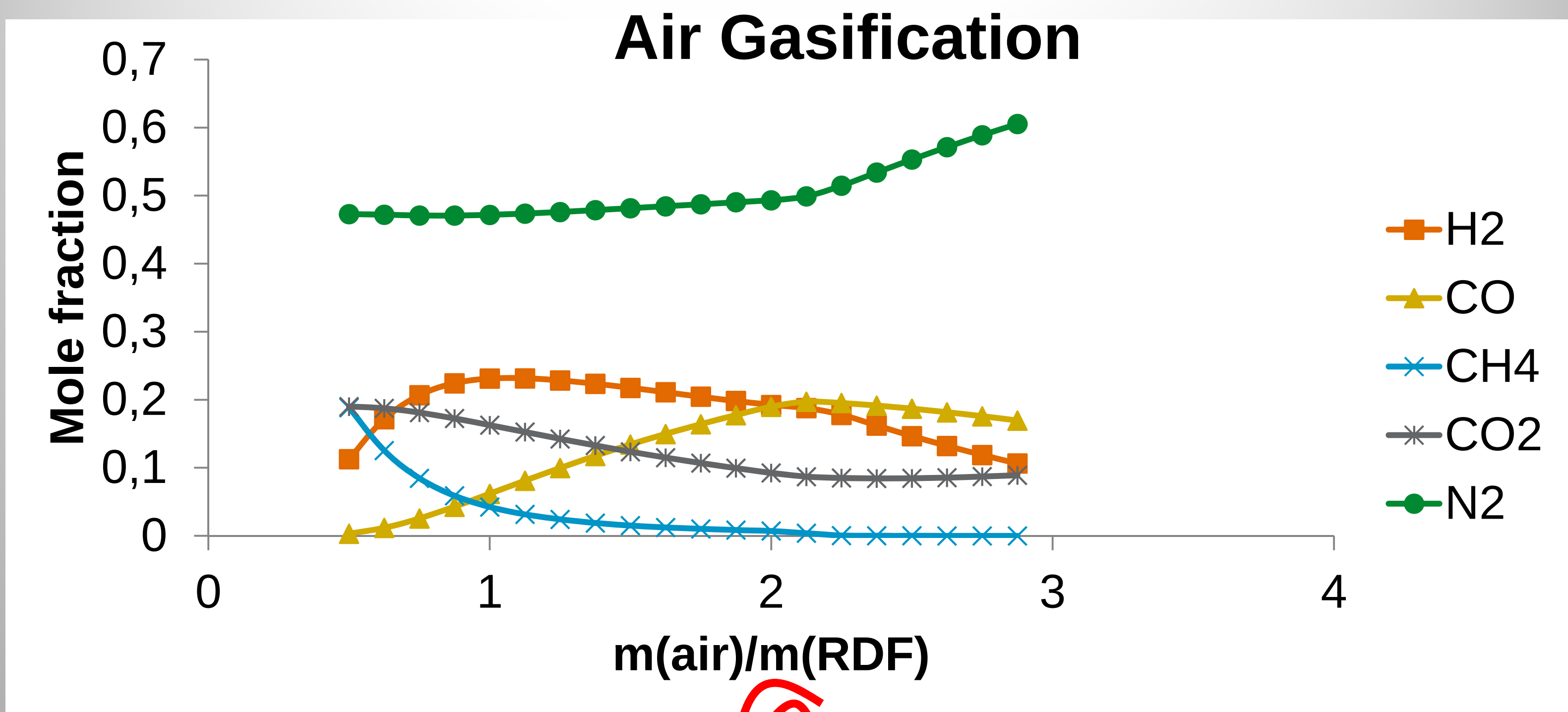
Observed parameters:

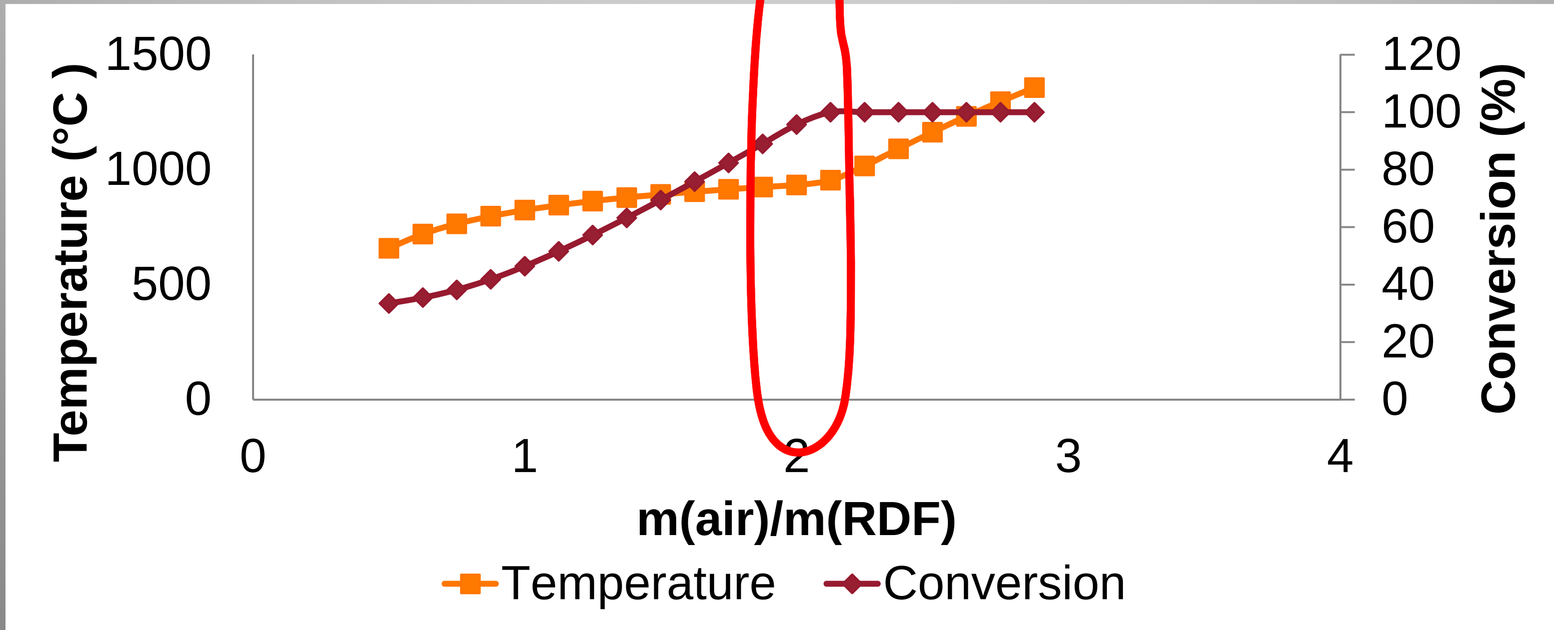
Conversion of RDF
Reactor Temperature
Gas composition
Content of pollutants (NH_3, H_2S, TAR)

