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FUEL CONVERSION IN FLUIDIZED DUAL-REACTOR SYSTEMS

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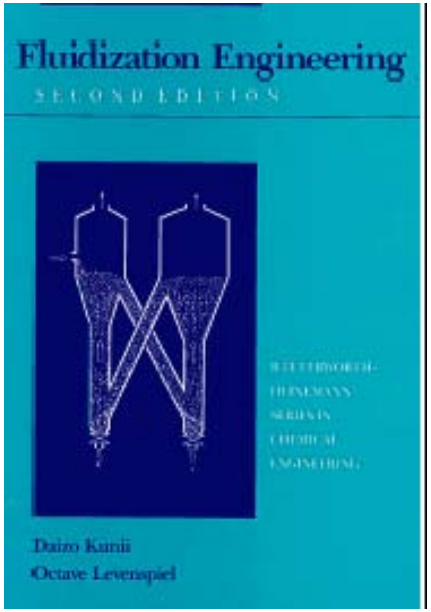
THIS PRESENTATION WILL GIVE EXAMPLES ON REACTORS AND MODELLING

REACTORS

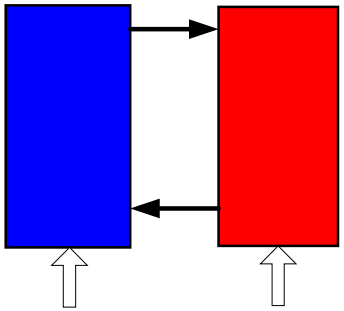
EXAMPLES OF
DUAL-REACTOR FUEL-CONVERSION SYSTEMS



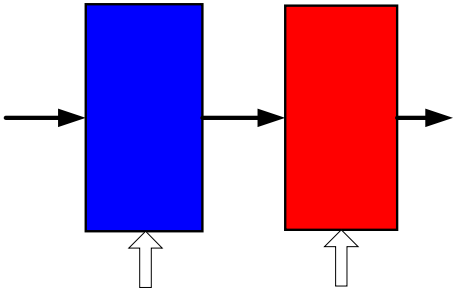
- Fluidized catalytic crackers
- Chemical looping conversion
- Pressurised FBC for coal conversion.
- Conversion of biomass to high-(medium) value gas.
- Pyrolysis-combustion plants for waste fuels.

