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Experimental research on gasification of coarse waste on a stoker system and separate afterburning as well as optimization with the aid of a process model.

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Abstract

Approximately 85% of the energy required by the industrial corporations of Germany is supplied by combustion processes, i.e. primary energy through fossil fuels. This can be divided up into the fields power generation (power stations), steam generation and heating (process steam, industrial and private home heating), transport and traffic (motorized combustion) as well as thermal treatment (industrial furnaces).

Thermal treatment processes are largely applied by the raw material industry with the aim of material conversion under use of industrial furnaces. However in most cases combustion, gasification or pyrolysis are included in connection with the supply of energy. The baking of cement in the rotary kiln, the melting of glass in a refractory vat, the production of pig iron or burnt lime in a shaft furnace, the baking of sanitary installations in tunnel furnaces, the sintering of fine ore in sintering belt conveyor systems, the production of cokes in shaft furnaces (pyrolysis), the gasification in shaft furnaces etc. are all exemplary for this.

One can fall back upon the process technology in the fields of industrial furnace design and energy conversion if the thermal treatment of waste is necessary after having taken into account the aspects of avoidance, reduction, use of remnants, with respect to other processes.

The partial tasks of the thermal treatment of waste, which ought to be considered, are covered in this lecture. Furthermore it is shown, with respect to the known units (e.g. pyrolysis, gasification, combustion) and apparatuses of the above mentioned fields, how the processes currently under discussion and the especially hereafter mentioned gasification and afterburning processes can be sorted in.

Next to the main influential parameters it becomes apparent that there have to be further controlling possibilities when taking a stoker system (first step) with an independent afterburning system (second step) into account.

Partial overlaps often exist between the reaction zones and the afterburning process in the case of the process proceedings of stoker systems. Hence, with that a relatively high total air ratio ($\lambda_{tot} \approx 1.8$) in order to achieve certain properties of the remnants at the end of the grate (e.g. low remaining carbon concentrations) and a simultaneous high burnout of the flue gas is required. A comparison of this to other processes often leads to the conclusion, that the stoker technology can not be considered for future requirements. The following main influential parameters, such as partial oxygen pressure, temperature and residence time controlled through measures as for instance air staging, oxygen enrichment, flue gas recycling, speed adjustments of the single grates, can be adjusted in a broad spectrum if the stoker system is divided up into several zones. The stoker process can be operated at low air ratios (gasification) if the stoker process is clearly separated from the afterburning process (multistage process). This gas which is produced (through gasification) can be burnt in a second separate afterburning stage. This consequently leads to an overall lower air ratio of $\lambda_{tot} = 1.3$ if compared to conventional stoker systems.

Experimental results obtained from such a multistage pilot plant are discussed.

A theoretical model on the conversion of solids in stoker systems and investigations on the solid conversion over a period of time in a batch-reactor are furthermore covered in the lecture.

Aim of the thermal treatment of waste

The composition and the properties of the remnants next to the important aim of waste disposal determine the sensibility of the the recovery/gain of valuable substances and/or energy utilization. A series of partial steps or tasks have to be considered due to the process control and the technological transferability of the apparatus. In this connection one first of all, basically with respect to the composition of the waste, has to decide between

- gaseous, liquidly and dusty as well as
- pasty and coarse substances.

Essential examples in the field of disposal and recycling of valuables in the case of treatment of coarse waste are summarized in fig.1. Often however when trying to optimize the partial tasks the problem exists that varying process conditions are required. Partial tasks have to be optimizable independently of one another depending on the requirements. The following partial tasks should in the case of the disposal of coarse waste be optimizable:

- high burnout of the solid remnants,
- reduction of gas and particle like emissions,
- influencing of the properties of the products remaining at the end of the process.

Process steps themselves are again depending on the need split up in several steps:

- treatment stage for the solid (e.g. gasification on a grate) and
- treatment stage for the gases produced in the first stage and the remaining fly dust (e.g. afterburning in a combustion chamber system) as well as
- heat transfer, etc.

Mayor influential parameters and systematic classification

It is sensible to divide the schematically presented process up into the sections, thermal main process and the following, cleaning apparatus (gas cleaning, flue gas cleaning, etc.). The main thermal process itself can generally as a rule be split up into two steps according to the basic units as shown exemplary in the following:

1. step	2.step	
a)combustion	combustion	which means combustion and afterburning process,
b)pyrolysis	combustion	which means pyrolysis and afterburning process,
c)gasification	combustion	which means gasification and afterburning process,
d)pyrolysis	gasification	which means pyrolysis and after-gasification process

(whereby a combustion of the produced gas or a further use of the chemical industry after the after-gasification stage following the connection to the gas cleaning is envisaged),

- etc.