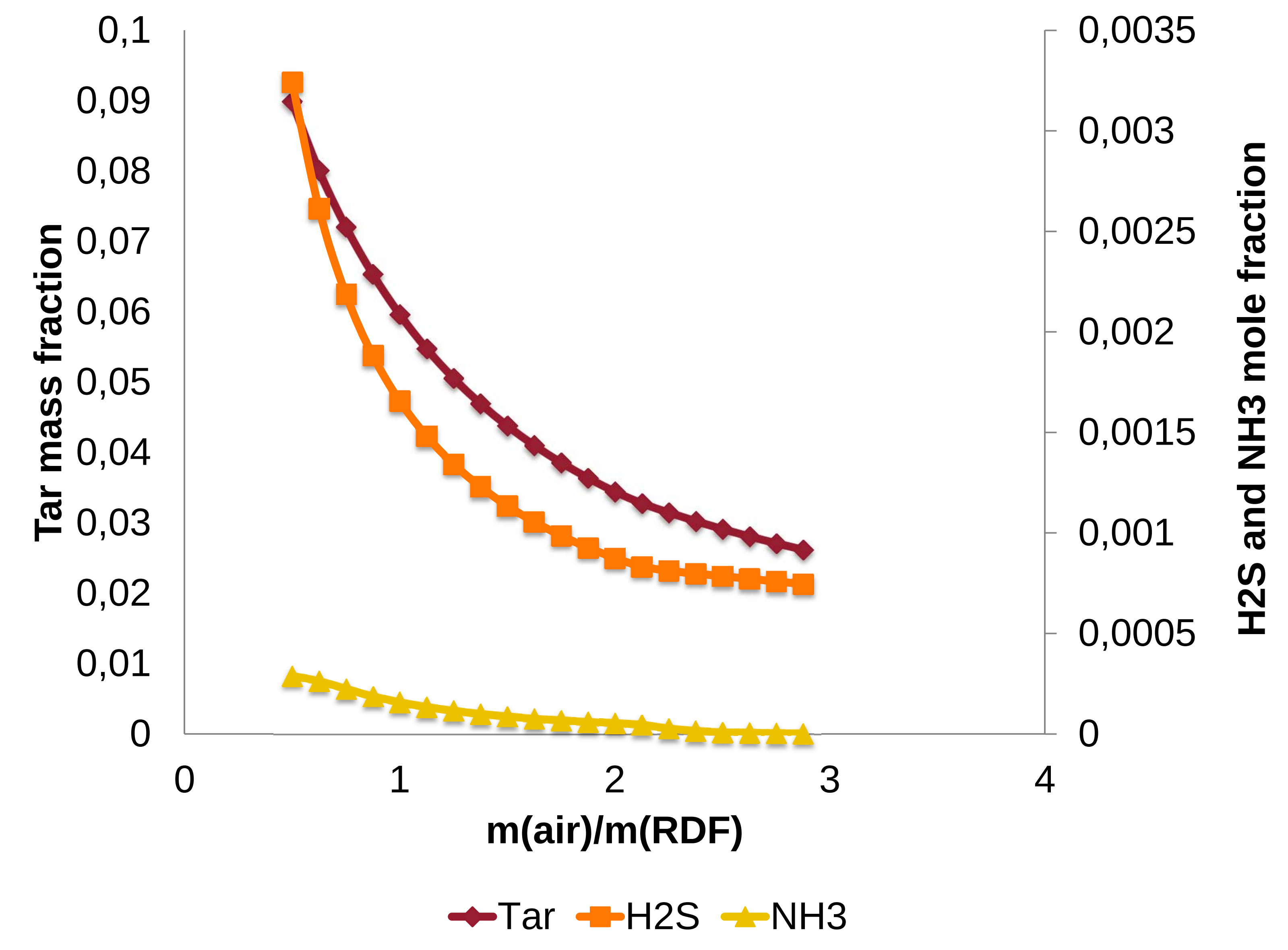
Variables:

Oxygen (air) to RDF mass ratio
Steam to RDF mass ratio



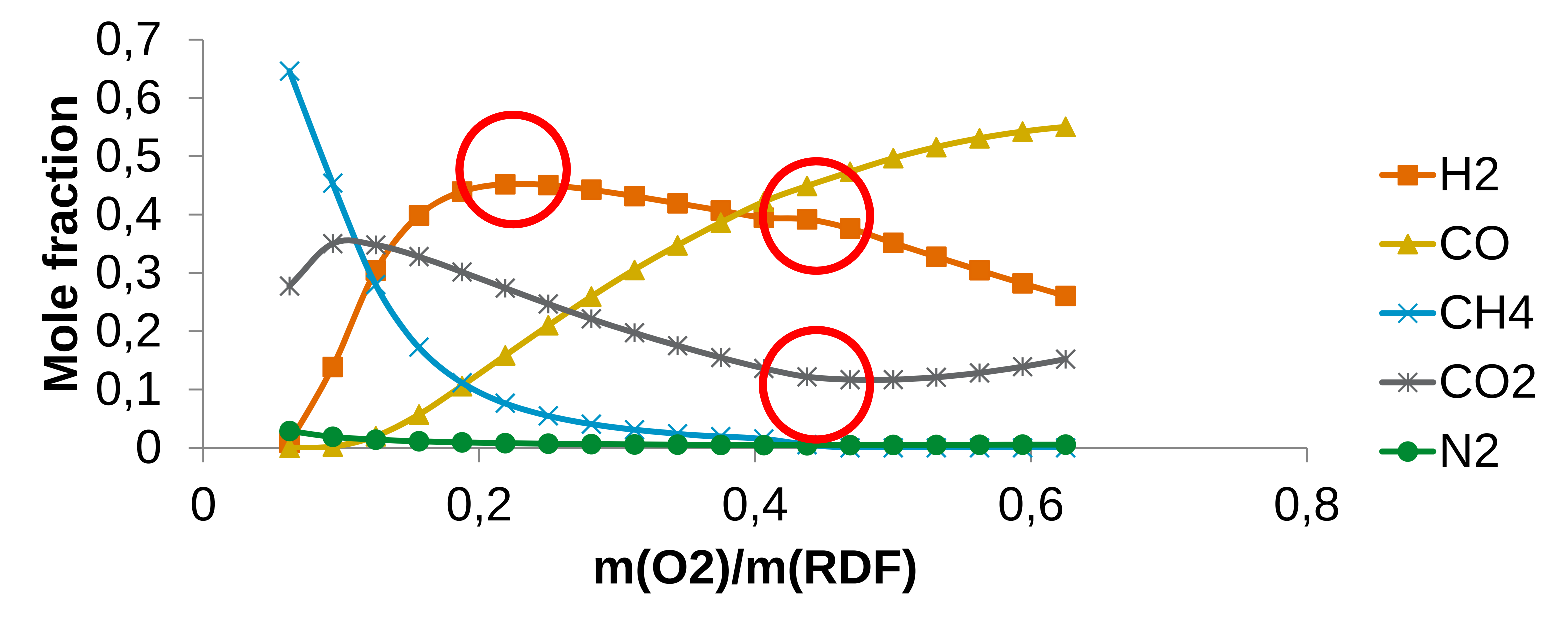

Air Gasification
Mole fraction
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
1
2
3
4
m(air)/m(RDF)
H2
CO
CH4
CO2
N2

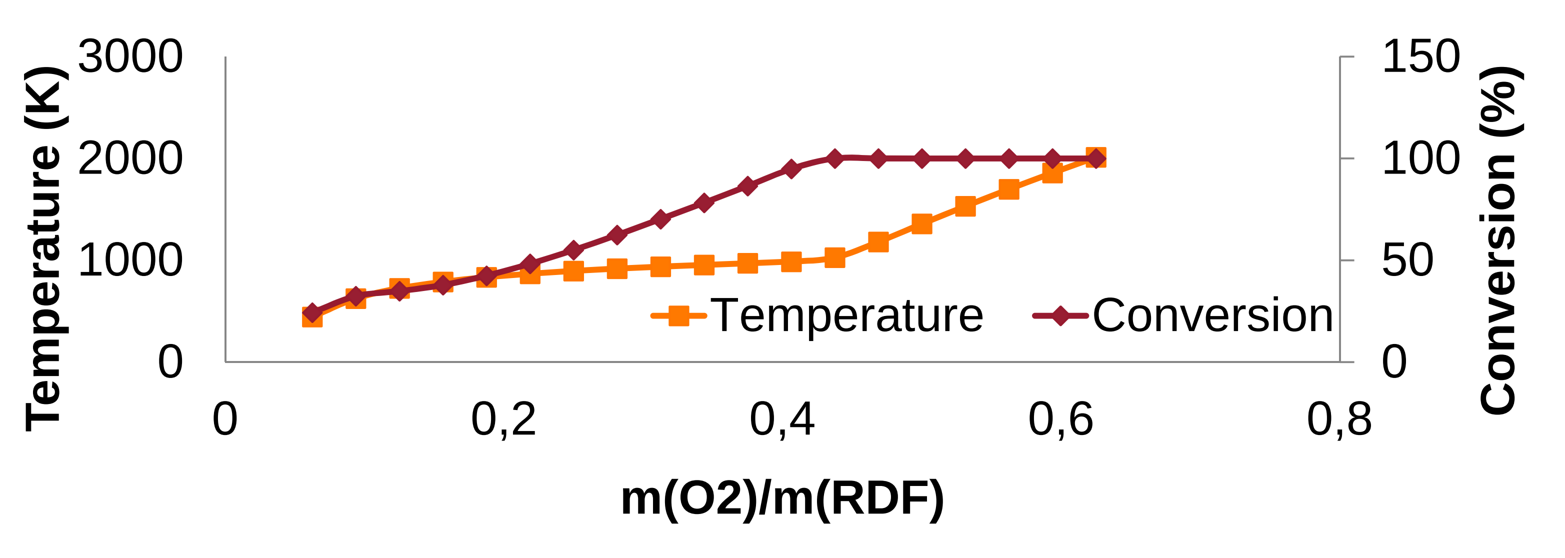

Temperature (°C)
1500
1000
500
0
120
100
80
60
40
20
0
Conversion (%)
0
1
2
3
4
m(air)/m(RDF)
Temperature
Conversion



0,1
0,09
0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0
Tar mass fraction
0,0035
0,003
0,0025
0,002
0,0015
0,001
0,0005
0
H2S and NH3 mole fraction
0
1
2
3
4
m(air)/m(RDF)
Tar
H2S
NH3