ARRANGEMENTS: The coupled reactors could be

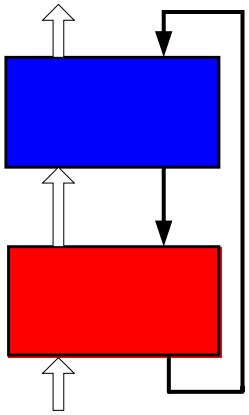
A. Circulating



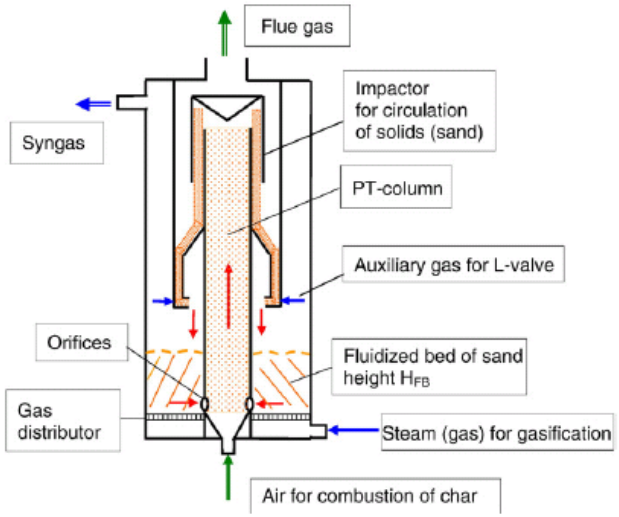
B. Sequential

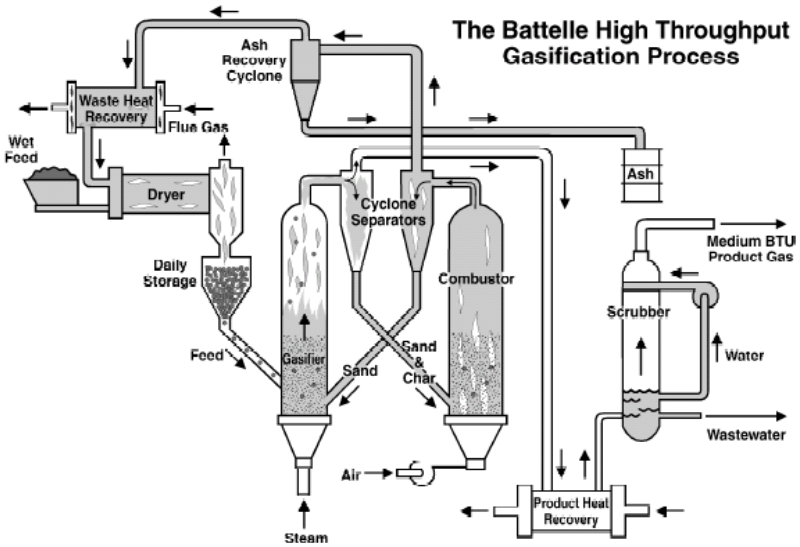


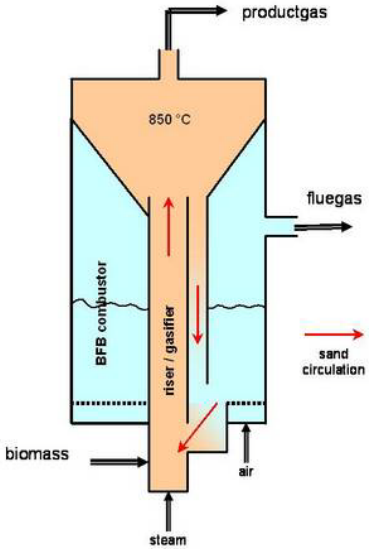
C. Gravitational

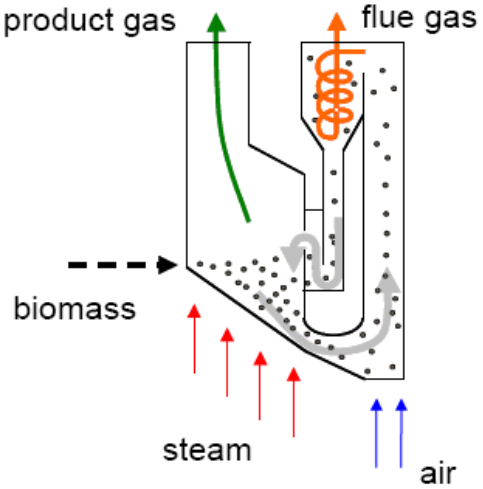


A. CIRCULATING SYSTEMS: VARIOUS PROPOSALS HAVE BEEN MADE FOR BIMASS GASIFICATION

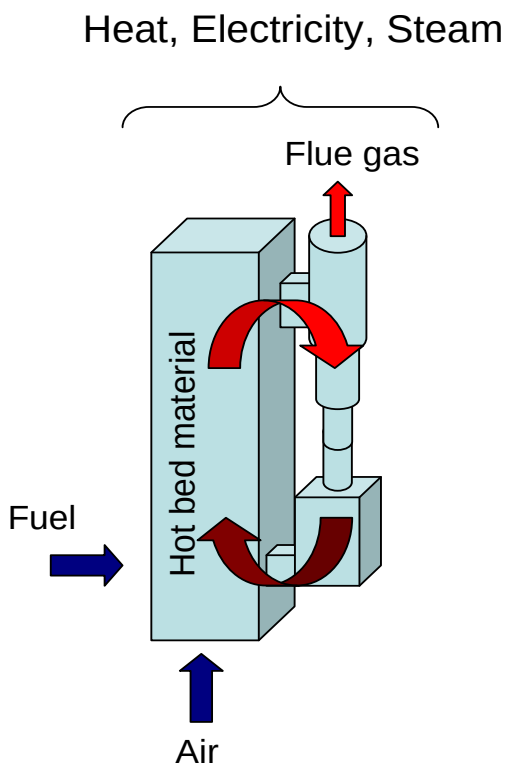


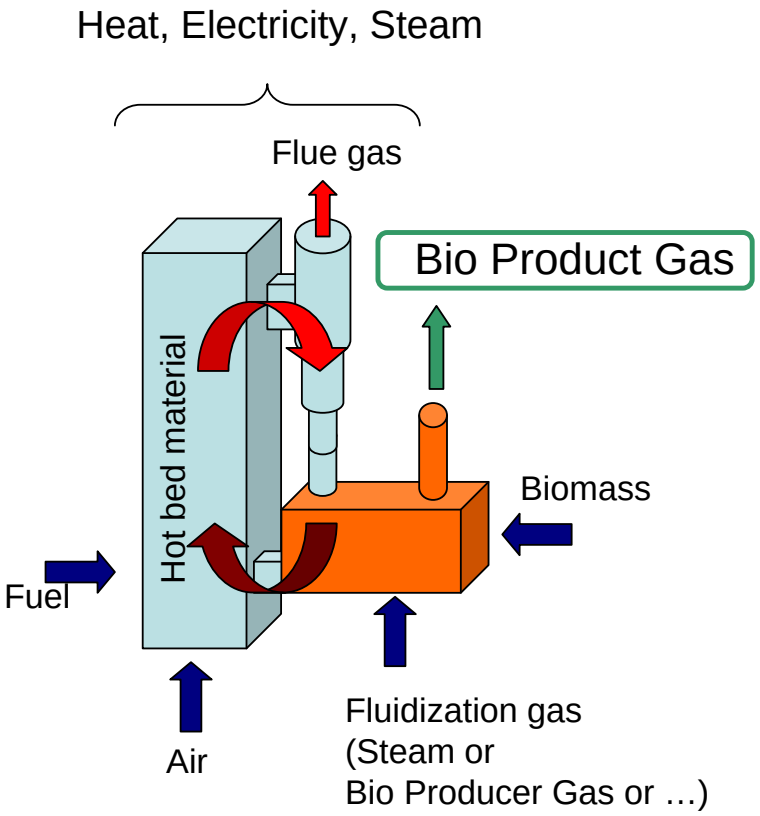




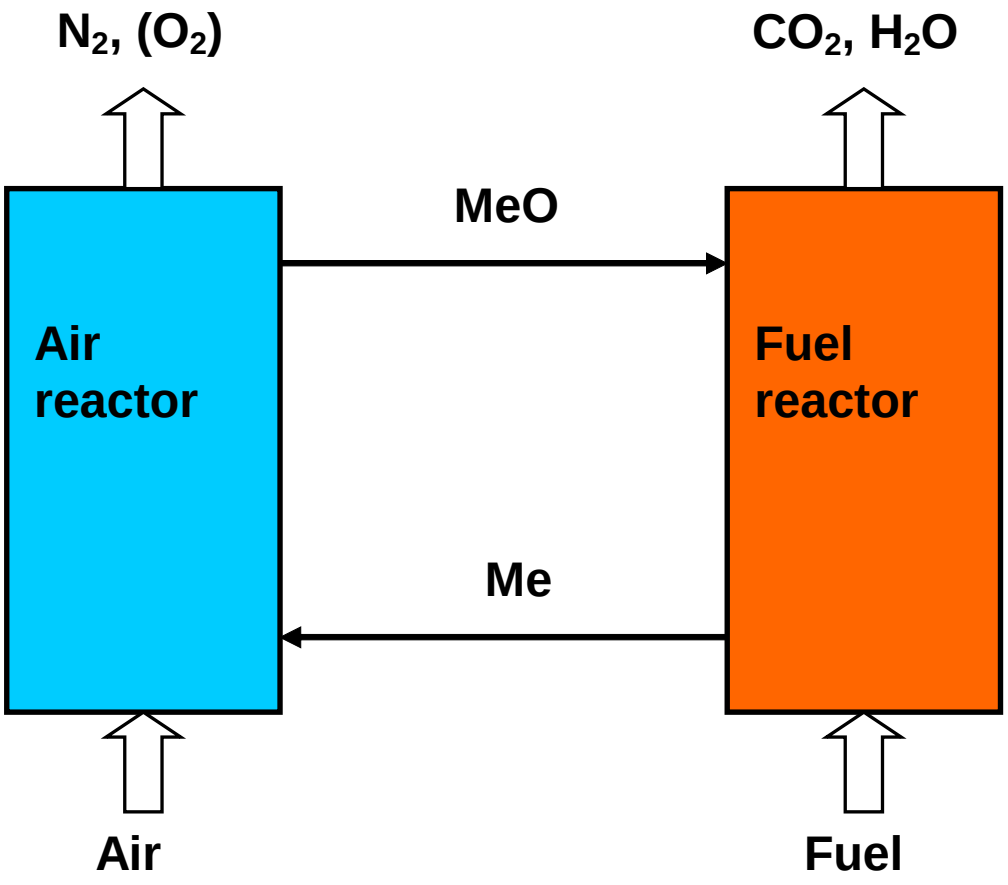


ADD-ON GASIFIER/CFB BOILER FOR BIOMASS GASIFICATION (The Chalmers unit [6])





Principle scheme: Chemical Looping Combustion (CLC)



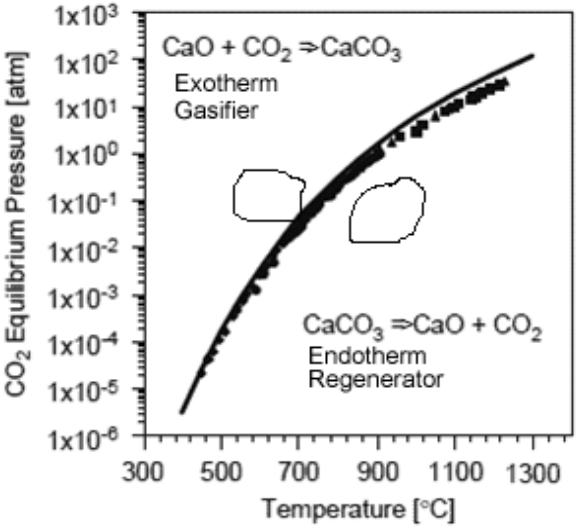
Particulate material and heat are brought from one reactor to the other

CLC WITH LIME FOR BIOMASS GASIFICATION [8]

Reactor 1:

$CaCO_3$+heat→CaO+CO_2

High-temperature combustion and calcination → CO_2 release



Reactor 2:

CaO+CO_2→$CaCO_3$+heat

Low-temperature gasification.

