Thermochemical Recycling of Municipal Solid Waste

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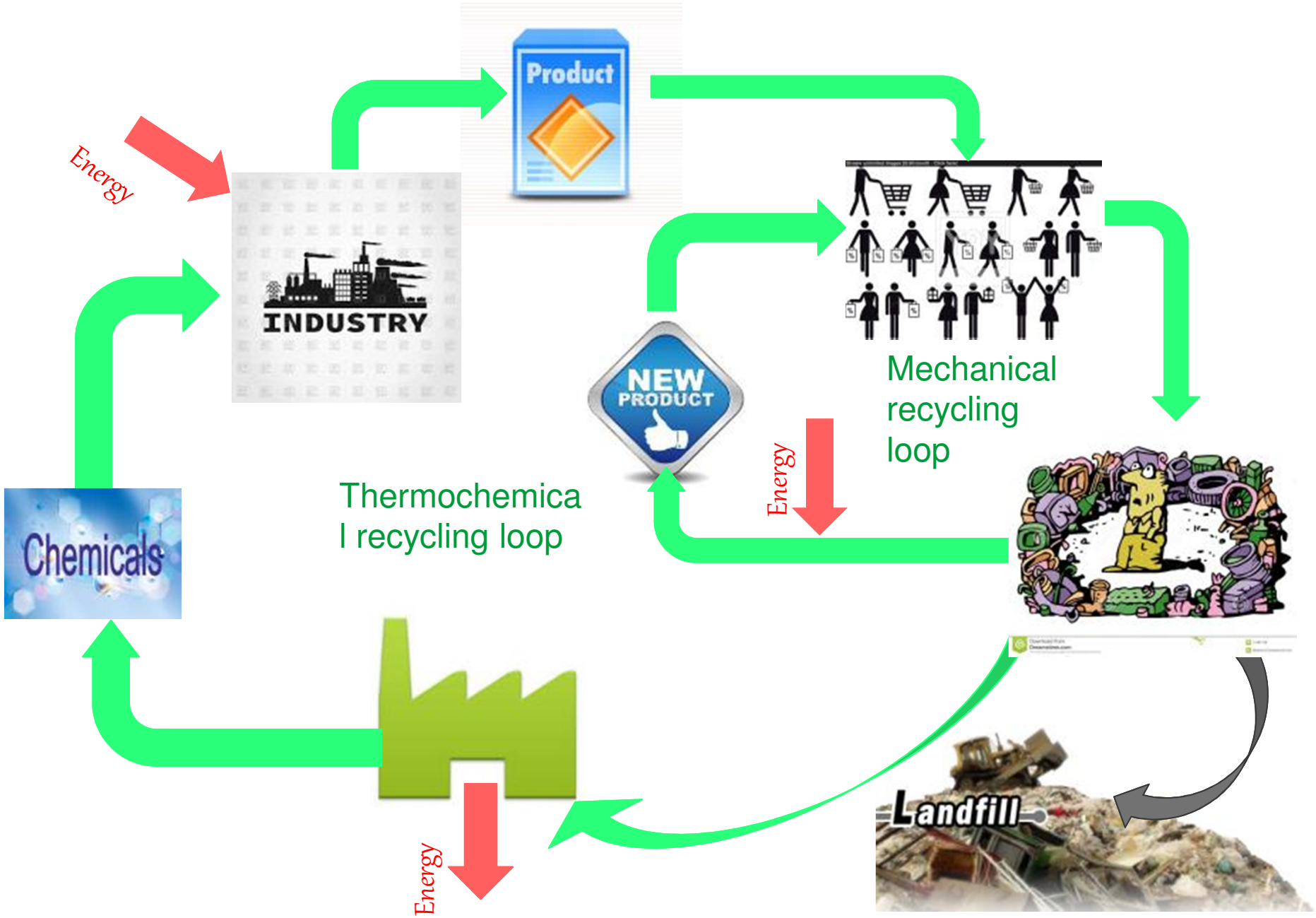
Cyprus 2016

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



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Refuse-Derived Fuel (RDF)

- Biodegradables
- Metals
- Inorganics
- Hazardous wastes

RDF composition

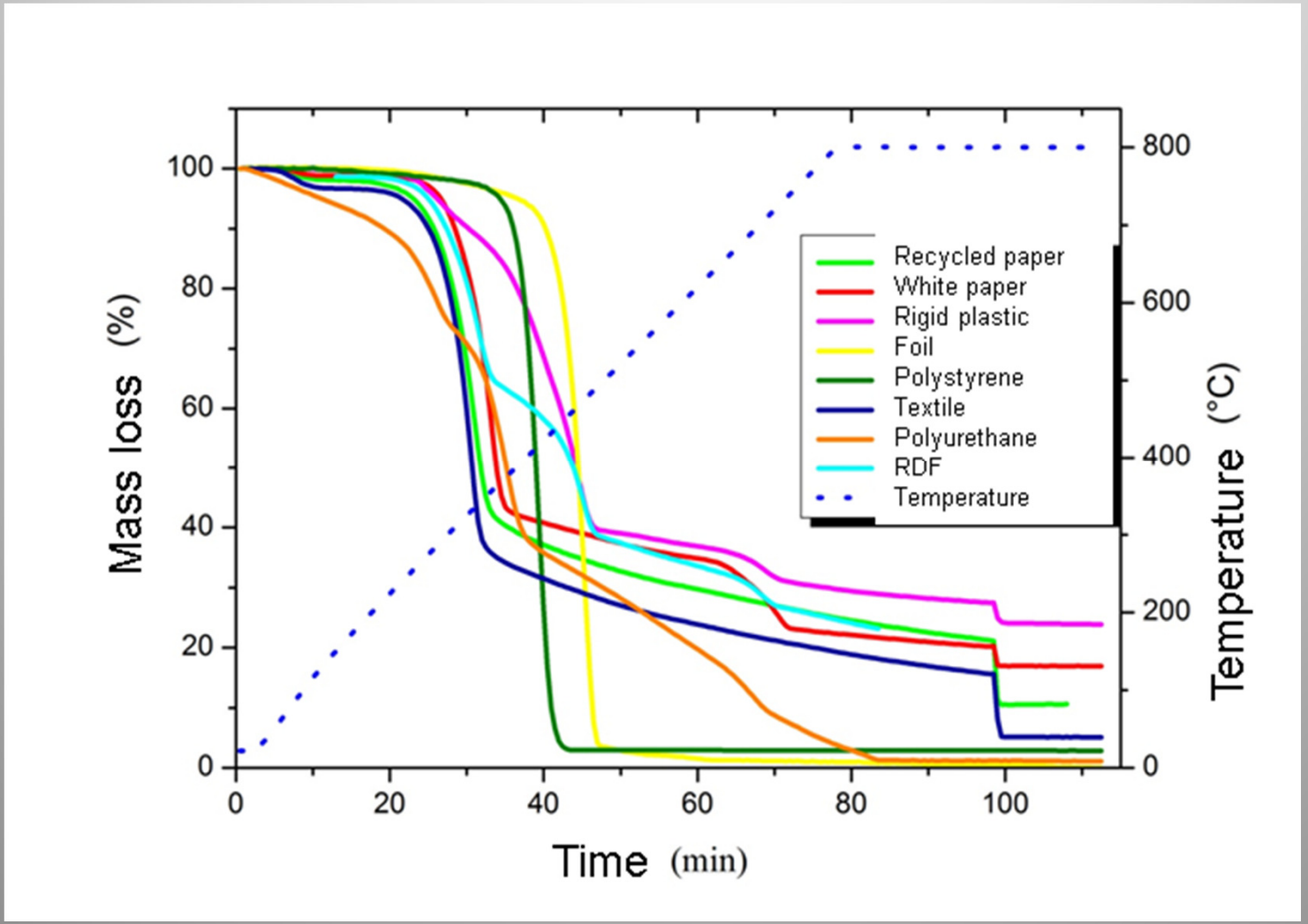
Component	Material	w_i [kg/kg]
Paper	White paper, recycled paper	0,6317
Foil	LDPE, HDPE	0,1578
Plastics	Rigid plastics, polystyrene, polyurethane	0,1910
Textile	Polyamide, polyester, cotton , wool	0,0194