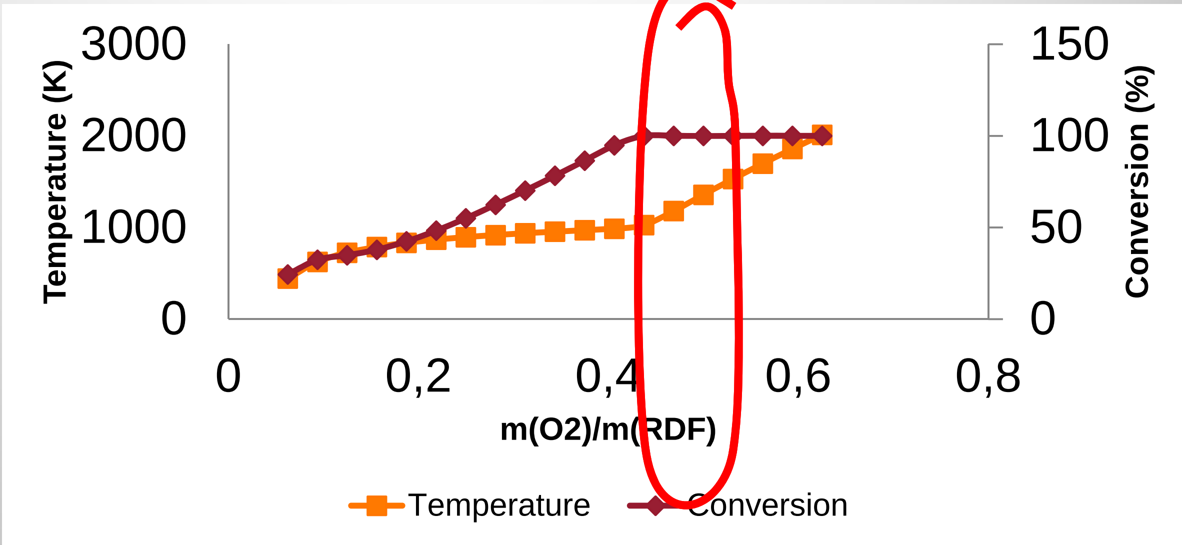
Gasification of RDF Using O_2



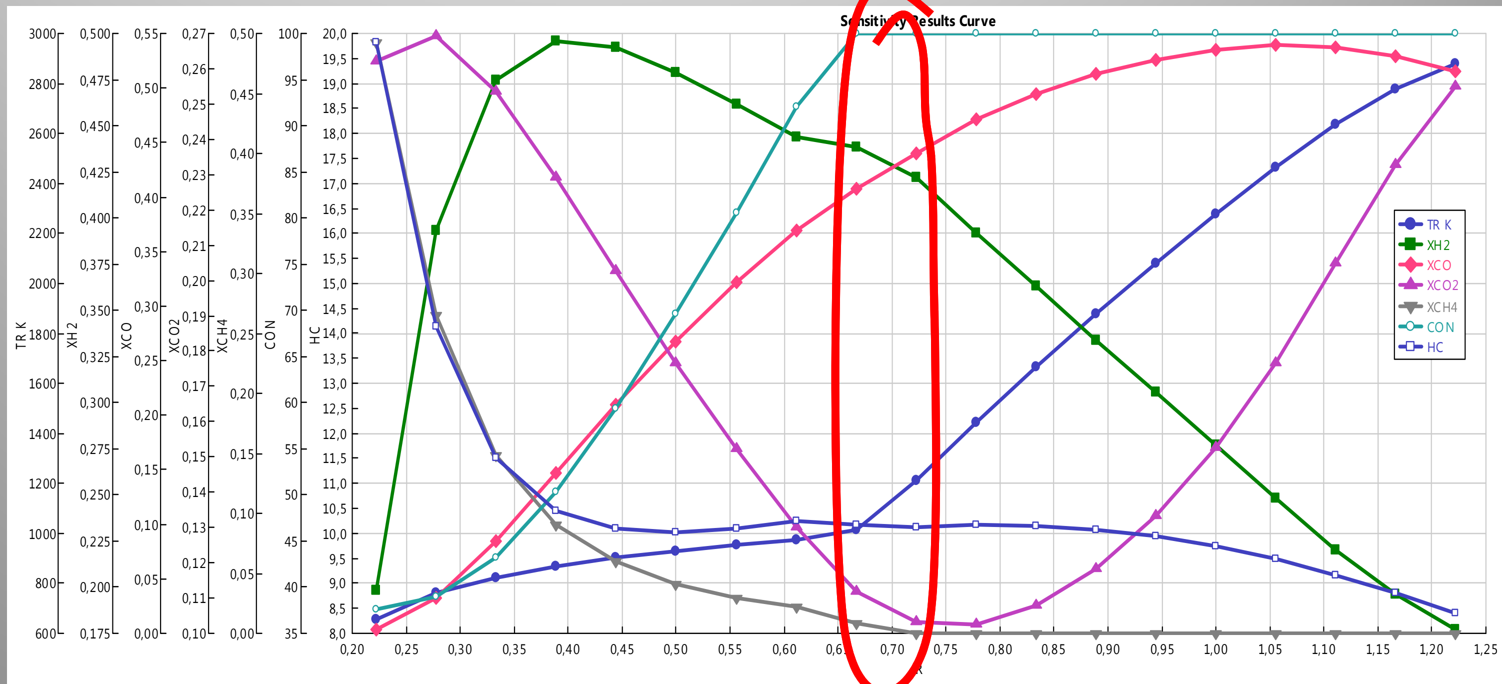


Effect of RDF composition

Com.	Wt. %
Mois	10
VM	75.5
FC	8.9
ASH	15.6
C	51.7
H	5.9
N	0.9
S	0.4
O	25.5



Com.	Wt. %
Mois	1.2
VM	80.22
FC	5.23
ASH	13.34
C	51.66
H	8.82
N	0.06
S	0.08
O	25.42