The classical burning of polluted waste initially being treated in a rotary furnace or municiple waste remains treated in a stoker system can be taken as an example for a). Fig.2 schematically represents the process. A concept, as given in c), is obtained if the first combustion stage in fig.2 is replaced by an independent gasification stage (i.e. stoker system). The organic components can in both cases, the combustion and the gasification, be "almost totally" converted. In contrast to this, solid organic substances remain (pyrolysis cokes) in the case of a pyrolysis stage. These remains have to be thermally treated (combustion, gasification) afterwards. The latter corresponds to a process as schematically shown in fig.3 and is for example tried to achieve by the so called "Schwel-Brennverfahren" of Siemens-KWU. In similar fashion a corresponding flowchart can be made up taking the concept of d) (e.g.Noell-Pyrolysis-Pressurized Gasification-Process or Thermoselect-Procedure) into account. Within the respective process stages there are again sufficient possibilities catered for, for the controlling of the main influential parameters (air staging, flue gas recycling, etc.) as shown in fig.4. For the realization of the apparatus for the respective process stages the professional trades (industrial furnace design, combustion and fuel technology) offer known systems. Here are some examples:

- rotary furnaces each in a single stage (solid, pasty and liquidly substances) for the combustion of polluted waste or treatment of waste remains (pyrolysis),
- stoker systems in a first stage (solid conversion) for waste remains,
- story furnace in a first stage for sewage sludge,
- combustion chamber systems in a second stage after the solid conversion for the afterburning of gas and dusts, the combustion of gaseous, liquid and dusty waste, high temperature gasification of dusty waste,
- fluidisation reactors in a first stage (solid conversion) for sewage sludge or corresponding recycled dust like or coarse waste fractions with a narrow particle size distribution
- continues operating furnaces in a first stage (solid conversion) for processes with extremely long residence times
- shaft rectors in a first stage (solid conversion) for high temperature processes with long residence times,
- etc..

Every apparatus is distinguishable with respect to the levels of the main influential parameters and the possibilities of their control [e.g. 1]. An overview for stoker systems is given as an example in fig.5.

Multistage process control of stoker systems

The optimization of especially the solids conversion on the grate is to be decoupled from the afterburning process of gasses produced on the grate as already mentioned. With this multistage concept in comparison to the conventional stoker systems air ratios of $\lambda_{gr} \approx 0.4$ can be set for the grate. The hot fuel gases produced in the grate stage allow for an independent multistage combustion process with near-stochiometrical conditions in the afterburning process. Among others, a near complete burnout of the solids is envisaged which means a remaining carbon concentration of the solid remnants as low as possible, leaves the grate. To achieve this a local overstochiometrical air ratio in the burnout zone is to be preset ($\lambda_{gr,e} \approx 1.2$).

Next to the possibilities that come about through the multistage process, with respect to intended optimization of the grate stage, the transfer of primary measures for the afterburning of the hot fuel gases produced in the stoker and left over fly dust will be covered in the lecture in the frame of a multistage combustion process. In the case of the multistage combustion process the lecture concerns itself with the tested and excepted measures for gaseous, liquidly and dusty fuels [e.g. 2 till 6]. Fig.6 shows an respective schematic block flowchart. A pilot plant of such a multistage gasification-afterburning process was built after investigations on such a system in collaboration with the industry, that includes the heat supply being incorporated in their operation [7], were carried out. The optimization possibilities of such a process control given by the concept are summarized in connection with the plant description shown in fig.7, as follows:

1) Both stages of the entire process (gasification-afterburning process) can be optimized independently of one another with respect to the mentioned partial tasks:
   - \+ the reaction flow rate can be adjusted to the conversion along the three zones of the grate path,
   - \+ a flue gas recycle or increase in oxygen is furthermore possible in the three zones,
   - \+ the residence time can be controlled in the separate zones through the grate movement,
   - \+ the tested primary measures in the case of the gas and dust firings for the reduction of nitrous oxides and the improvement of the burnout (CO, C_xH_y, fly dust, etc.)

     are transferred to the separately installed combustion chamber, which allows for independent combustion of the gases or fly dust formed on the grate
2) Due to the grate being operated understochiometrically (gasification), a combustible gas is formed, which can, at near stochiometrical conditions, be brunt in a sperate afterburning chamber hence decreasing the total air ratio from $\lambda_{tot} \approx 1.6$ till 1.8 down to $\lambda_{to} \approx 1.2$ till 1.3.

It still has to be proven to what degree a recycling or gain of valuable substances is possible.

Taking contaminated remains of wood, a comparison between the two processes (gasification on the grate system and afterburning in a combustion chamber system in contrast to an overstochiometrically operated stoker system) based on same amounts of solid conversion, a reduction in the amounts of flue gas, particles and gas emissions, is made within the given scope of the investigations on the pilot plant.

Statements can be confirmed by experiments carried out in a pilot plant or much rather a batch-reactor (see below) using for example refuse-derived fuel, remains from the leather and paper industry or old tires. In connection with the thermal treatment of chromium tanned remains of leather it shall be mentioned that next to a high solids conversion in the grate stage achieved through the process control, an aim of chromium extraction (recovery of valuables) is envisaged. A slight sintering of the remaining substances of the paper industry (eluat procedure) from the grate process is an assignment.

An investigation on contaminated wood showed, that a sufficient solid conversion (remaining carbon concentration of less than 1% by mass) can be achieved in the case of an understochiometrically operated stoker (λ_{gr} = 0.8), if the last grate of the stoker is operated overstochiometrically. The remaining carbon concentration was in the order of the same magnitude in the case of an overall overstochiometrically operated stoker.