Proximate and Elemental Composition of RDF

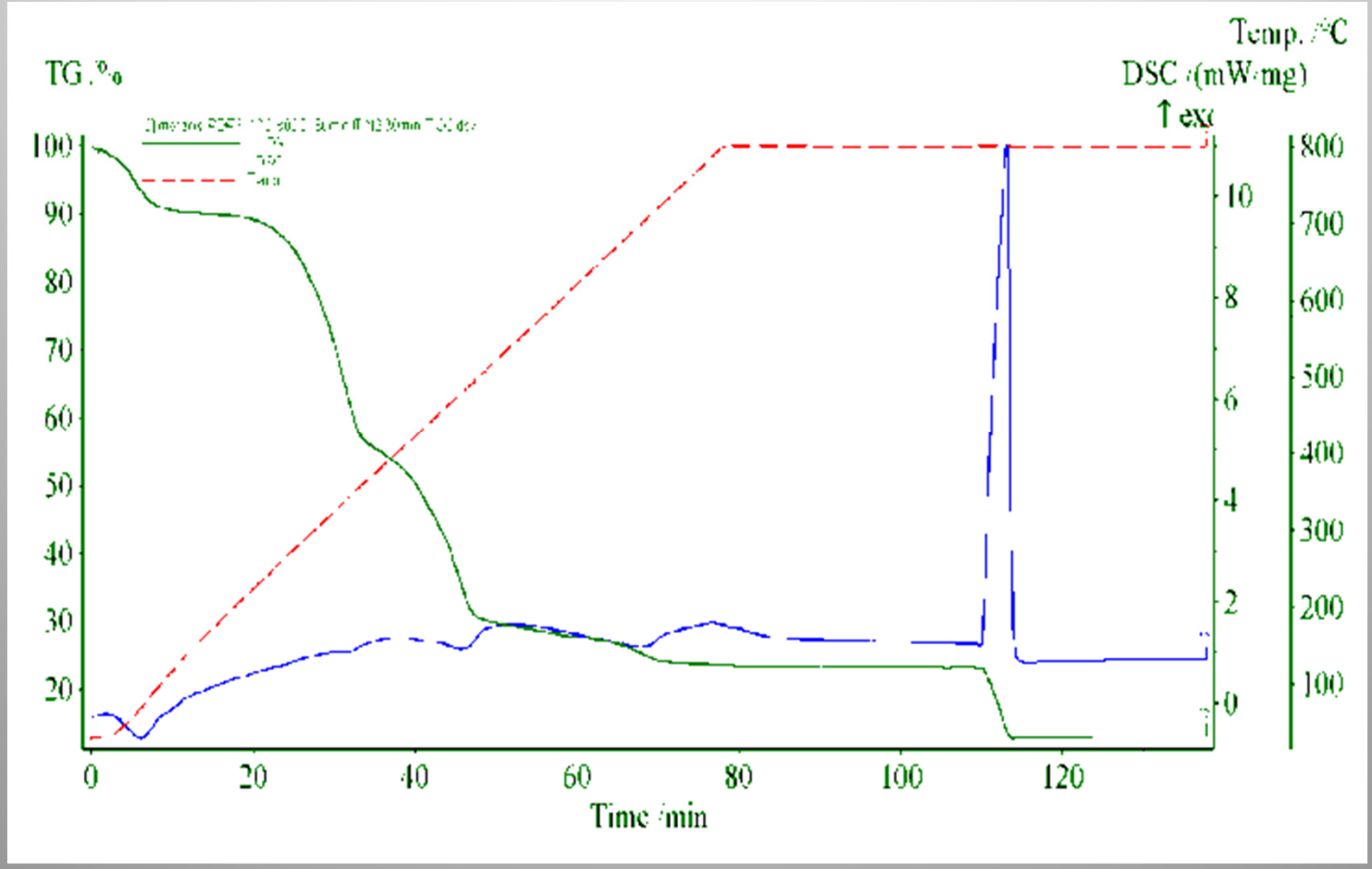
Com.	Mois.	VM*	FC*	ASH*	C	H	N	S	O**
Wt. %	10	75.5	8.9	15.6	51.7	5.9	0.9	0.4	25.5

