Technical report

Conceptual design for waste electrical and electronic equipment (WEEE) pyrolysis reactor

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Step 1: Experimental facility design

1. Process overview

The lab-scale facility which is shown in the Figure 1 was designed and constructed especially for WEEE fractions. The experiments were performed at laboratory of Division of Energy and Furnace Technology at Royal Institute of Technology in Stockholm.

Figure 1 Photo of experiment facility

The small scale reactor is electrically powered (1KW). The temperature range can vary from room temperature to 1300° C, according to the controller of the temperature limitations. It has been design to use as inert gas of the process all kind gases even though for the pyrolysis of WEEE N_2 mainly used. Additionally, this reactor has been connected to a steam boiler provided by the division in order to examine the steam as a medium for steam gasification experiments. Sophisticated cooling system has been purchased and installed for the process in order to have homogeneous temperature on the collecting point of the condensable fraction.

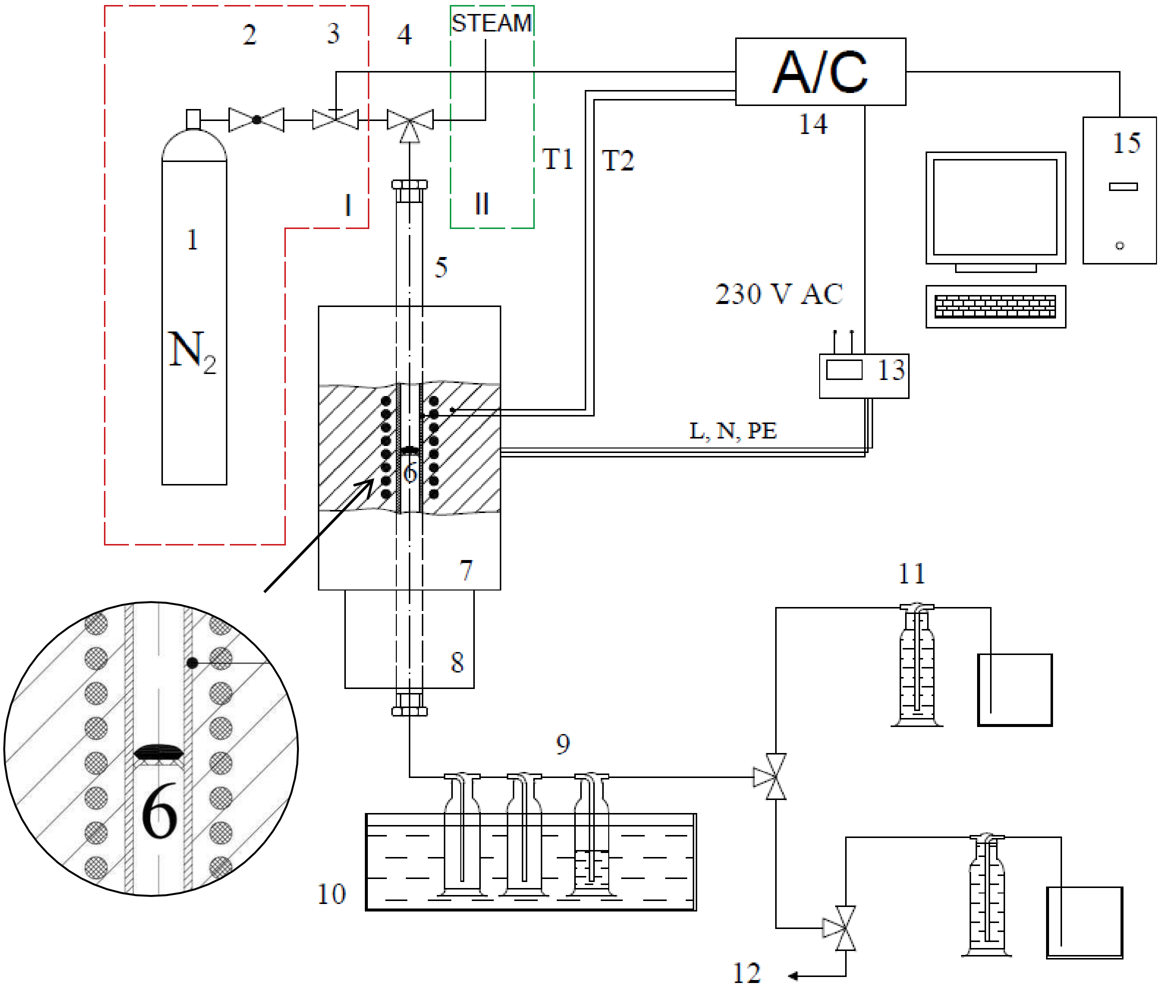


Figure 2 The scheme of the experiment facility

On the Figure 2 the scheme of the experiment facility is shown, where all the parts of the facility are presented:

1. Nitrogen supply
2. Gas regulator,
3. flow meter
4. three way valve
5. reactor (length L=100 cm, inner diameter D=2,33 cm)
6. sample and mesh support
7. electrical heater (power output P=1 kW),
8. insulation,
9. tar measurement vessels,
10. cooling system,

11. gas measuring vessels,
12. exhaust gases output,
13. heater controller,
14. analog-to-digital converter,
15. data recording,

T1, T2 – thermocouples K-type,

I – pyrolysis line with N2,

II – gasification line with steam.

The red and green envelops show sources of nitrogen and steam. In case of pyrolysis, nitrogen is used, therefore, the line marked in red was working. In case of steam gasification, steam agent is used, therefore, the line marked in green was working. Switching between nitrogen and steam lines was provided by high temperature, corrosive resistant three-way valve.

For steam production additional boiler was used. The parameters of the steam were: temperature T=140°C and atmospheric pressure. As a heating source necessary during pyrolysis and gasification, electrical heater with power output P=1 kW was used in order to heated up the samples and start thermal decomposition of their organic fractions.

Step 2 : WEEE reactor

1. Process Overview

The overall pyrolysis process is shown in Figure 1. The process consists of 3 stages.
The 1st stage is the WEEE feeding stage were the WEEE is introduced in the reactor. Two air locks are used to minimise backflow of the reactor gases to the feeding line. The use of airlock minimises the use of N_2 in the feeding line.
The 2nd stage is the auger reactor where thew WEEE material is forwared with the help of a screw in at tube which walls are heated externally.The control of the roational speed of the screw detemines the residence time of the WEEE material in the high tempeature zone. The remaining solid materail is sent to a bin where it can be removed from the process while the vapours are driven upwards.
The 3rd stage is the gas/vapour treatment stage where the gases/vapours are cleaned and cooled down.

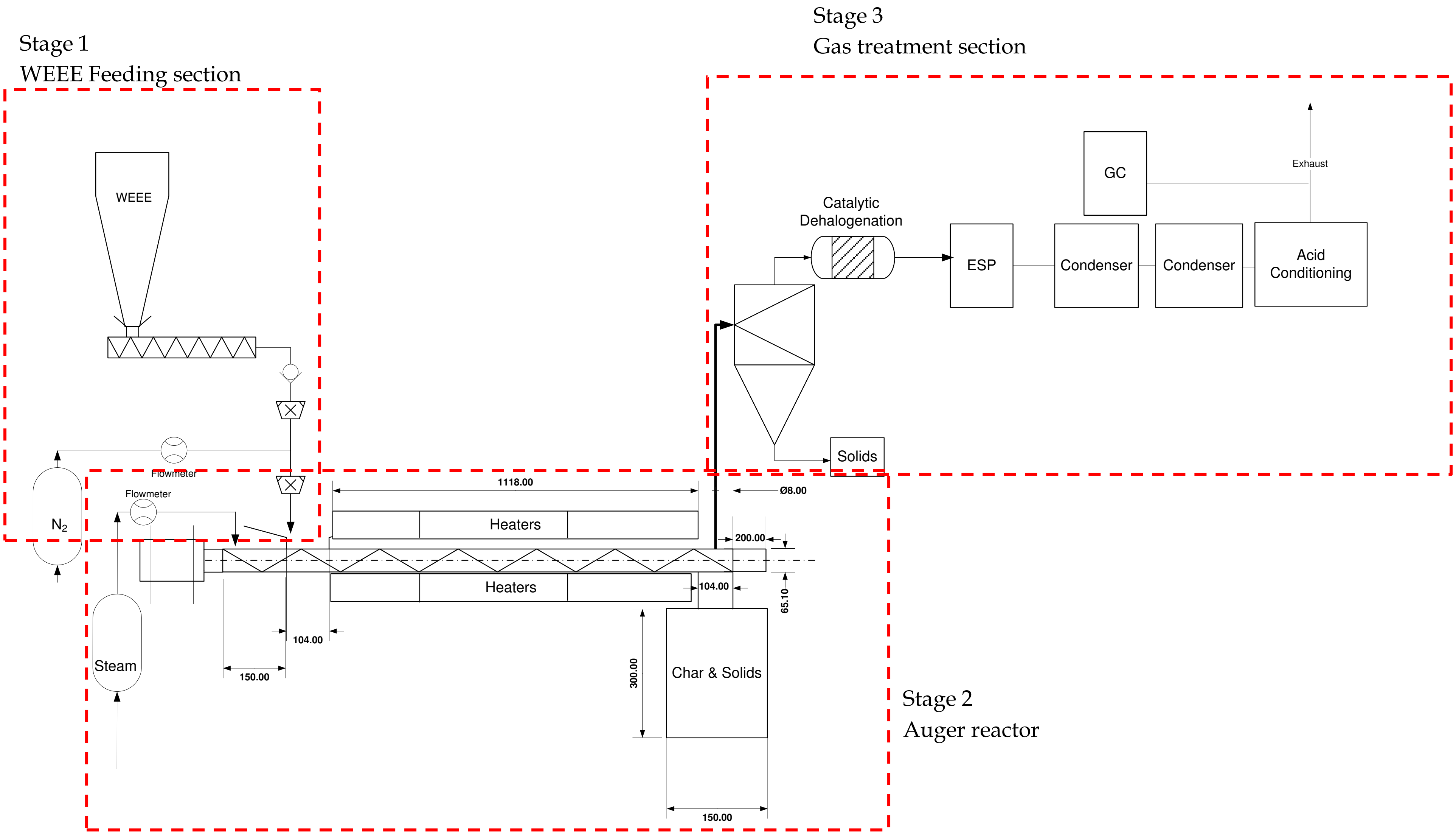
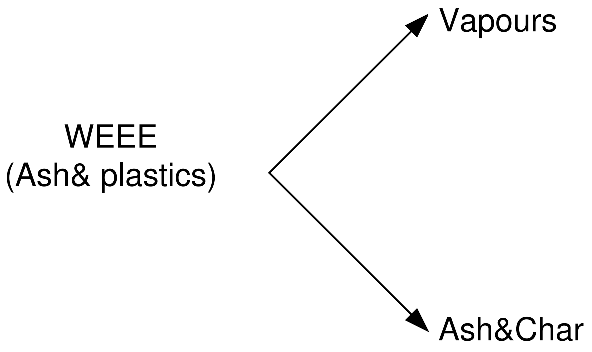