As can be seen in fig. 8 one can achieve a significant reduction in the NO-emissions through a multistage process ($\lambda_{gr} = 0.8$; $\lambda_{tot} = 1.3$) by air staging in the afterburning system in comparison to a singlestage process ($\lambda_{gr} = \lambda_{tot} = 1.3$). Especially in the case of very moist waste wood, the among others through discontinual feed achieved irregulareties through air staging in the grate can hardly be counteracted in time, which as in this case leads to corresponding high levels of CO-concentration in the case of single stage process. In contrast to this one achieves, in the case of a selfsupporting afterburning of the the hot fuel gases, which are produced in the stoker process, next to a reduction of the NO, a high burnout (only CO is shown in fig. 8) of the gases and fly dust similar in fashion to the gasfiring.

In addition to this the specific flue gas flow rates and dust amounts for the two above mentioned procedures are shown in fig. 9. As expected, due to the low air flow rates and the corresponding low velocities of flow through the bed for understochiometrical operation of the stoker system (gasification) in comparision to the overstochiometrical operation, one obtaines a lower concentration of fly dust. In connection with the specific flue gas mass a corresponding lower specific dust load becomes apparent.

Attention is further given, to an industrial plant, using the possibility of an additive (for the reduction of SO_2, HCl and HF-emissions) for the waste before it enters the stoker system [7].

Mathematical model and investigations on a batch-reactor

A mathematical model is introduced in the present contribution which explains the interaction of the most important main influential parameters as for instance partial oxygen pressure, temperature, residence time, mixing behavior (reactor behavior) and additional substances (e.g. inert substances).

The questioning to which degree the generally complex overlapping matter and heat transfer as well as the chemical reaction mechanisms have to be taken in account should first of all depend on the accessibility and precision of necessary basic data as for instance composition shape and size, reactive surface area, pore structure, etc. , and transport behavior (flow through he reactor bed, transport of solids on the grate, etc.). Keeping this in mind a simplified mathematical approach (model) is chosen [8] and discussed with respect to the important existing demands, i.e. a high solid burnout.

Depending on the type of stoker the solid bed is more or less thoroughly mixed while traveling through the stoker. A characteristic residence time behavior results from the type of stoker and the fuel employed. This residence time behavior is first of all of importance irrespective of the chemical kinetics. With respect to the residence time behavior one distinguishes in the field of chemical process technology between the borderline cases continuous stirred tank reactor and plug flow reactor behavior [e.g. 9]. The illustration of the actual or real residence time behavior can be achieved by a corresponding serial cascade of continuous stirred tank reactors, as presented schematically in fig.10. The number of the single elements as model parameters can be determined through the adjustment of the for instance experimentally determined residence time distribution with the aid of a material balance (e.g. tracer) performed on a cold experiment (as a first approach) (look at for instance [10] for the investigations done on the residence time behavior in firing systems). If necessary one also has to think of every reactor element above its own height (bed height) represented in fig.10 to be shown as a series of partial continuous stirred tank reactor elements.

First of all a single stirred tank reactor element is chosen and looked at more closely from the point of view of a "accompanying observer". This way of looking at it is initially sensible with respect to experimental investigations done on a batch reactor with a corresponding low bed height. If one first of all performs an energy balance on the chosen reactor element one has to pay attention to the gas mass flow rates $\dot{m}_{g,in}$ (e.g. air) and $\dot{m}_{g,out}$ (flue gas) and the corresponding enthalpy flow. In addition to this the energy flow, created through the conversion of the carbon mass flow rate $\dot{m}_c(t)$ by chemical reactions, has to be taken into the balance as a so called source term. In order to describe the nonsteady state behavior during the heating or cooling phase the enthalpies (storage and source terms) here connected to the main terms, which are the remaining carbon ($m_{c,Re}(t)$) and the inert material (m_{In}), have to be considered. The heat transfer between the hot walls and the cell under consideration (CSR-element) is described by the heat radiation transfer approach ($\dot{Q}_S$) with a balance temperature (similar to industrial furnace model approaches; refer to example [11]) as well as a heat flow loss $\dot{Q}_l$ which describes any further losses. The following energy balance can be summarized:

$$\overset{A}{\dot{m}_{g,in}\, c_{p,g,in}\left(T_{g,in}-T_0\right)dt} + \overset{B}{\dot{m}_c(t)\left(-\Delta h_{ch}\right)dt} + \overset{C}{\dot{m}_c(t)\, c_c(T-T_0)\, dt} + \overset{D}{\dot{Q}_R dt} = \qquad \text{Eq. (1)}$$

$$\underset{E}{\dot{m}_{g,out}\, c_{p,g,out}\left(T-T_0\right)dt} + \underset{F}{m_{c,Re}(t)\, c_c\, dT} + \underset{G}{m_{In}\, c_{In}\, dT} + \underset{H}{\dot{Q}_l dt}$$

For the carbon conversion mass flow rate $\dot{m}_c(t)$ an approach is chosen taking into account the reactive surface area, an effective coefficient of reaction and the oxygen concentration:

$$\dot{m}_c(t) = M_c\, A_{sp,os}(t)\, k_{eff,os}(t)\, \frac{p_{O_2}(t)}{R\, T(t)} \qquad \text{Eq. (2)}$$

The approach is simplified since with an increase in the complexibility of the models several very detailed informations on the waste matter are needed. These informations can however not be easily obtained. The remnants of the experiments can at a later stage be used to determine the equation no.2 through for instance the product of the reactive surface area and the effective reaction coefficient ("summarized kinetic data"). It can than be seen, whether such simplified approaches for the inspection of the whole process can be supported.