CO_2 is bound by CaO → H_2

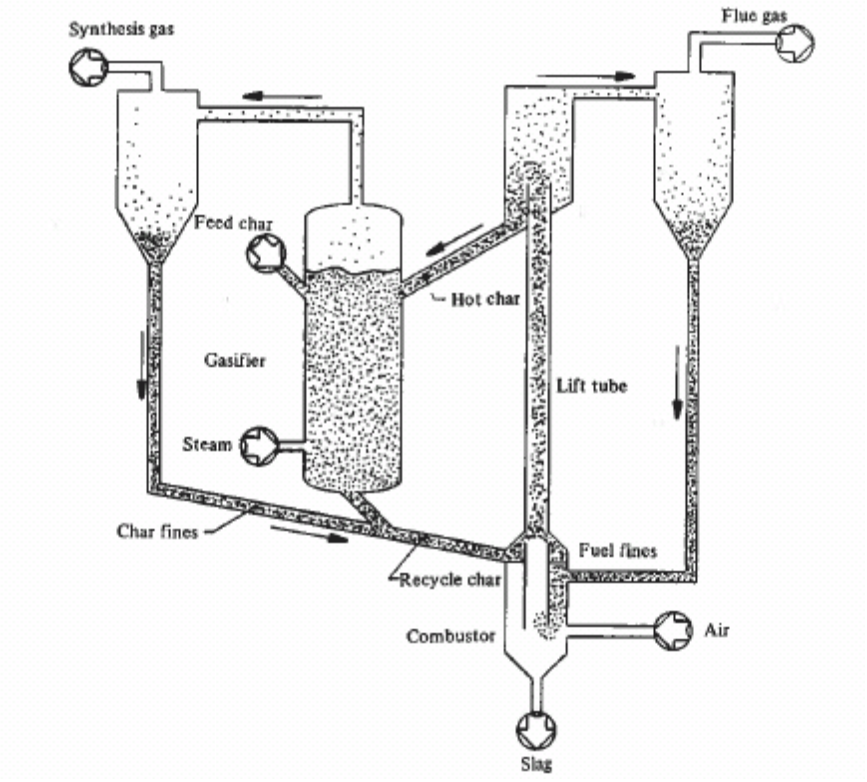
because the water-gas shift reaction is dominant in biomass gasification

$$CO+H_2O \Leftrightarrow CO_2+H_2$$

DEVELOPMENTS FOR COAL GASIFICATION

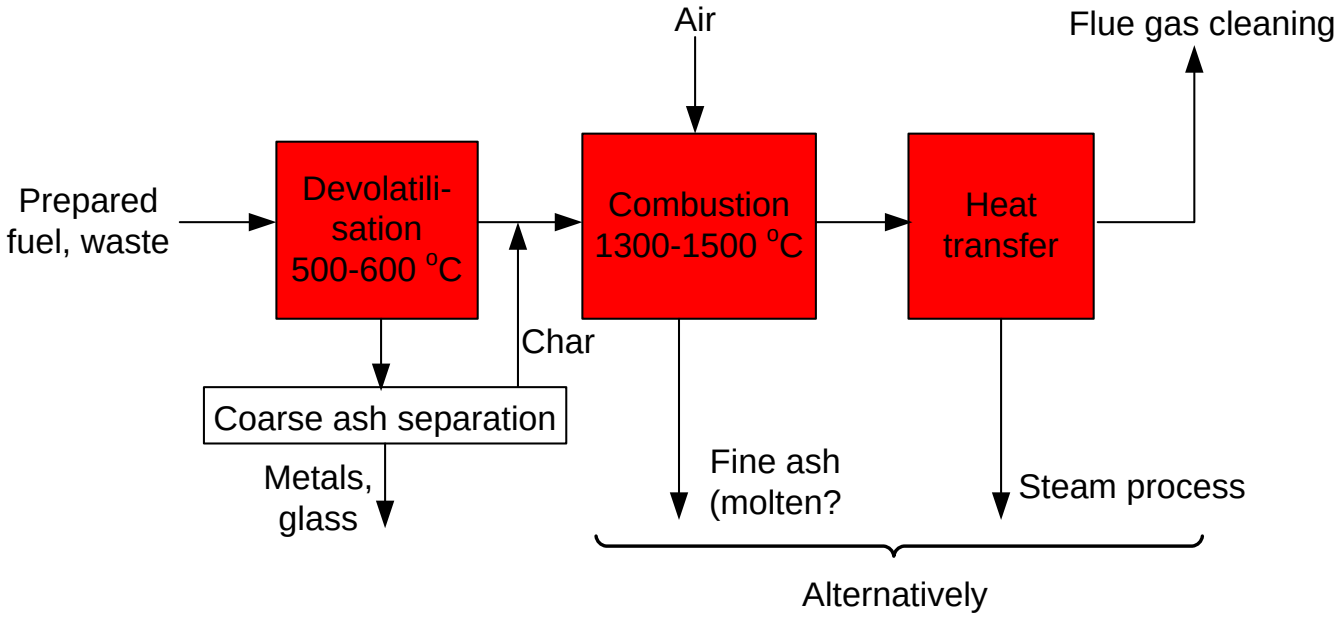
To improve conversion efficiency dual-reactor systems were proposed (for coal gasification in fluidised bed).

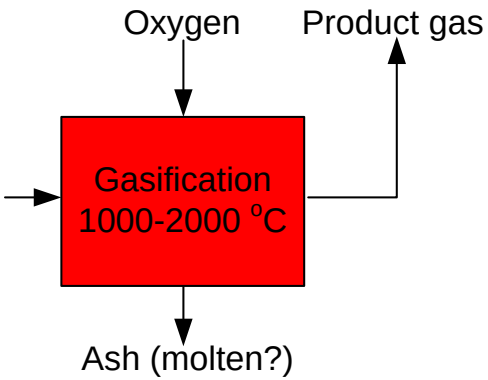
There were many proposals, for instance, the ”Cogas” gasifier (1974)



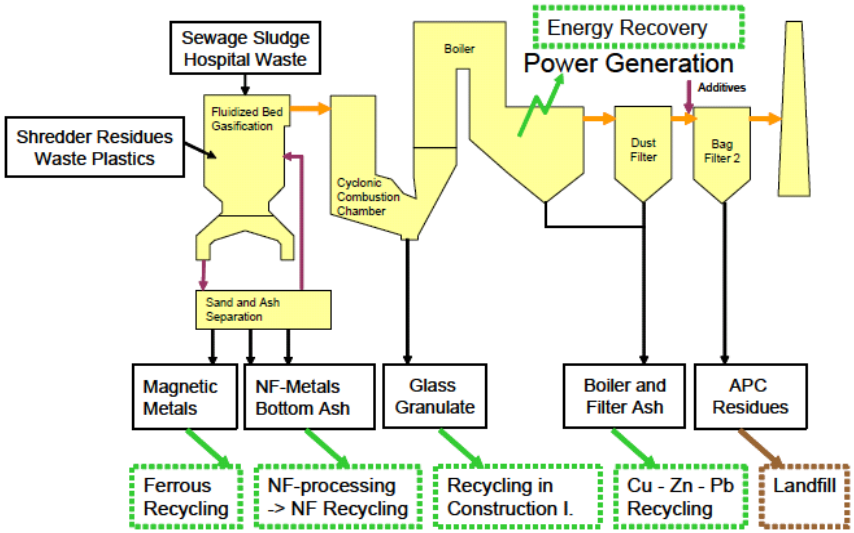
B. SEQUENTIAL REACTORS FOR WASTE CONVERSION