Figure 1 WEEE pyrolysis process overview

2. Mass Balances, Chemical reaction kinetics and energy requirements.

WEEE is considered to consist of ash (inert) and organic content. Its thermal decomposition produces a mixture of vapours and a solid residue which can be considered that is essentially the ash content of the material. This implies that the organic solid waste is converted to vapours according to the following:



The WEEE material has the following properties:

Particle size [mm]	0-6
Bulk Density [kg m^{-3}]	500
Ash content [wt %]	50
Organic content [wt %]	50
Heat of pyrolysis [kJ kg^{-1}]	530 (*1*)

A 1st order single step chemical reaction is considered for the thermal decomposition of solid material into vapours and char-ash.

The differential conversion of the material with respect to time can be described as follows:

$$\frac{d\alpha}{dt} = k(T)(1-\alpha) \qquad (Eq.1)$$

where a is the material conversion and k is the Arrhenius type reaction constant. a is defined as follows:

$$a = \frac{m_0 - m_t}{m_0 - m_f}$$

Where:

$m_0: initial\ mass\ of\ WEEE$

$m_t: mass\ of\ WEEE\ at\ time\ t$

$m_f: final\ mass\ of\ WEEE = m_{ash}$

$m_{org_0}: initial\ mass\ of\ plastics$

$$m_{org} = m_{org0}(1 - \alpha)$$

$$m_{vap} = m_{org0}a$$

$$a = \frac{m_0 - m_t}{m_{org_0}} \Rightarrow$$

$$a = \frac{m_0 - m_t}{m_0 - m_f} \Rightarrow$$

$$a = \frac{m_0 - m_t}{m_{org_0}} \Rightarrow$$

$$\frac{d\alpha}{dt} = k(T)(1 - \alpha)$$

$$\frac{dz}{dt} = u$$

$$u\frac{d\alpha}{dz} = k(T)(1 - \alpha)$$

$$\varDelta\dot{Q} + \sum F_i H_i|_V - \sum F_i H_i|_{V+\varDelta V} = 0$$

$$\varDelta\dot{Q} = UA_{exch.}\varDelta V(T_\alpha - T)$$

$$UA_{exch.}(T_\alpha - T) + \frac{\sum F_i H_i|_V - \sum F_i H_i|_{V+\Delta V}}{\Delta V} = 0$$