The following equation is derived for the overstochiometrical case (e.g. at the end of the stoker) under the assumption of an evenly spread bed of burning spherical shaped matter and a constant void volume in order to determine the mass flow rate of carbon $\dot{m}_c(t)$:

$$\dot{m}_c(t) = m_{c,0}\left(\frac{1}{k_{eff,os}(t,T)}\,\frac{d_{p,0}\,\rho_p}{6}\left(\frac{m_{c,0}}{m_{c,Re}(t)}\right)^{\frac{2}{3}}\frac{R\,T(t)}{M_c\, p_{tot}} + \frac{M_{O_2}}{M_c}\,\frac{\rho_{g,in}}{\rho_{O_2}}\,\frac{m_{c,0}}{\dot{m}_{g,in}}\right)^{-1}\frac{p_{O_2,in}}{p_{tot}} \qquad \text{Eq. (3)}$$

The processes of a cell moving over the grate can be simulated experimentally with a sufficiently low bed height. Fig.11 shows the schematic structure of the experimental apparatus. The method of investigating the solids conversion over a given period of time in a batch reactor has already been proven to be reliable and is currently still in use [e.g.12 till 15]. The solids conversion over a given period of time can be assigned to a position along the reaction path under the assumption of a transport speed. Resulting are first statements about a suitable air staging over the entire length of the stoker, the effectiveness of oxygen enrichment or the recycling of flue gas, a mounting of the inert matter etc. The experiments on the batch-reactor and investigations with a thermo gravimetrial scale furthermore serve for the collection of "summarized kinetic data", as for instance $k_{eff,a}$ for every matter under consideration, for the above mentioned model. In the lecture first conclusions can be made for the operating conditions of a stoker system with the aid of the experimental results gained from the batch experiments and the results obtained by the model. Furthermore keypoints concerning the paths of the oxygen concentrations will be covered for the model fuel (lignite) in absence of inert matter (ceramic spheres). Further details with respect to the boundary conditions will be covered in the lecture. The influence of elements D, G, and H in equation no. 1 become apparent in the fig.12 where oxygen concentrations are shown over a given period of time. If neglecting heat transfer conditions (terms D and H of equation no. 1) in a first step, a lower gradient is achieved for a fuel with an increase of inert matter in the burning out phase and vice versa a higher gradient for a fuel without inert matter. Further consideration of the heat transfer conditions leads as can be predicted to a decrease in the oxygen concentration due to the time taken for the heating up of the bed (begin of the reaction) and a relatively flat increasing gradient during the burnout phase (end of the reaction). A steep gradient in the burnout phase is for example an indication that the flow of energy which is connected to the conversion of solids, the present heat transfer conditions as well as the energy stored in the bed for the heating of the feeding gas mass flow rates $\dot{m}_{g,in}$ are not sufficient and the bed is "blown out", i.e. the reaction is halted at a still relatively high carbon concentration. The danger of a "blow out" can as the experimental results have already shown be reduced by the addition of inert matter which stores energy during the main combustion phase (term G of equation no. 1). When looking at the paths of the oxygen concentration in fig.13 one can see that the tendency is correctly described. Next to the influence of the increase of the inert matter further measures such as air staging and oxygen enrichment are covered in the lecture.

It can be seen that through relatively simple experiments with a batch reactor and with the aid of a mathematical model time-consuming and extensive experiments can not be avoided for future experimental programs performed with a pilot plant but however the number of experiments can be reduced.

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Notation

Latin characters

(large)

A	area
FGC	flue gas cleaning
M	molar mass
Q	heat
R	universal gas constant
T	temperature

(small)

c	specific heat capacity
d	diameter
h	specific enthalpy
h.e.	heat exchange
m	mass
t	time

Greek characters

(small)

ϑ	temperature
λ	air ratio
ρ	density
ψ	concentration

Indices

(overline)

.	flow rate

(subscript)

0	start
C	carbon
ch	chemical
e	end
eff	effective
g	gaseous
gr	grate
In	inert
in	input
l	loss
O_2	oxygen
os	outer surface
out	out
p	pressure, particle
R	radiation
Re	remainder
sp	spherical shape
tot	total

Figures (page 9 till 15)