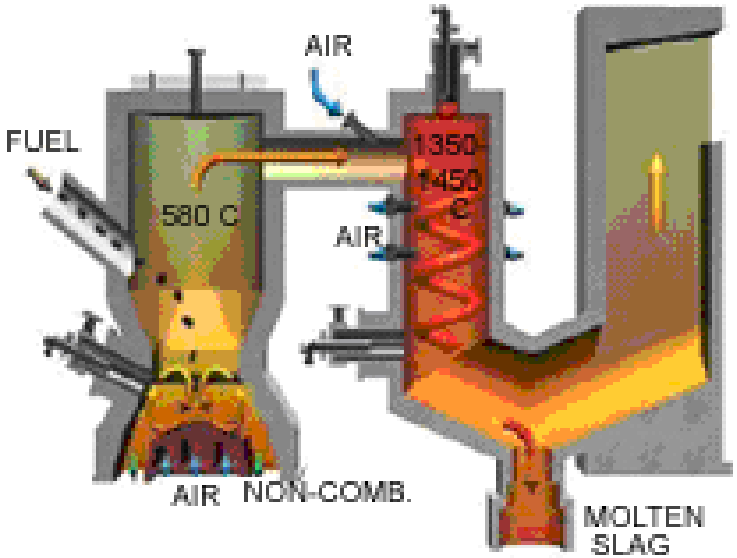
Many arrangements follow the general layout:



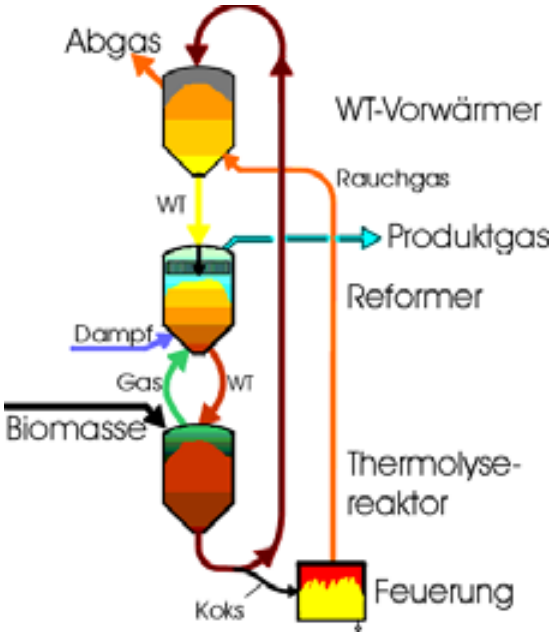


Example: WASTE COMBUSTION, EBARA

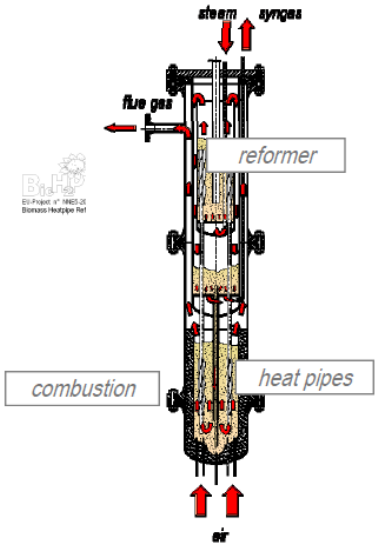




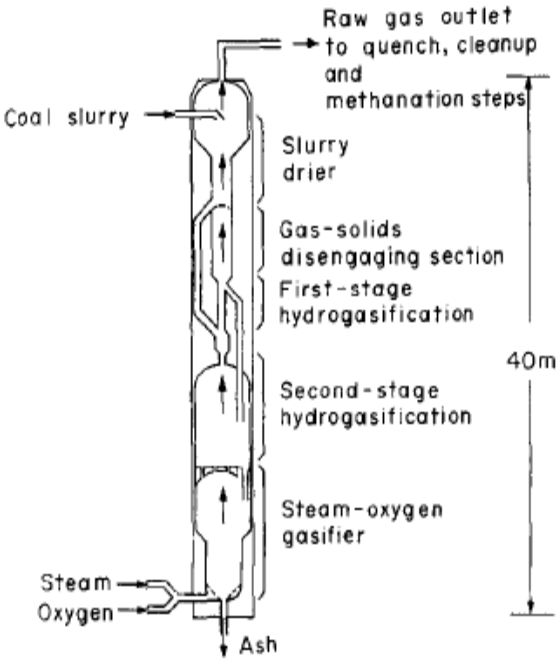
C. GRAVITY TYPE OF GAS GENERATORS



Blauer Turm, Muehlen



Biomass Heat pipe Reformer, J. Karl



Hydrogasification of coal for methane production 1974 IGT [9]

THE HEAT-PIPE REFORMER

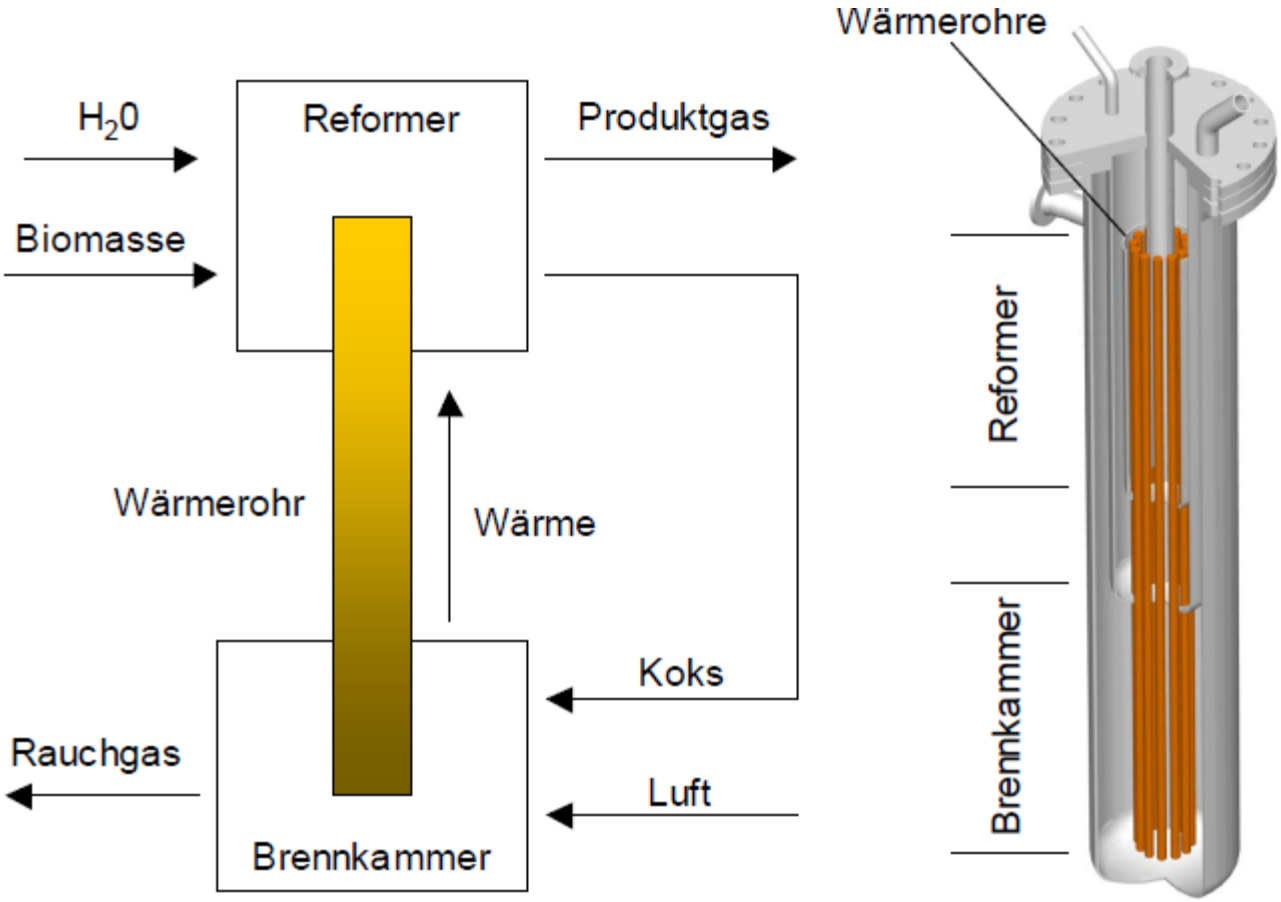


Abbildung 9: Schema des Heatpipe Reformers

CONCLUSIONS

Dual-reactor systems (recirculating or once-through) are proposed for many applications