*moisture free basis
**calculated to 100%

Behaviour of Thermal decomposition



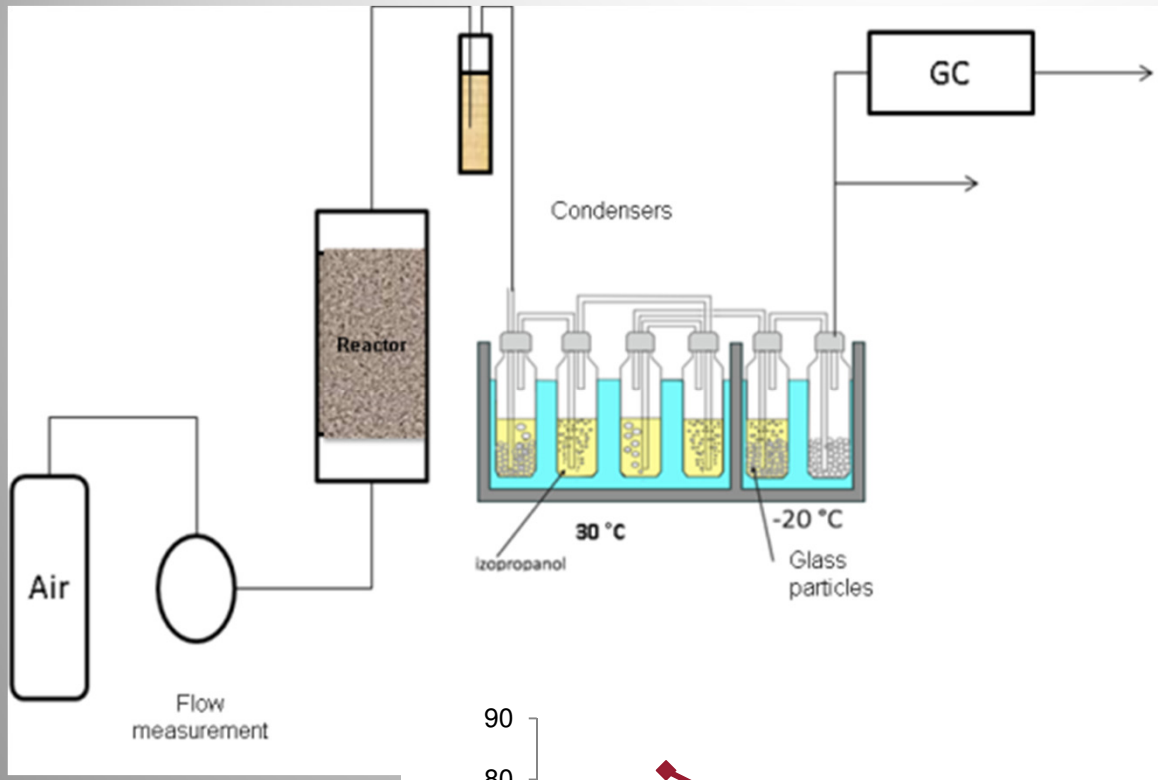
Behaviour of Thermal decomposition

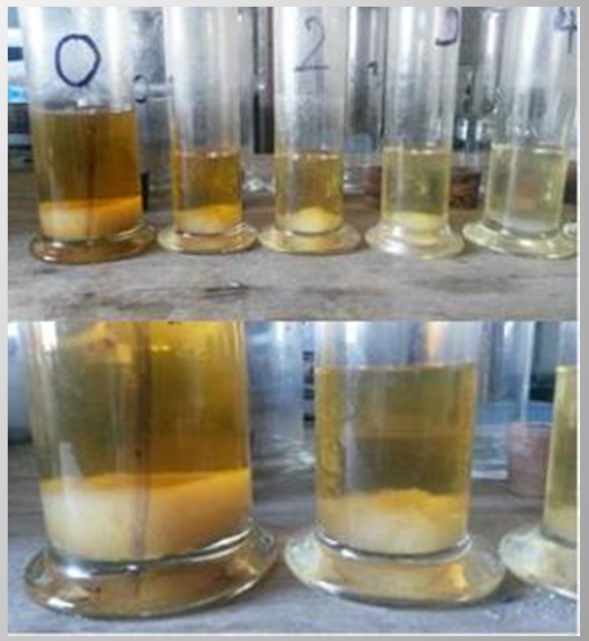


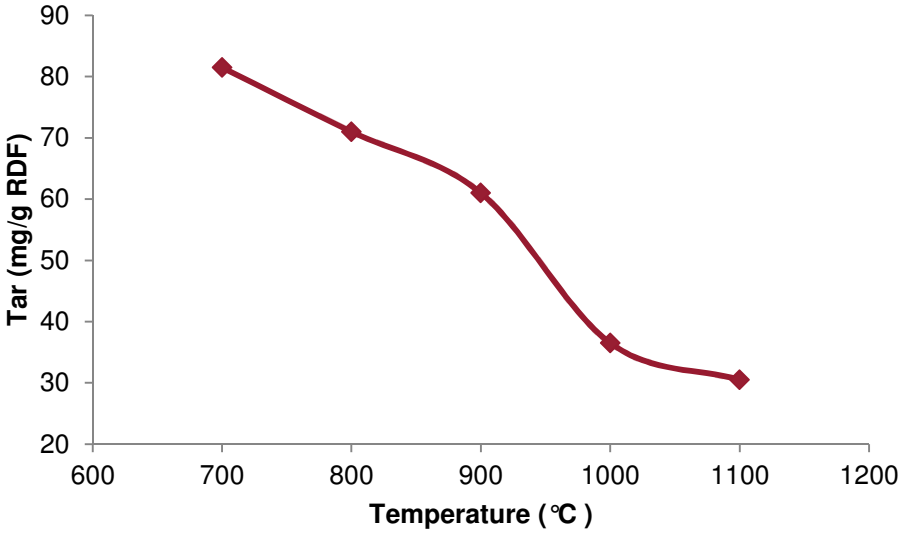
Heating value of RDF

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

Tar content measurement







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-1K^{-1}]