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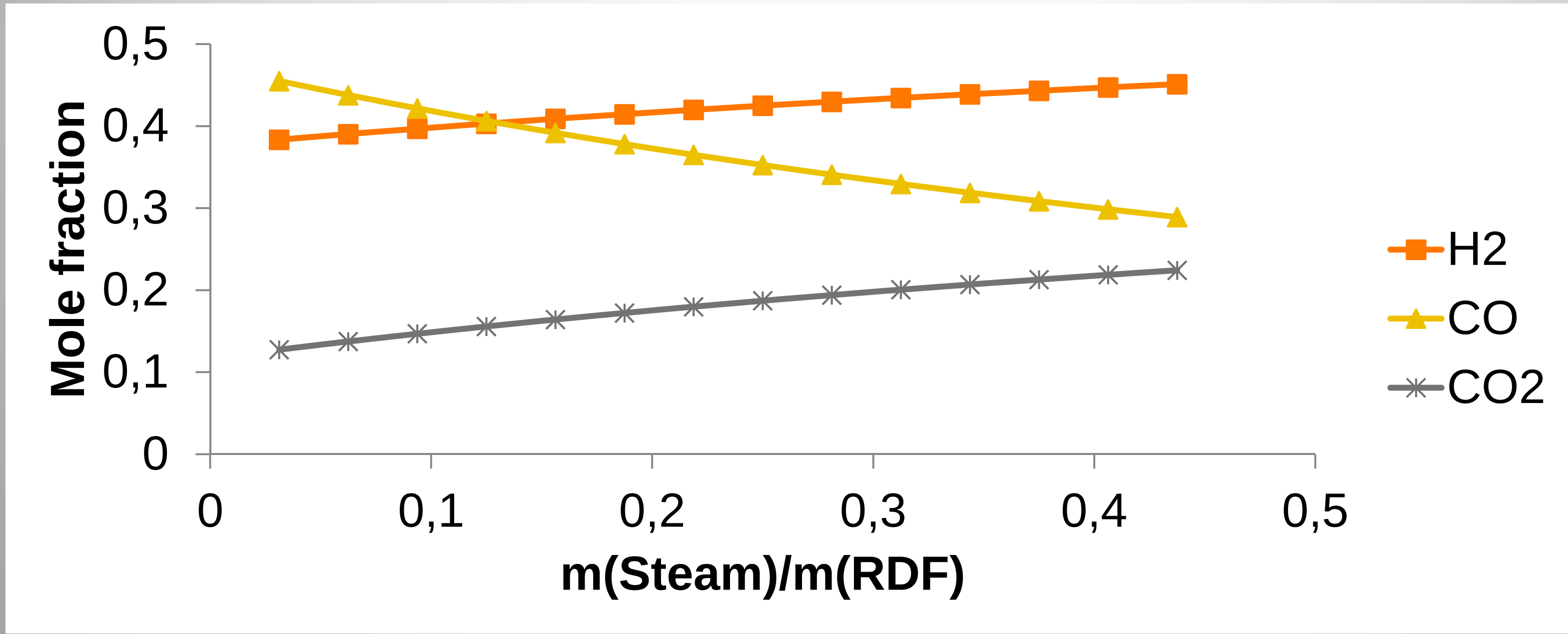
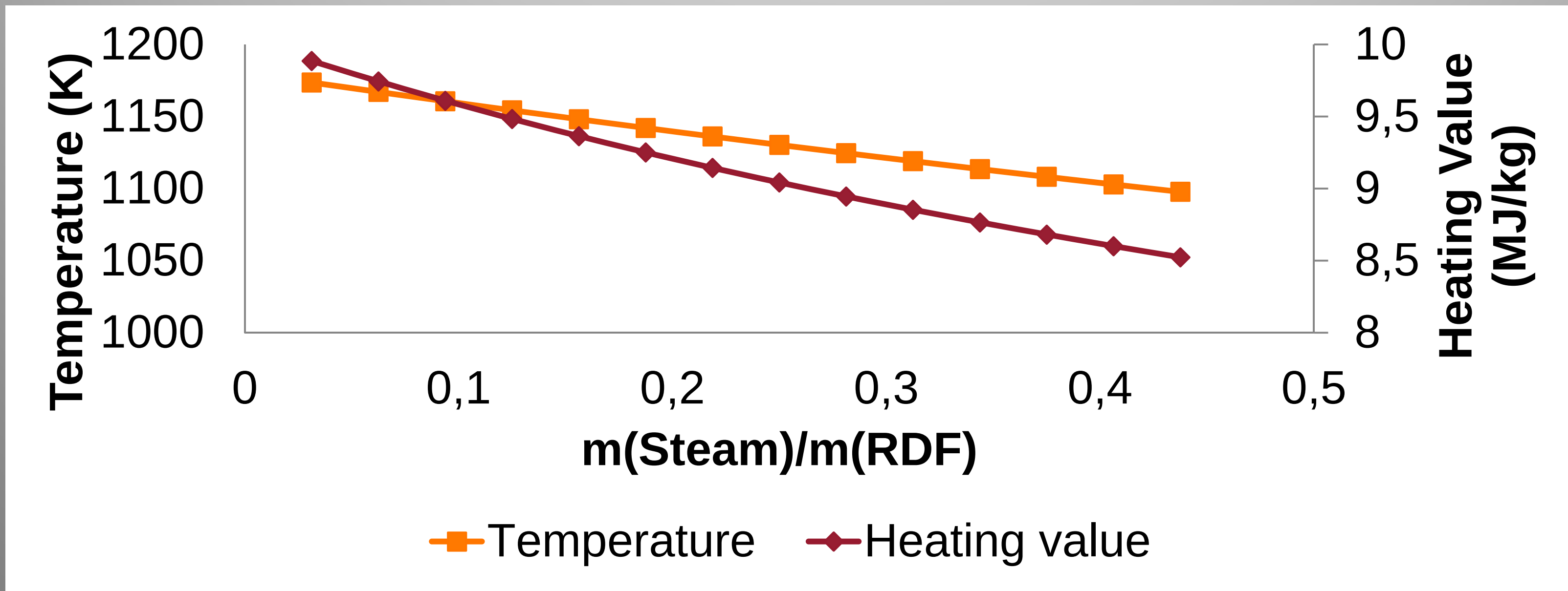
Effect of Steam in RDF Gasification





Conclusion

- For RDF studied in this work,100% of RDF conversion in **gasification by air** was reached at m_{air}/m_{RDF}=2,2. However, the gas heating value was 4,4 MJ/Nm^3
- Gasification of RDF using **Oxygen** enables production of a gas with heating value around 10 MJ/Nm^3 at m_{O2}/m_{RDF}=0,45
- Elemental Composition of RDF has a crutial effect on riquired m_{air}/m_{RDF}
- Raw untreated gas tar content was 3.3 mass %; tar fraction content a solid phase insoluble in isopropanol
- By increasing the m_{steam}/m_{RDF} the content of H2 and CO_2 increased, However, the content of CO, reactor temperature and gas heating vale decreased

Thank you for attention

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