Advantages

- High efficiency (high char conversion)
- High heating-value gas
- Opens up possibilities in waste conversion, CO_2 removal, H_2 production

Drawbacks

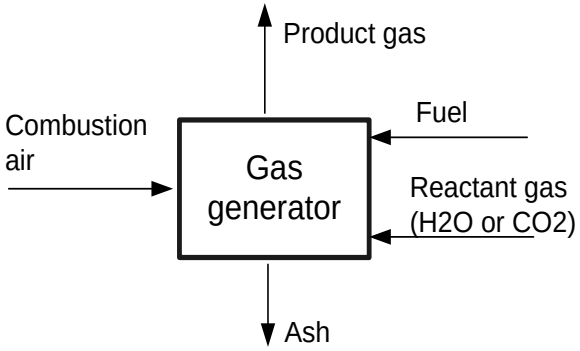
- Increased complexity
- Not well developed so far, although known for a long time

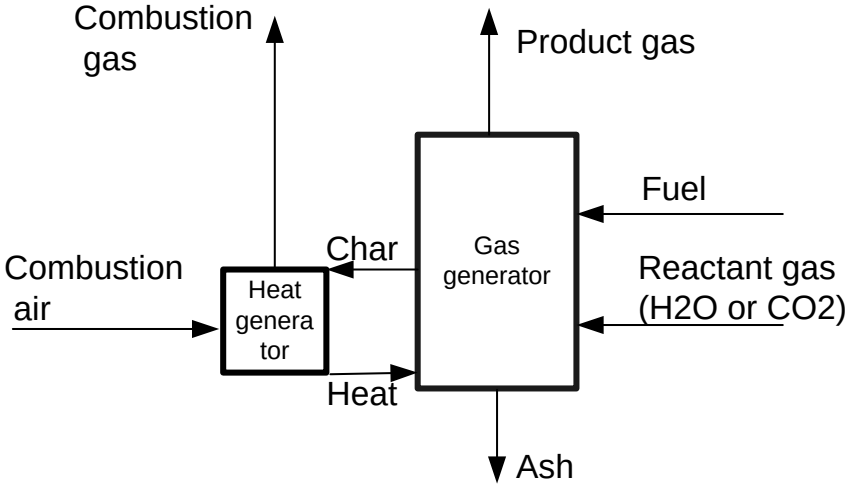
MODELLING

The simplest possible model presented in a survey comprising 400 references will be explained.

(A. Gómez-Barea and B. Leckner, Modeling of biomass gasification in fluidized bed, Progress in Energy and Combustion Science 36 (2010) 444–509).

COMPARISON BETWEEN DIRECT AND INDIRECT GAS GENERATORS BY HEAT AND MASS BALANCES

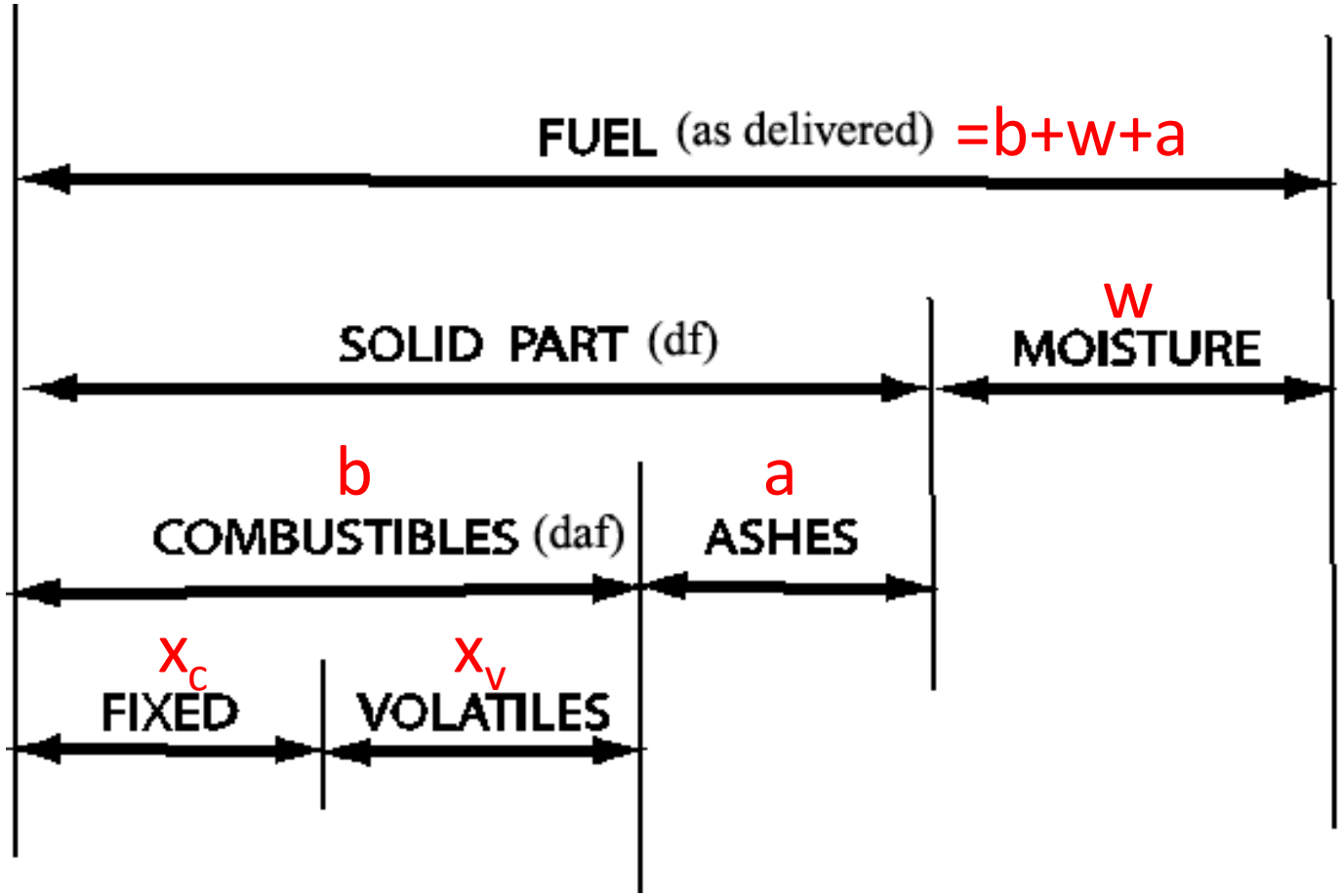




Autothermal or direct

Allothermal or indirect

COMPOSITION OF SOLID FUELS



METHOD OF ANALYSIS

The comparison is based on heat and mass balances of the entire reactors plus a few assumptions. The fuel analysis is given.

ASSUMPTIONS

- Devolatilisation x_v and drying take place in the gasifier
- The char $x_c = 1 - x_v$ is gasified to an assumed extent φ_{gas}.
- The autothermal case: remaining char is a loss and volatiles are burnt for heating
- The allothermal case: remaining char is burnt in the combustor and volatiles are only burnt if the char is completely consumed

THE FUEL

$$m_{f,in} = m_f (1 + \xi_u + \xi_b) \qquad (4)$$

ξ_u is the loss of fuel kg/kg fuel converted due to incomplete conversion
ξ_b is fuel consumed to produce heat, expressed in kg/kg fuel converted.