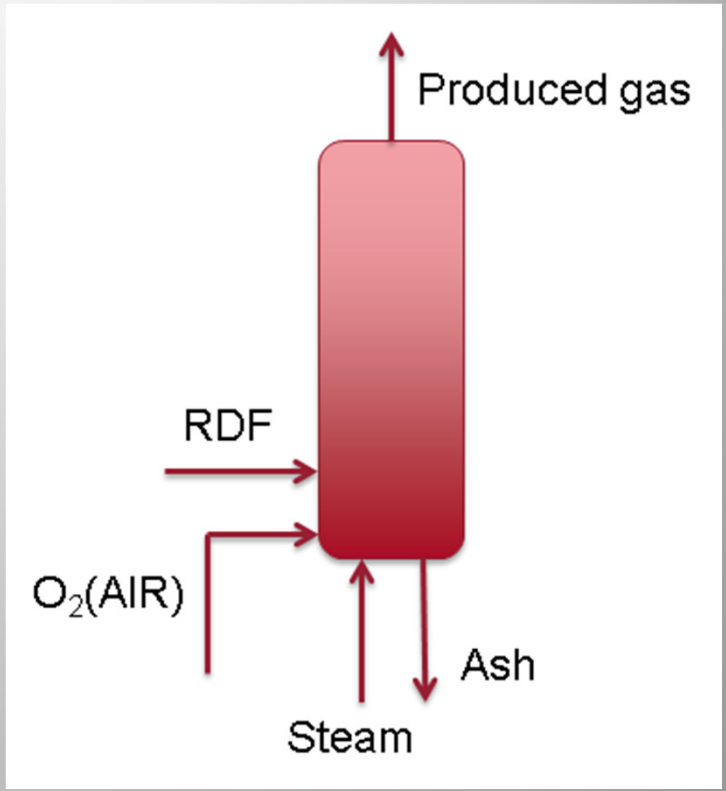
Results of modelling RDF gasification

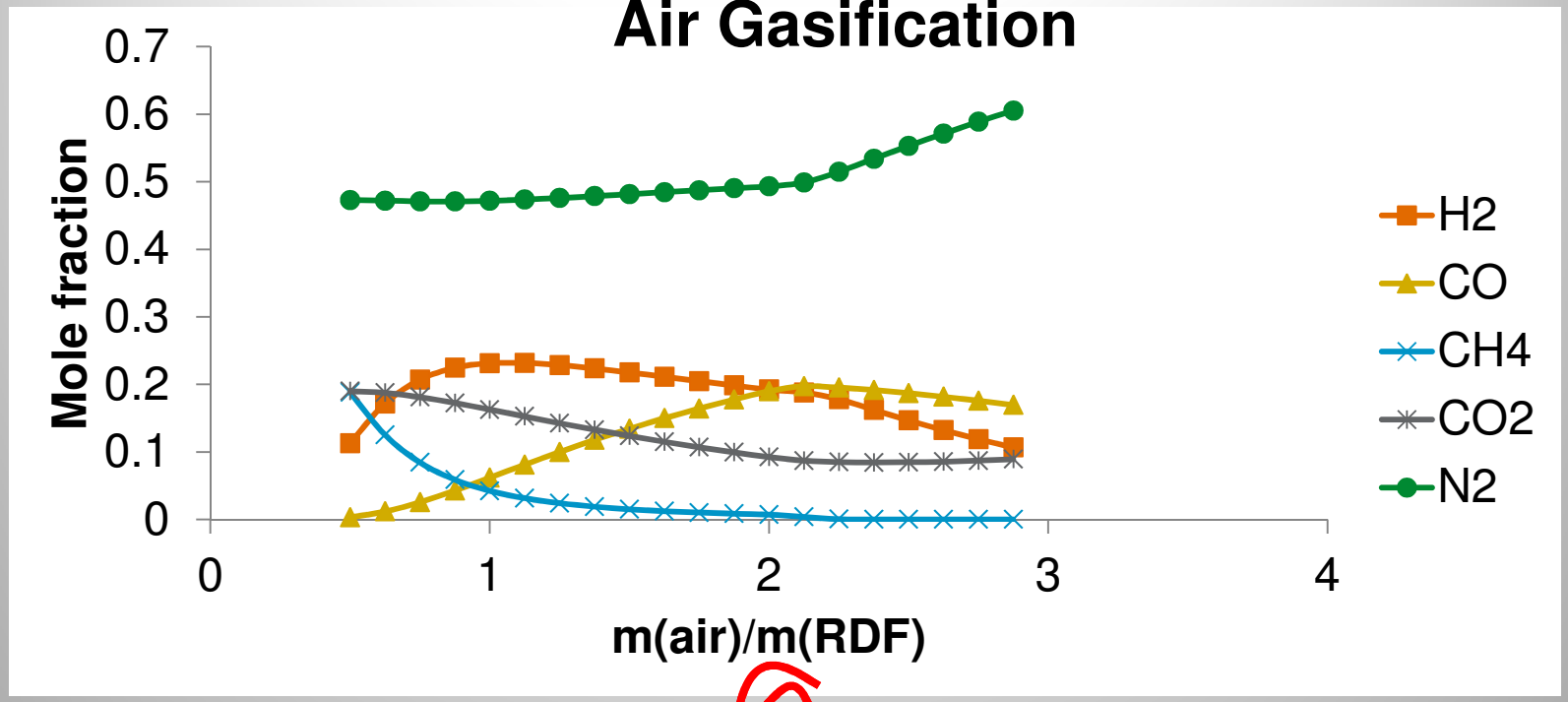
Observed parameters:

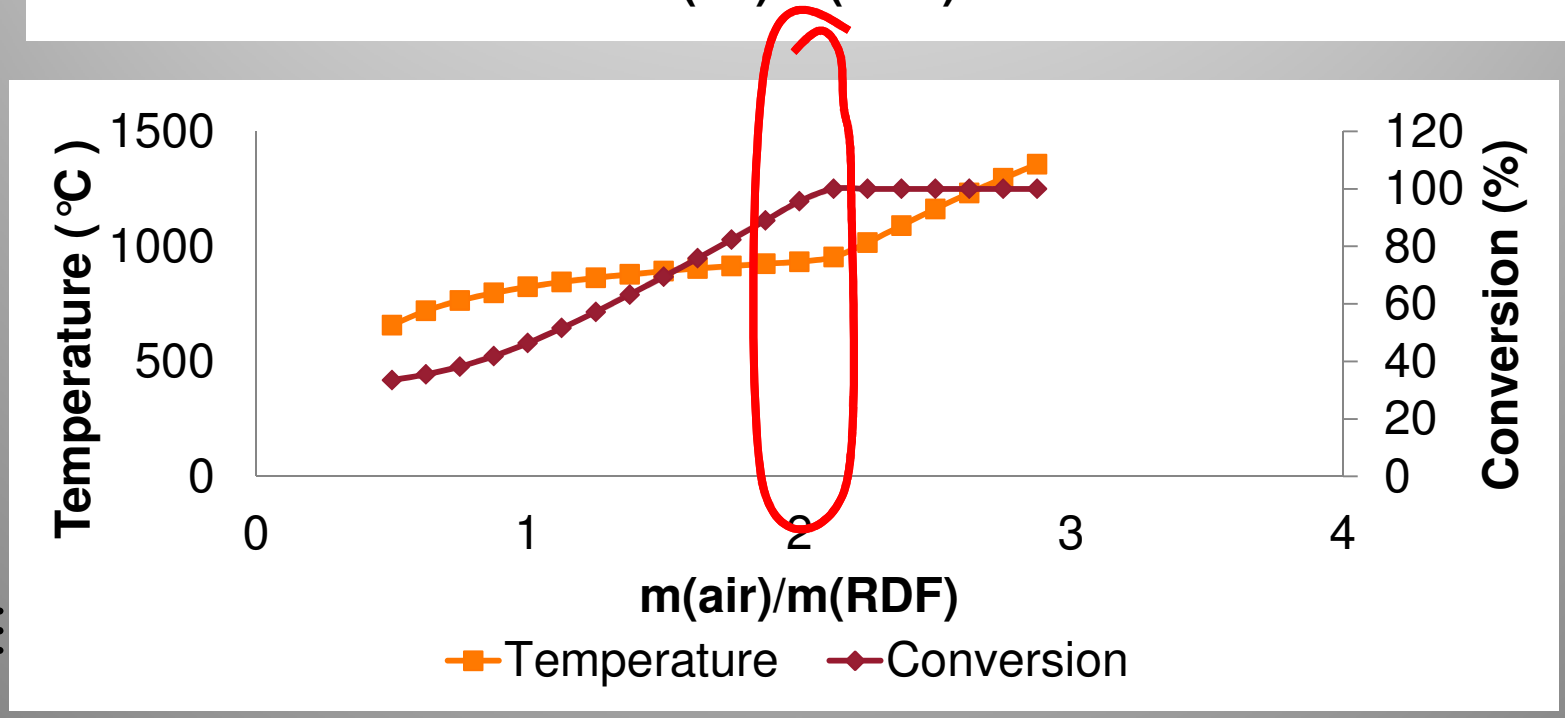
Conversion of RDF
Reactor Temperature
Gas composition
Content of pollutants (NH3, H2S, TAR)

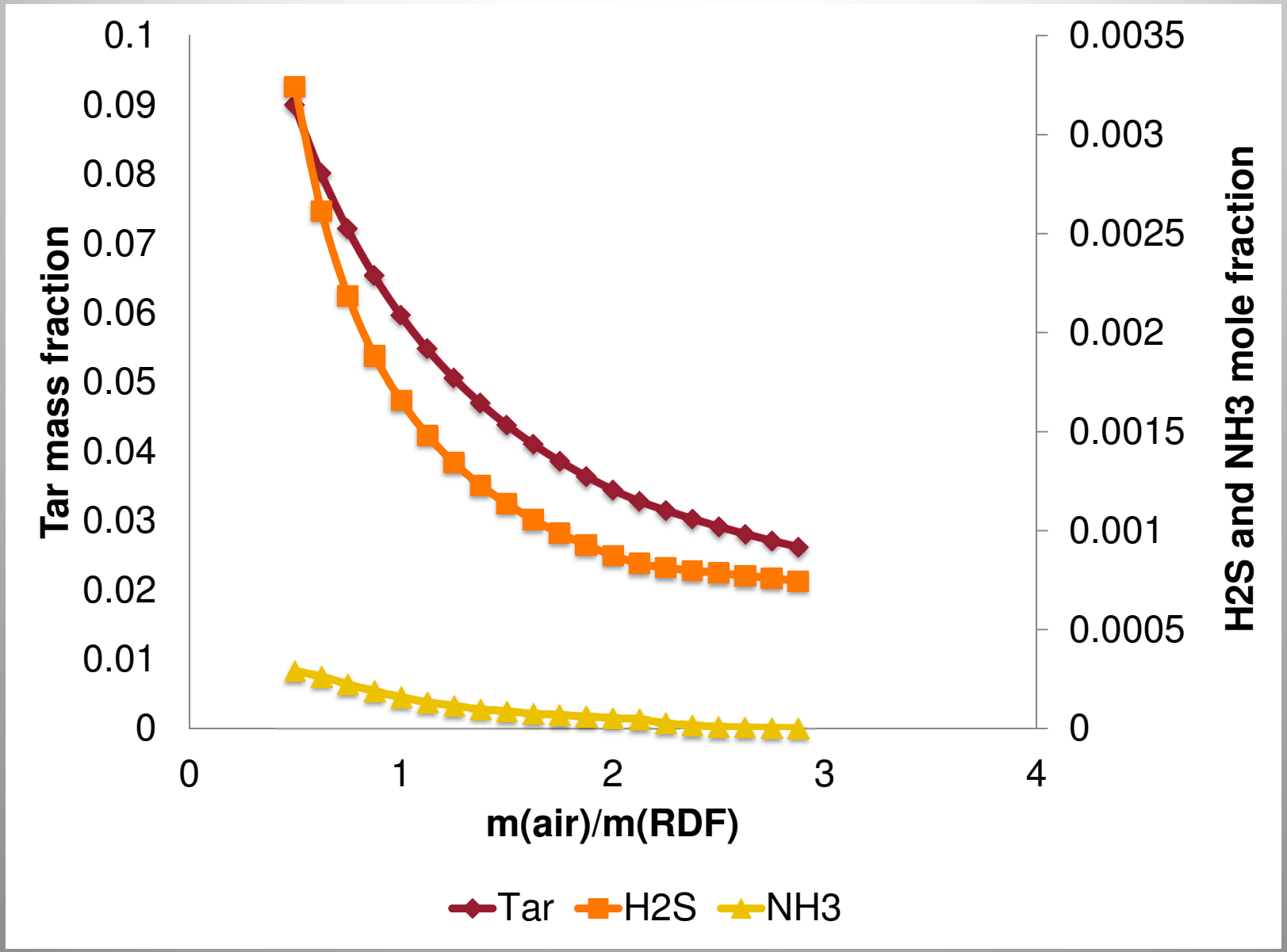
Variables:

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

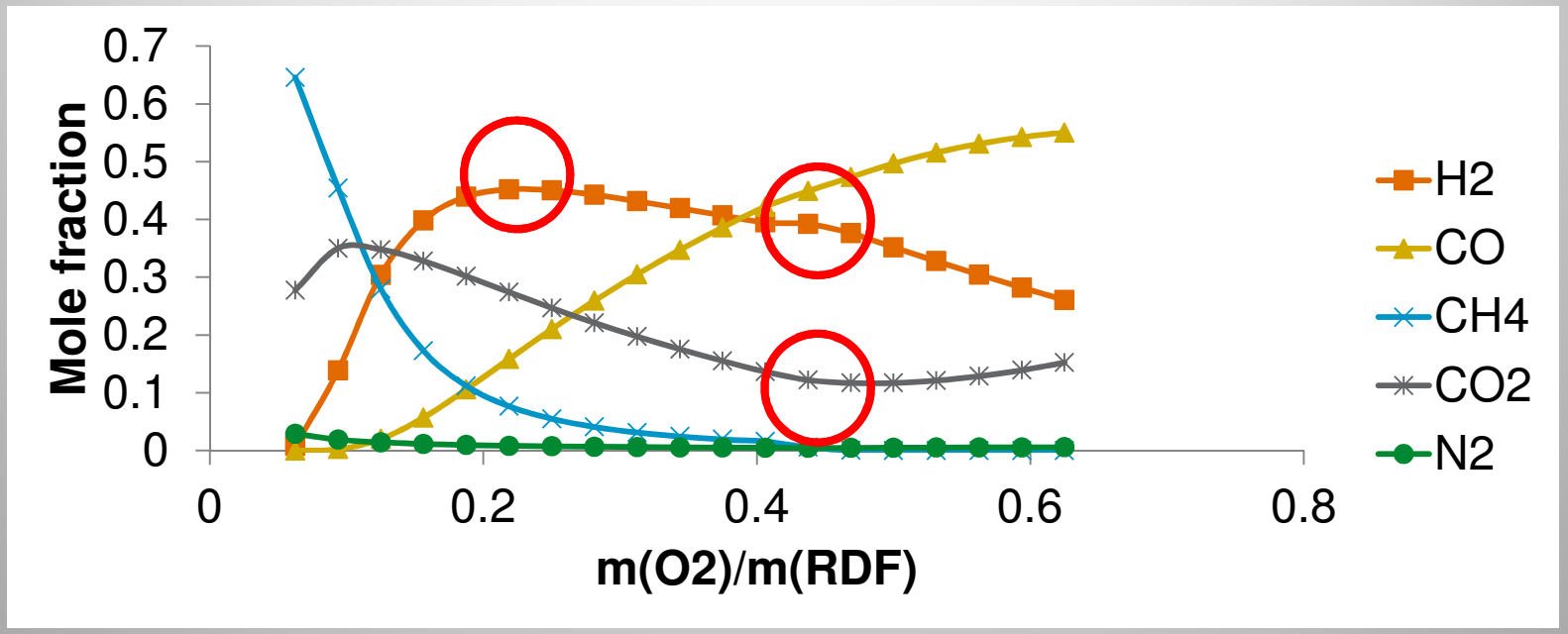


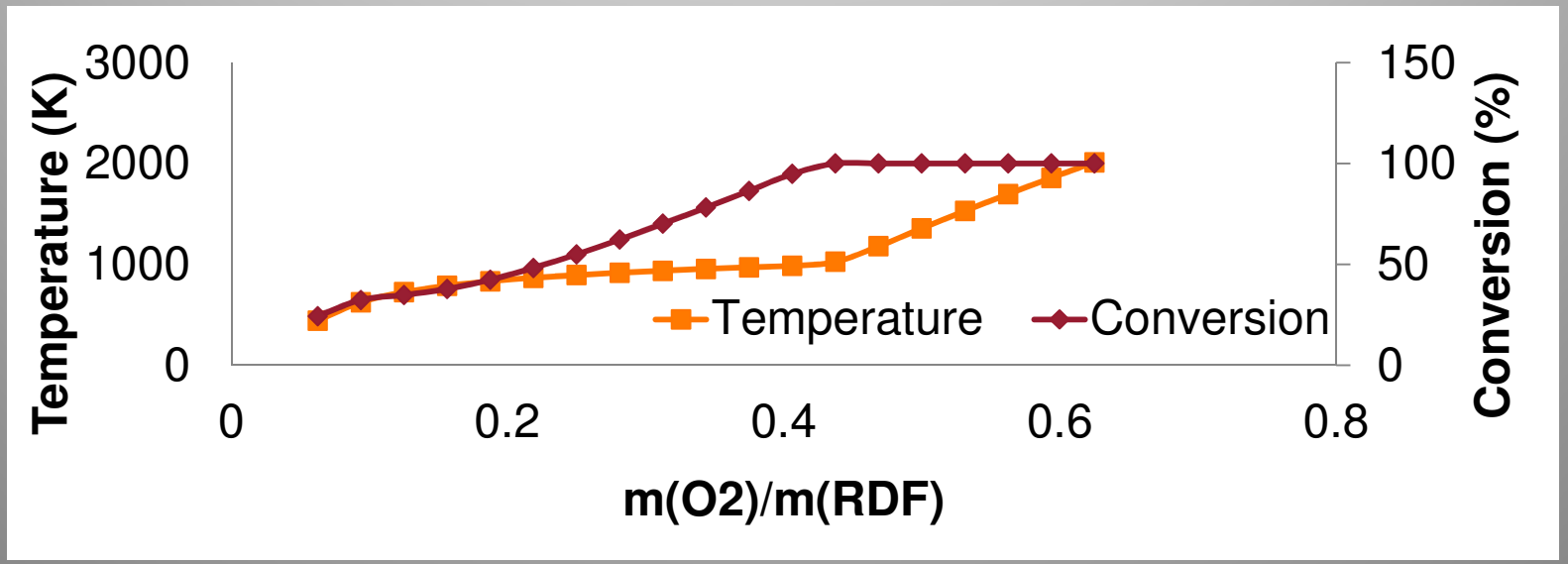

Air Gasification
Mole fraction
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
m(air)/m(RDF)
H2
CO
CH4
CO2
N2