	Goal or objective **Waste disposal** (e.g. municipal waste remains)	Goal or objective **Recovery of valuables** (e.g. recycling of coated steel-parts)
Solution through a series of process steps and measurements (description in the text)	(1) conversion of complex chemical substances into simple recognizable substance (2) high burn out of the solid remains (3) take aim at influencing the solid remains, i.e.: "functional" treatment for + further use + specific bonding of harmfull substances (pollutant) + immediate storage eg. through additive, phase change (slightly sintered solids, slag)... (4) reduction in flue dust amounts (5) high burn out of flue dust (6) reduction of the absolute flow rates of exhaust gas (7) high burn out of the exhaust gas (reduction of emissions: CO, C_xH_y,...) (8) reduction of nitric oxides (9) reduction in the use of secondary energy (if possible energy self-sufficient) (10) If necessary on energetic use	(1) reduction of organic substances in the solid phase + for the separation of valuables + for the thermal decoating + ... if possible without changes in phase of the valuables (2) high burn out of solid anorganic remains (3) directly wanted influence of remnant anorganic solids for instance through additives, phase change (slightly sintered so lid,slag)... i.e. "functional" treatment for + further use + specific bonding of harmfull substances (pollutant) + immediate storage after classification of the valuables (4) till (10) as shown on the left hand side

Fig.1. Exemplary partial tasks of the thermal disposal and recovery of the valuables

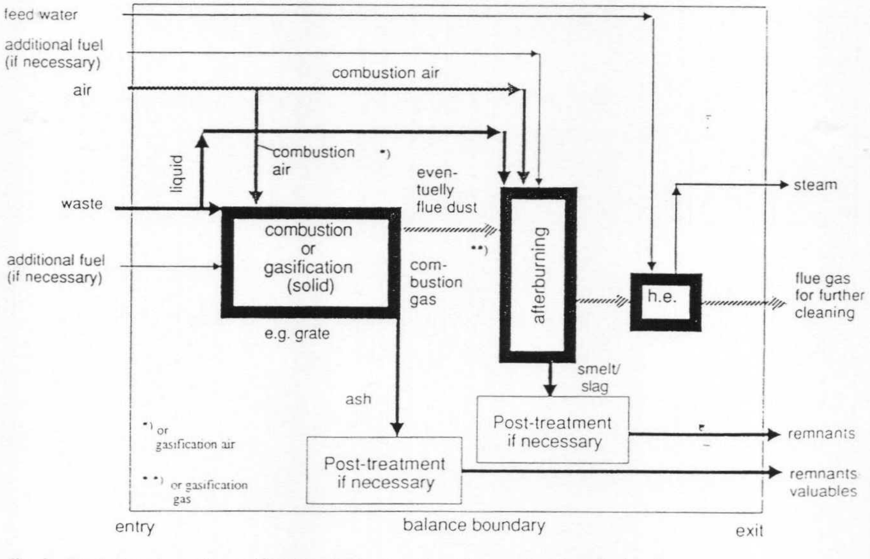

Fig. 2. Block flowchart of a gasification-afterburning (or rather combustion-afterburning process) with solid separation after the first step

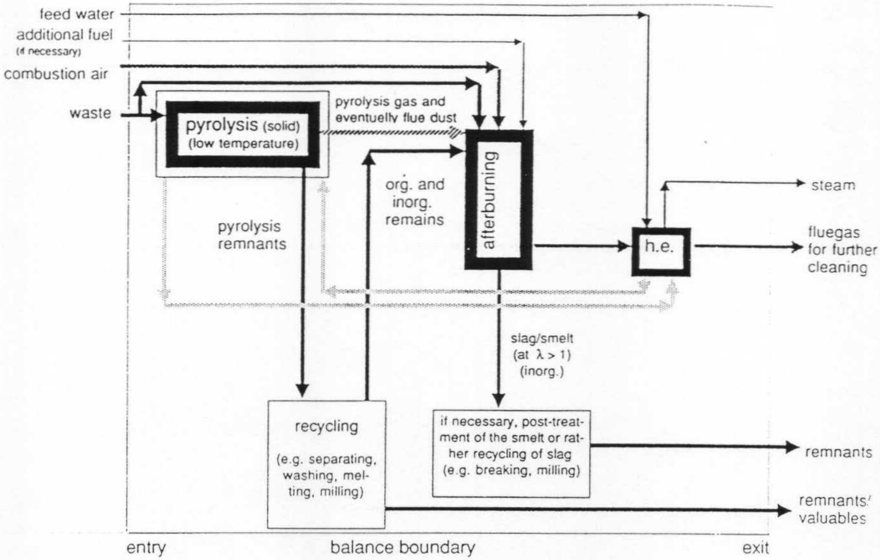

Fig. 3. Block flowchart of the thermal main process "pyrolysis-afterburning-process":
with solid separation after the first stage

waste materials	**physical properties**		gaseous, liquid, paste like, solid (dusty or lumpy)	
	chemical properties		composition (problematic substances)	
partial oxygen pressure	**pyrolysis** $\lambda = 0$	**gasification** $\lambda < 1$	**combustion** $\lambda \geq 1$	
reaction gas	air, oxygen, nitrogen, carbon dioxide, steam, recycled flue gas....			
temperature	**low** $\vartheta < 600\ ^oC$	**until**	**high temperature** $\vartheta > 1000\ ^oC$ (to 2000 °C a. higher)	drying, degasification, melting, evaporation, sublimation
pressure	**low pressure** $p << 0.1$ MPa	**atmospheric pressure** $p = 0.1$ MPa	**high pressure** $p >> 0.1$ MPa	
reactor behaviour	**continuous stirred reactor(CSR)** $Pe = 0$	**real reactor** $0 < Pe < \infty$	**plug flow reactor (PFR)** $Pe \rightarrow \infty$	
residence time	**short** several s	**long** several min up to hr	**very long** several hours up to days	
additional substances	**additive** (e.g. bonding of pollutants, controling the melting behaviour) **additional fuel** bed (e.g. fluidized bed, solid bed, circulating bed, binding matrix, ash recovery)			