This gives

$$\begin{aligned} m_{f,in} = m_f a(1 + \xi_u + \xi_b) + & \quad ashes \\ + m_f w(1 + \xi_u + \xi_b) + & \quad moisture \\ + m_f b(1 + \xi_u + \xi_b) & \quad combustibles \end{aligned} \qquad (5)$$

The combustible part is

$m_f b$	gas from volatiles and gasification of char
$m_f b \xi_u$	conversion loss, mostly unreacted char
$m_f b \xi_b$	consumption to maintain reactor temperature

The combustible part consists of char x_c and volatiles x_v (from fuel analysis). Then the heating value of the volatiles is

$$H_{u,v} = (H_{u,b} - x_c H_{u,c}) / x_v \qquad (3)$$

THE GAS PRODUCED

The amount of gas produced (kg gas/s) is

$$m_{gas} =$$

$$= m_f b +$$ Volatiles+gas from gasified char, $m_f b x_c \varphi_{gas}$.

$$+ m_{f,in} w +$$ Fuel moisture

$$+ m_f b \xi_b g_0$$ Combustion gas in the autothermal reactor

Additional assumption for the autothermal reactor: the flue gas g_0 and air demand l_0 are those of combustion of fuel with char withdrawn.

HEAT AND MASS BALANCES

$$m_f b \xi_b H_{h,b} =$$

Input of energy with fuel burnt

$$= m_{f,in} \left\{ c_{pmf} (T_b - T_0) + wH_w \right\}$$

Heating of fuel + evaporation of moisture

$$+ m_f b x_c \varphi_{gas} \left\{ c_{pm,H2O} (T_b - T_0) + H_{C,H} \right\}$$

Heating of gasification vapour + heat for production of gas

$$+ m_f b \xi_b \ell_0 c_{pm,air} (T_b - T_0)$$

Heating of combustion air

$$+ radiation \quad losses \quad from \quad reactor$$

(neglected here)

where

$H_{u,b} = H_{u,v}$ in an autothermal reactor and $H_{u,b} = H_{u,c}$ in an allothermal one

and T_b is the bed temperature

PERFORMANCE CHARACTERISTICS

The heating value of the gas

$$m_{gas}H_{u,gas} = m_f b\, H_{u,v}(1- x_c)+ H_{C,H}\, x_c \varphi_{gas}$$

The cold gas efficiency of gasification

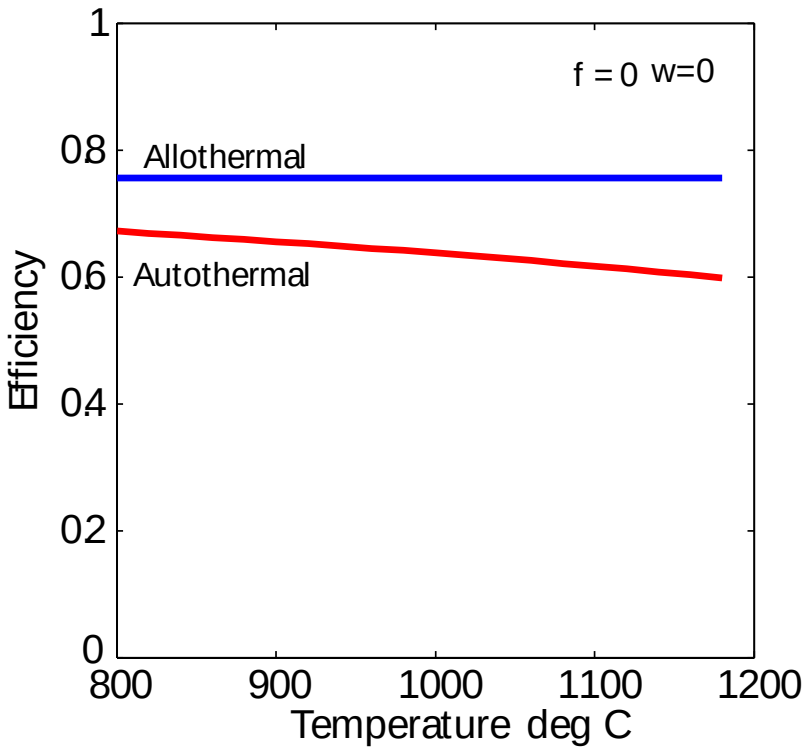
$$\eta_g = m_{gas}H_{u,gas} /(b m_{f,in}H_{u,f})$$

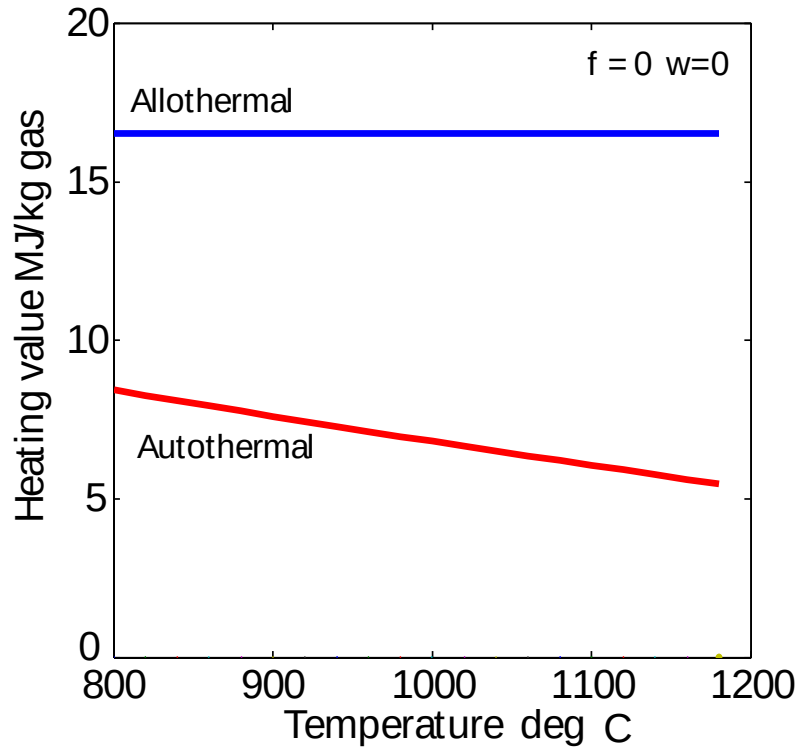
The fraction of the combustibles burnt

$$\xi_b = \frac{m_{f,in}}{m_f} \frac{w(c_{pmf}\Delta T + H_w) + m_f b x_c \varphi_{gas}(c_{pmH2O}\Delta T + H_{C,H})}{b(H_{u,b} - \ell_o c_{pmair}\Delta T)}$$