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

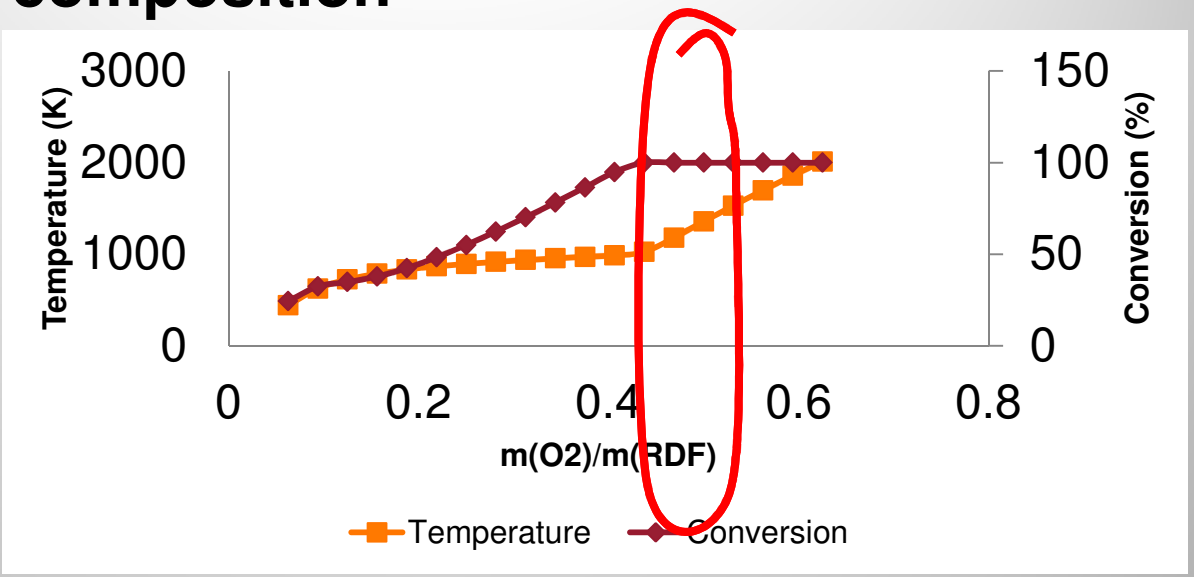
Gasification of RDF Using O_2



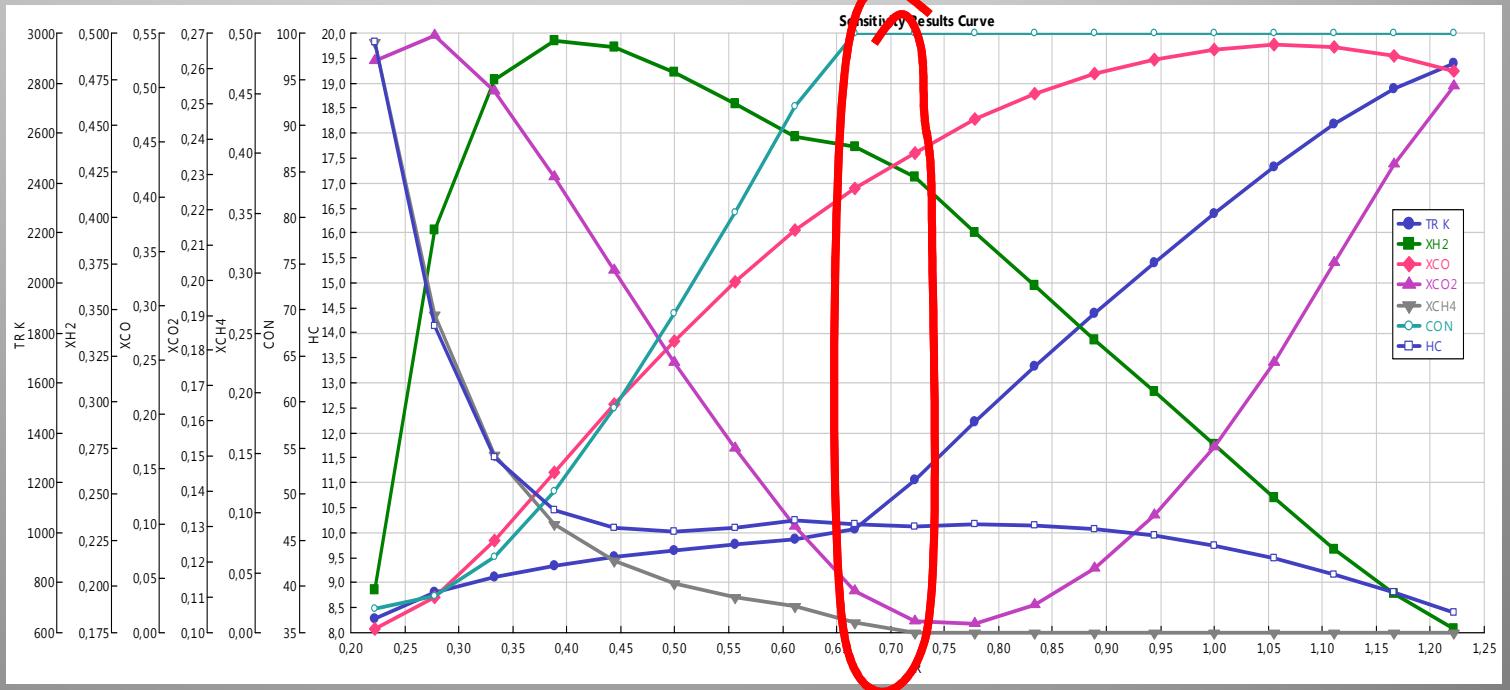


Effect of RDF composition

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



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