Fig 4. Main influencial parameters for thermal treatment

apparatus	grate systems
substances employed	lumpy, in connection with a solid or inert bed also paste like
oxygen concentration level	usually overstochiometrical; understochiometrical (gasification) is possible through which a self sustained post-combustion is possible; conclusion of oxygen (pyrolysis) is not customary
control along the reaction path	separately very easily adjustable in the separate zones (eg. air/oxygen staging, fluegas recycling, ...); the partial steps drying, degasification, gasification, remain burnout of the solid can be influenced in connection through temperature control.
temperature level	bed surface temperature up to approx. 1000 °C and higher, middle bed temperature is lower
control along the reaction path	also very sufficient possibilities through division into several zones, as for in the case of the controlling of the oxygen concentration (air pre-heating, fluegas recycling, water/steam cooling)
pressure	near atmospheric pressure, as a rule due to technical reasons a few Pa underpressure.
reactor behaviour solid	depend on the grate movement, the single zones can be made to simulate the CSR-characteristics (eg. revers acting grate) or the PFR-characteristics (eg. travèling grate); when viewed over the entire reactor length the PFR-characteristics can be approached
gas	a) oxidants etc. flow through the bed by force and distribute themselves evenly over the bed surface; hence very good contact between gas and solids. b) flow above the bed is possible in counter- and co-current, gas treatment is necessary in the following process step (eg. after burning)
residence time level (average residence time)	ranging from a few minutes up to hours; adjustable through grate speed and massflow rate
control along the reaction path	very good adaption is possible through separable adjustments in the speed of the grate elements in the single zones; if necessary, for additional improvement of the burnout at the end of the gate, the discharge roll can be controlled.
additional substances	additive for the bonding of pollutants in the solid and influence of the remnant properties (Ash, partialy molten ash, slag); inert-bed eg. binding matrix for possible easy melting substances such as plastics.
ranges of applications (examples)	combustion as part of a process (remnant waste, solid burn-out);separation of metals from compound substances at low temperatures and simultaneous understochiometric conditions.

Fig. 5. Characterization of grate systems [1]

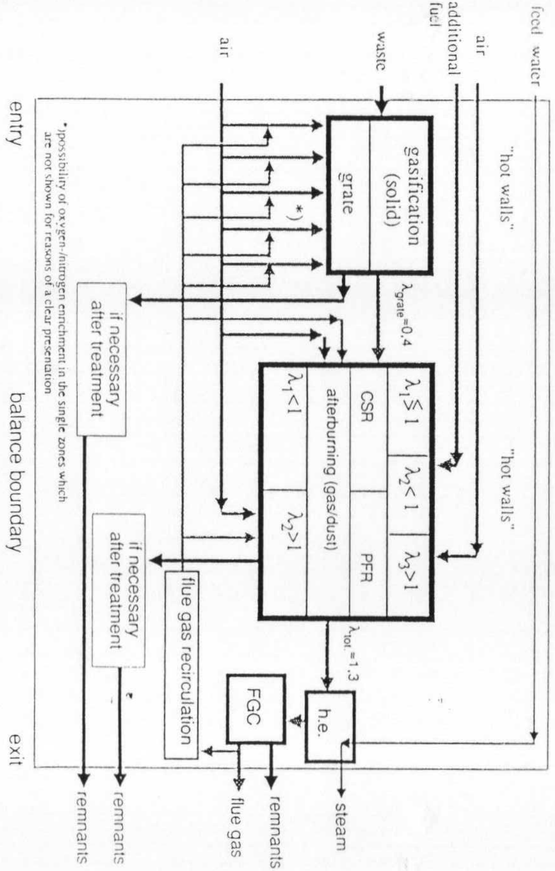

Fig. 6. Block flowchart of the possibility for the influencing of the process in the case of grate systems with a separate afterburning-stage

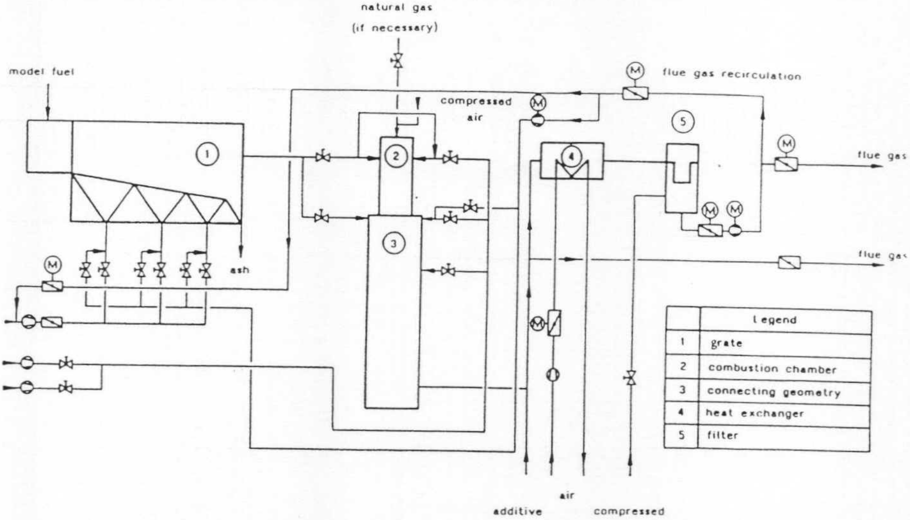

Fig.7. Schematic presentation of a continuously operated experimental grate system with an independent afterburning