GASIFIER EFFICIENCY AND HEATING VALUE OF EXIT GAS VS REACTOR TEMPERATURE

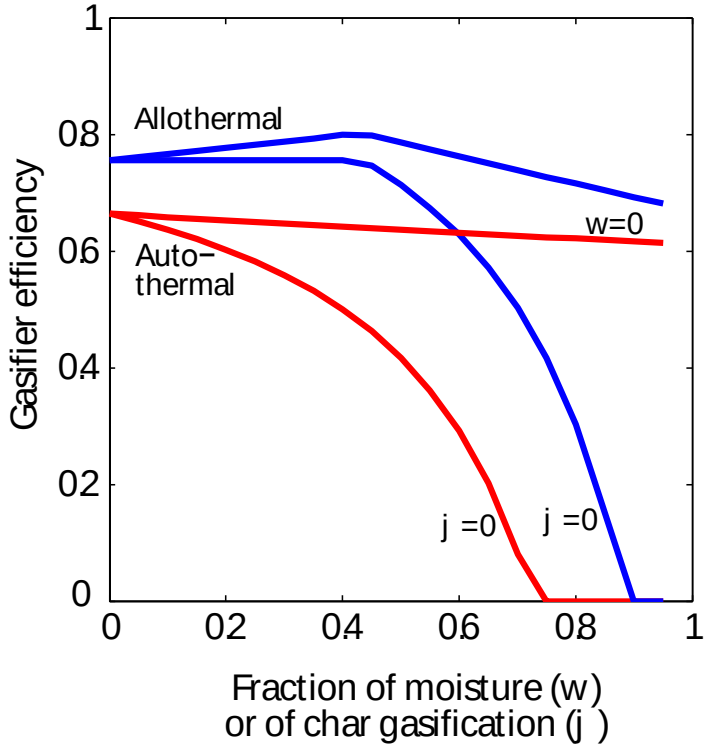
Zero moisture (w=0) and no gasification of char (ϕ_{gas}=0) in auto- and allothermal gas generators.

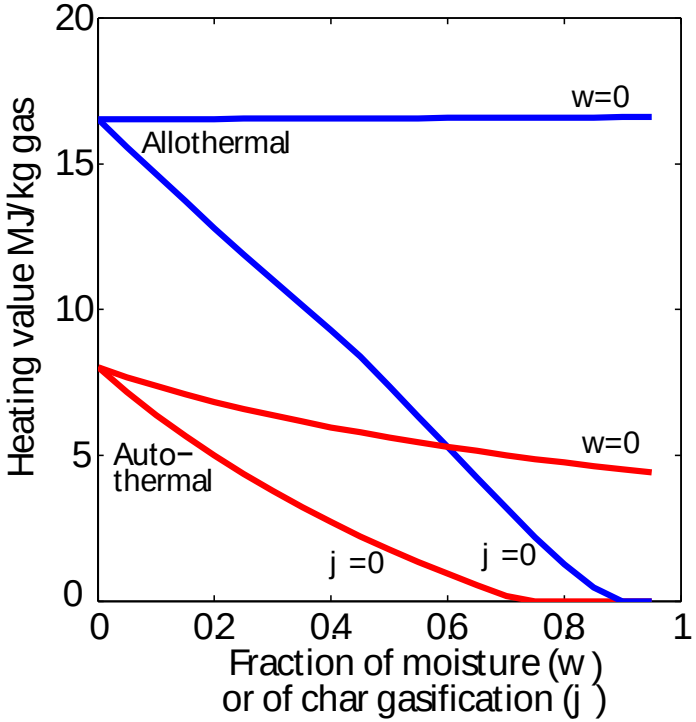




EFFICIENCY AND HEATING VALUE OF EXIT GAS

1) Various moisture contents in the fuel (w varies) and no gasification of char (ϕ_{gas}=0).
2) No moisture (w=0) and various ϕ_{gas} are also shown.

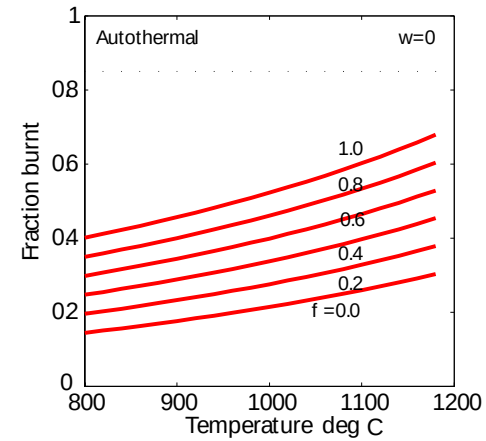


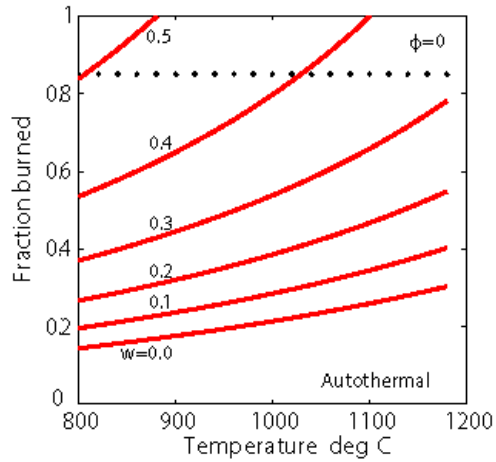


FRACTION OF FUEL NEEDED TO ATTAIN A CERTAIN GASIFIER TEMPERATURE, $m_f b\ \xi_b$,.