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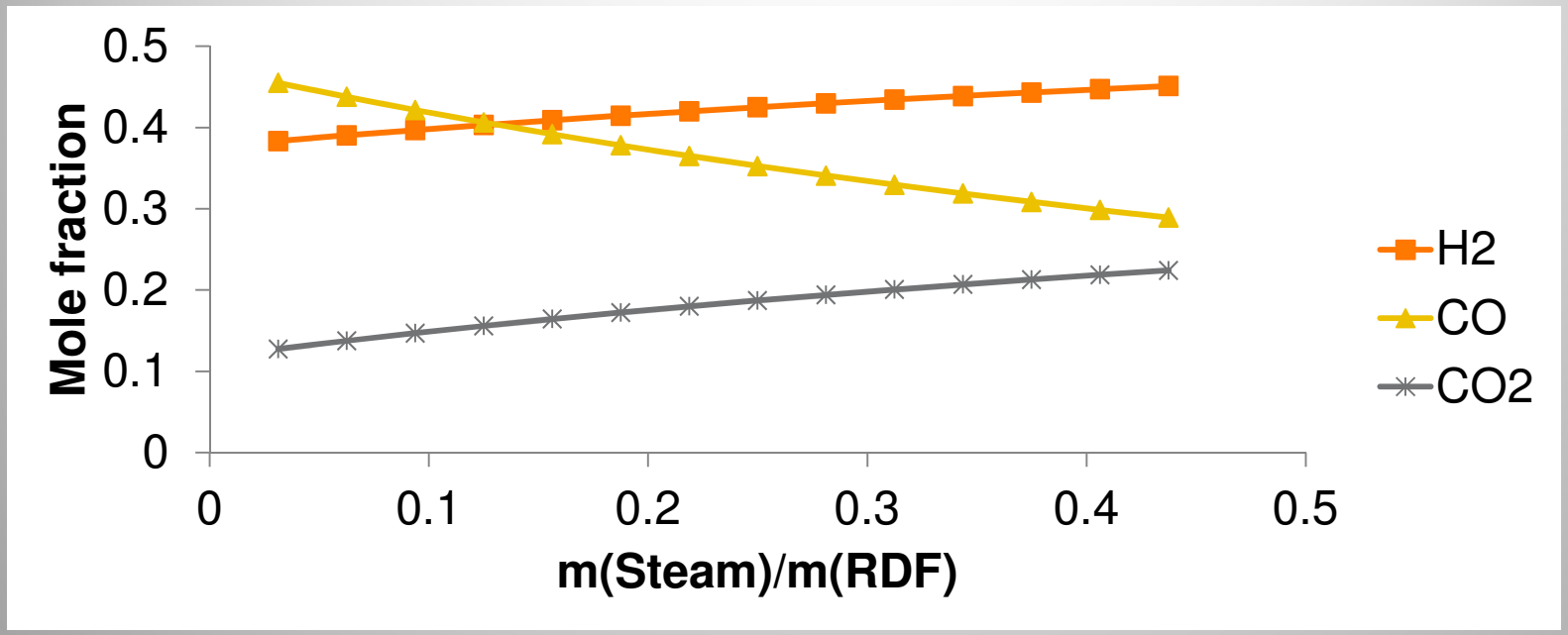
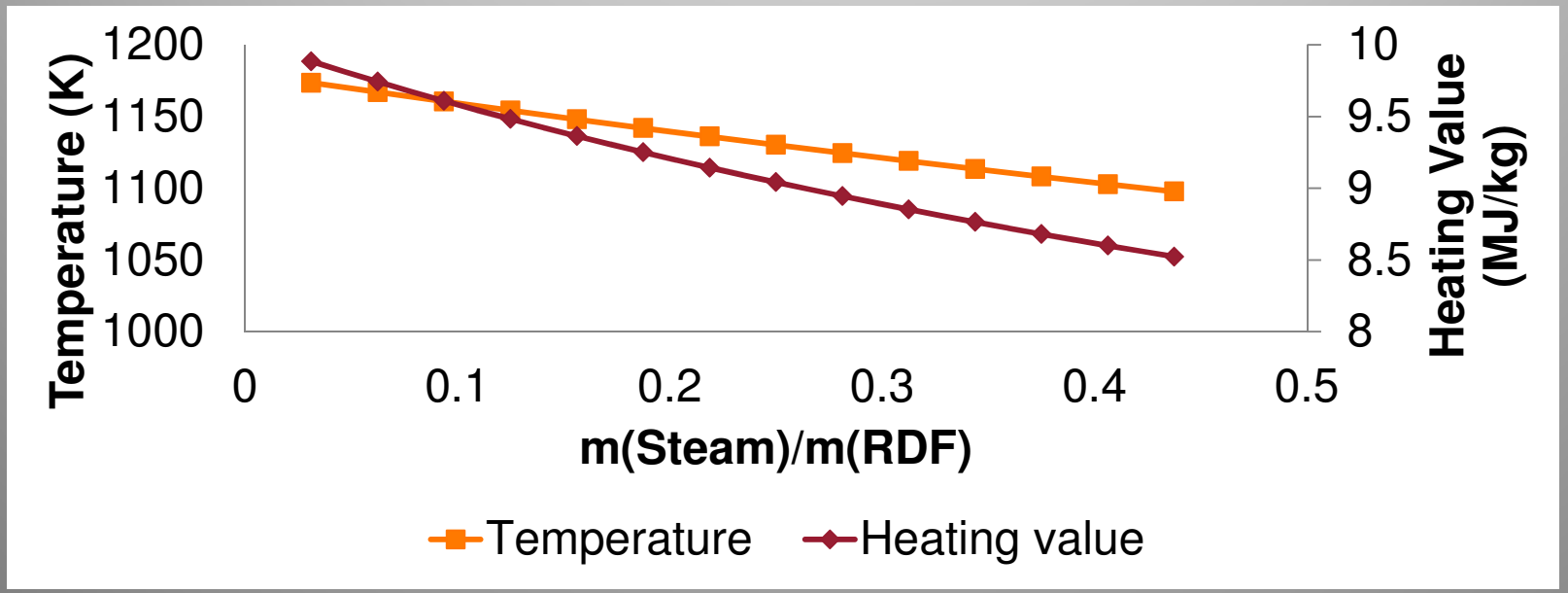
Effect of Steam in RDF Gasification





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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