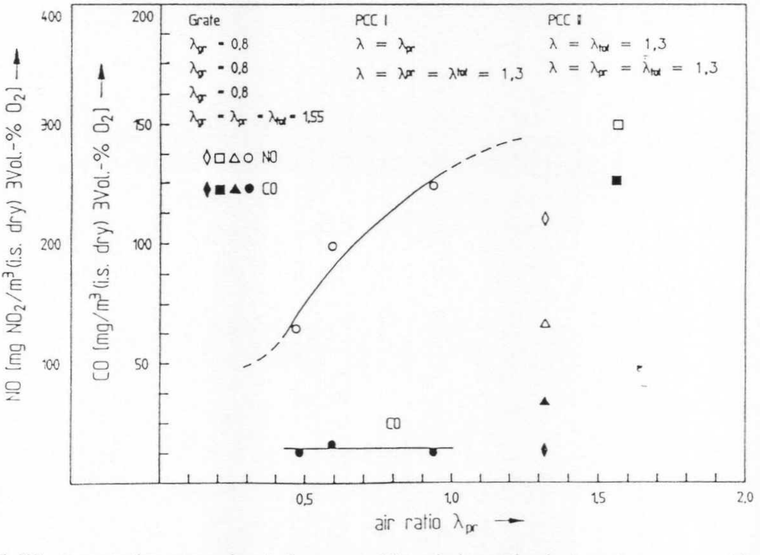

Fig.8. NO_x-concentration versus air ratio for over stochiometical operation in the stoker system and for understochiometical operation in the stoker system by air stating in the selfsupporting afterburning process

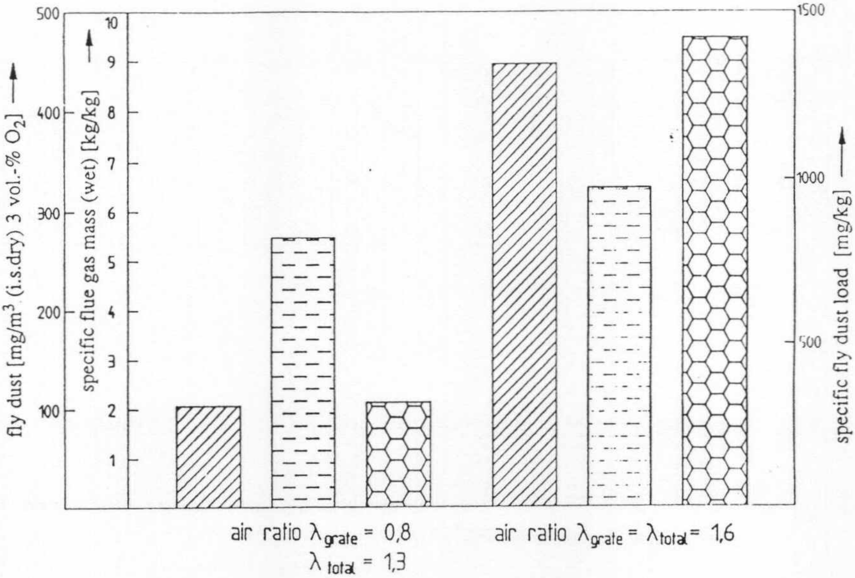

Fig.9. Fly dust concentration, specifc flue gas mass and specific dust load for under- und overstochiometical operation in the stoker

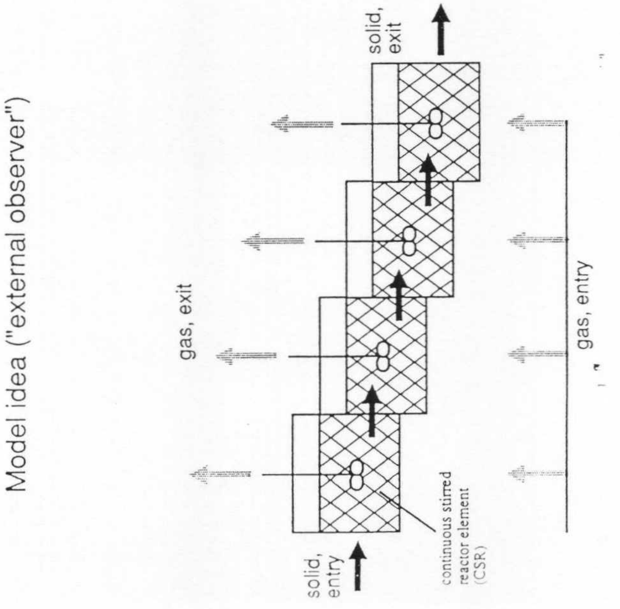

Fig. 10. Continuous stirred reactor-cascade as a model idea for the description of the solid transport in a grate system