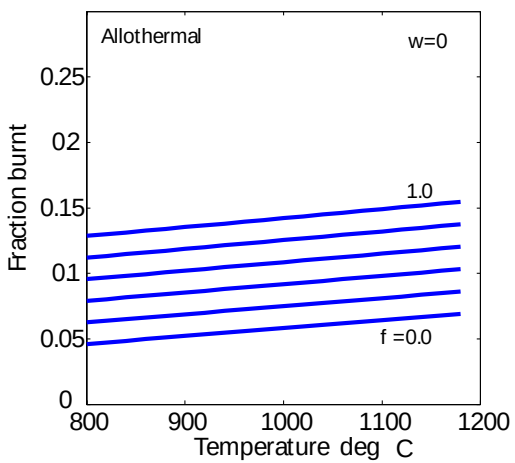
Degree of gasification

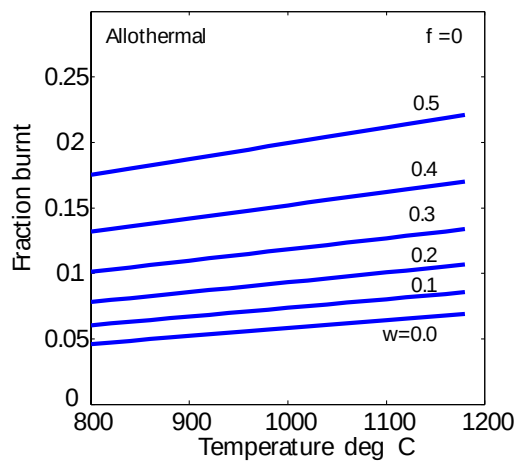
Moisture content





Autothermal

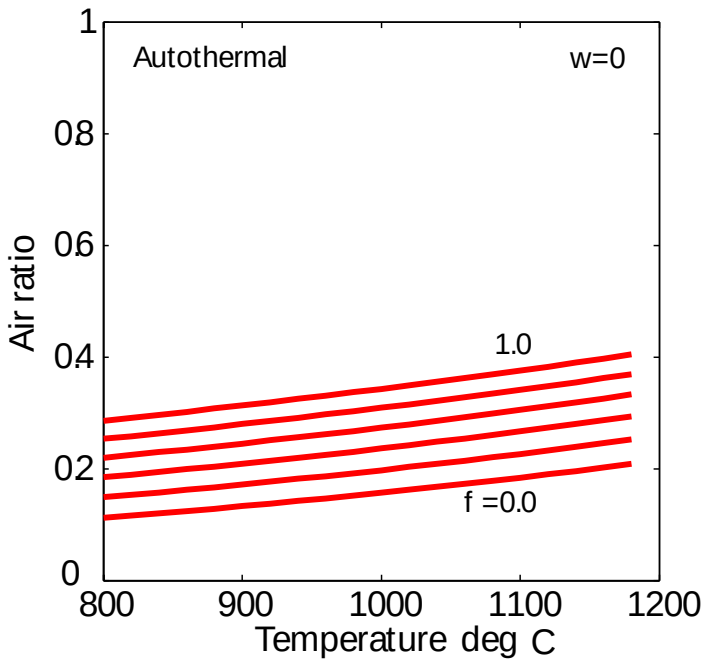


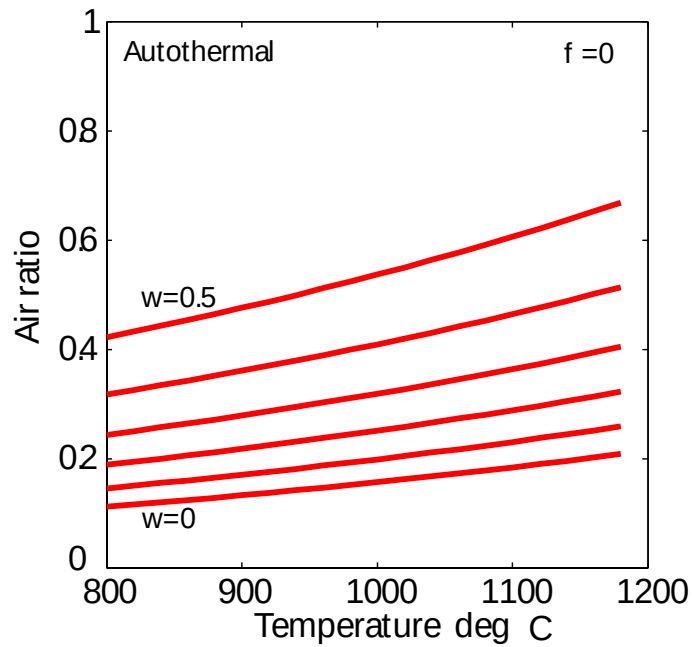


Allothermal

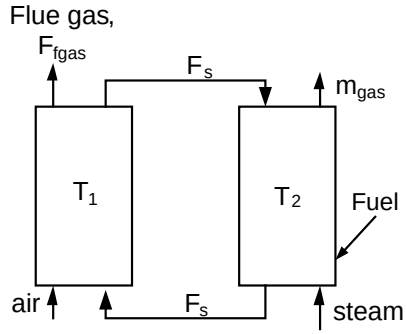
AIR RATIO BASED ON FUEL ADDED.

$$\lambda = m_f b \xi_b l_o / m_{f,in} b\, l_o = \xi_b / (1 + \xi_u + \xi_b)$$





THE COUPLED REACTORS



With fuel bunt $m_f b \xi_b = B$ and flue gas $B_f g_v = F_{f,gas}$, the heat transferred between the two reactors 1 and 2 is

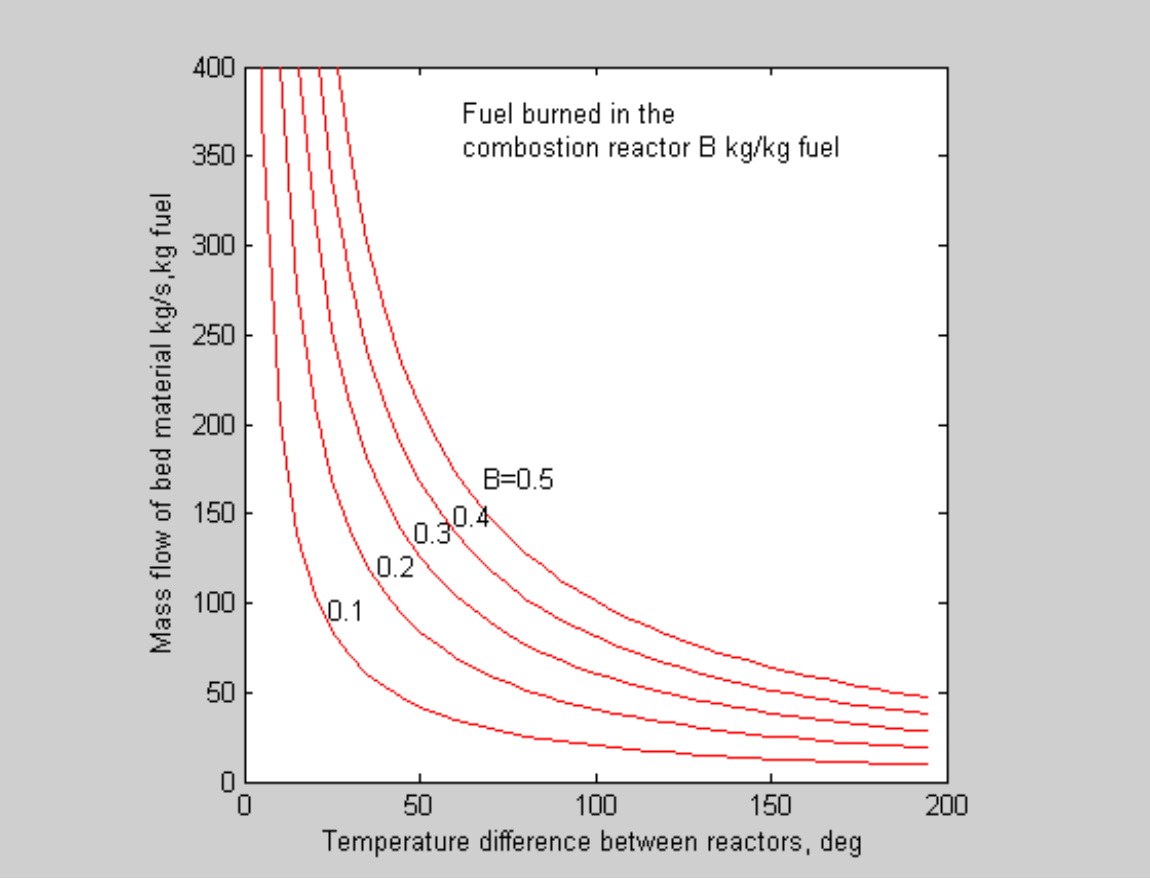
$$BH_{u,b} = F_s c_{pms}(T_1 - T_2) + F_{f,gas} c_{pmg}(T_1 - T_o)$$

With the adiabatic temperature $T_{ad} = H_{u,b} / (F_{f,gas} c_{pmg}) + T_0$

The flow of solids between the reactors

$$F_s = F_{f,gas} c_{pmg}(T_{ad} - T_1) / (T_1 - T_2) c_{pms}$$

ENERGY TRANSPORT BETWEEN COUPLED REATORS



CONCLUSIONS

A simple balance model can be used for performance analysis

The limitations are:

1. The amount of char gasification φ_{gas} has to be estimated by more advanced modelling.

2. The gas composition has to be predicted by additional models, e.g. equilibrium models in combination with species balances. However, the formulation gives this information with a low resolution: produced gas+water vapour from moisture + combustion gas.

3. Fluidisation conditions and reactor dimensions have to be determined

CONCLUSION REGARDING THE PERFORMANCE

- The energy in the char is about equal to the quantity of heat required for the gasifier. So, no gasification is really needed, only devolatilisation.

- There is an effort to design autothermal reactors to avoid the predominant combustion of volatiles and instead burn char.

- The location of the control surface for balance has to be considered (what is to be included/excluded).

- In the allothernal case just one point of operation balances the fuel burnt and the heat requirement. In all other points there is either too much char (loss) or too little char (additional fuel is needed).

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