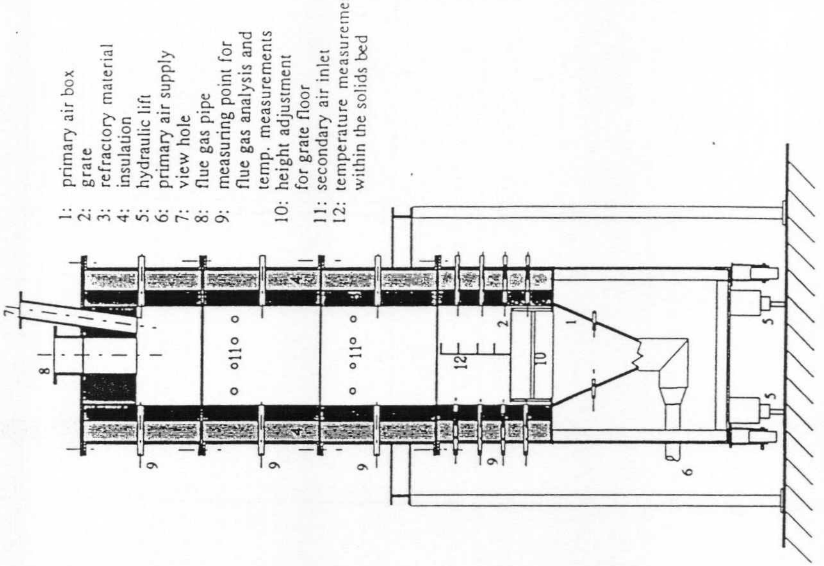

Fig. 11. Schematic presentation of a discontinually operated experimental grate facility (Batch reactor)

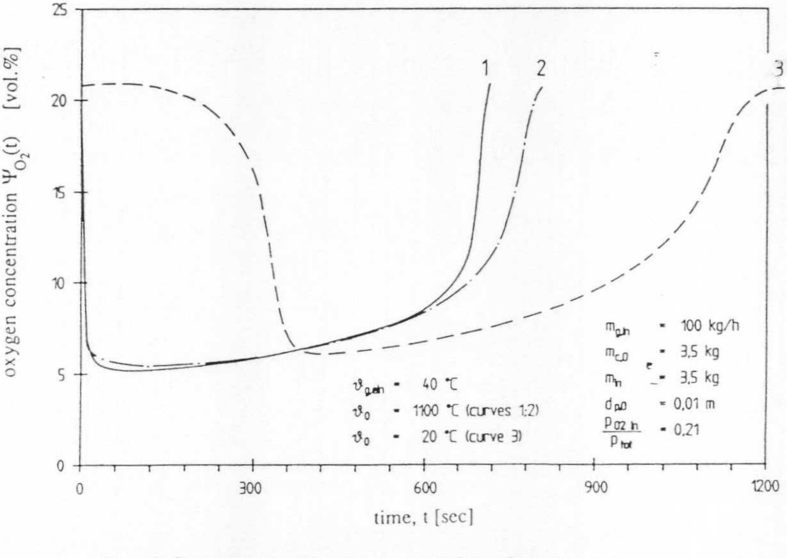

Fig. 12. Oxygen concentration over a period of time for a given bed

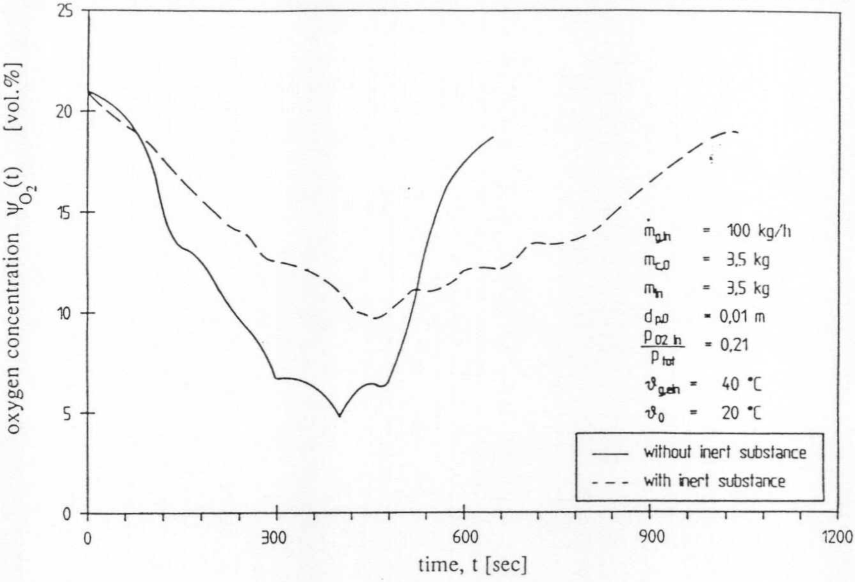

Fig. 13. Experimentally determined course of the oxygen concentration over a period of time for a given bed with and without inert substances