Taking the limit of ΔV→0 we result in the following expression:

$$UA_{exch.}(T_\alpha - T) - \frac{d\sum(F_i H_i)}{dV} = 0$$

$$UA_{exch.}(T_\alpha - T) - \sum\left(\frac{dF_i}{dV}\right)H_i - \sum\left(\frac{dH_i}{dV}\right)F_i = 0$$

$$UA_{exch.}(T_\alpha - T) - \sum v_j(-r_A)H_i - \sum \frac{C_{pi}F_i}{A_{cross.}}\frac{dT}{dz} = 0$$

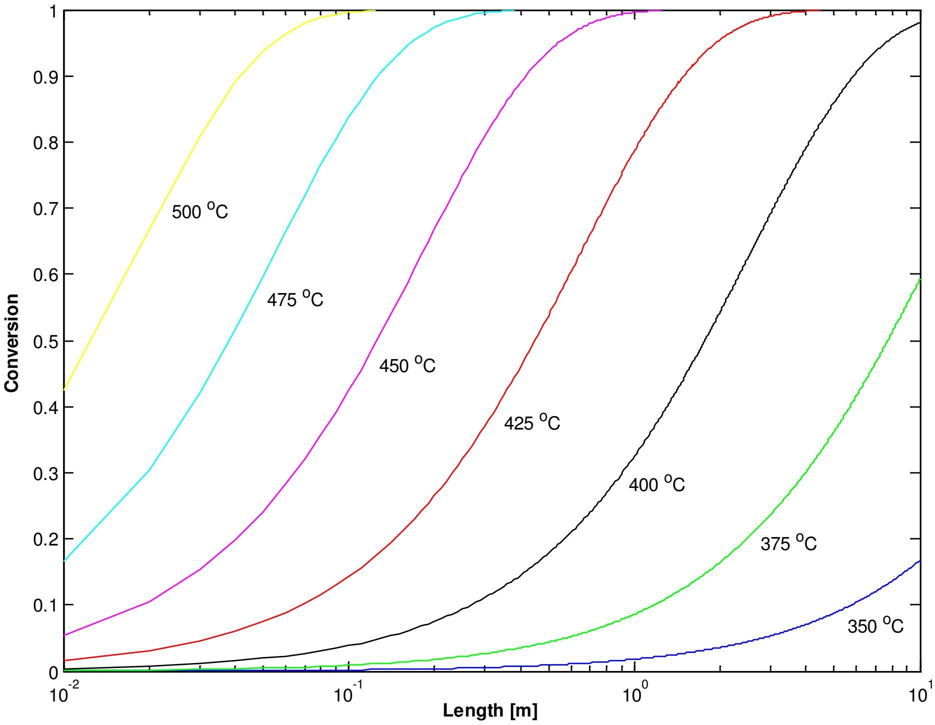


Figure 2 Required reactor length for 99,99% conversion during isothermal treatment (instant heat transfer) for linear velocity 0,1 m/min

It is obvious from Figure 2 that for high conversion (>90%) at a reasonable reactor length (<3m) the material has to be exposed at temperatures greater than 450°C.

3. Design of Auger Reactor

The WEEE material has a maximum hard particle size of ~6mm (~0.24 in) and therefore is classified as granular material with designation code C½ .The WEEE material is of average flowability (designation 3) and abrasive (designation 7) the elevated temperature is designated as code (Z). Therefore the material code is C½37Z.

The bulk density of the material is:

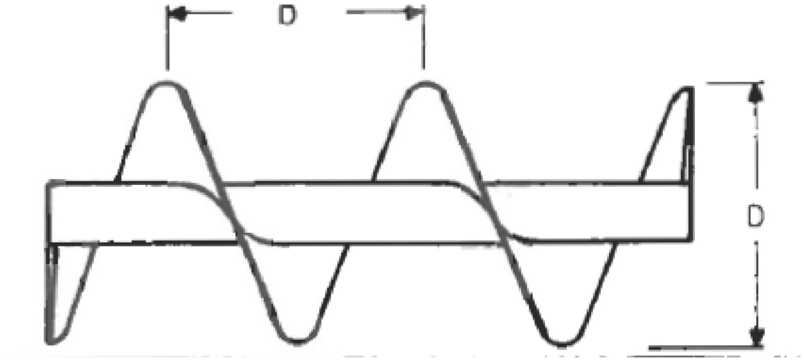
$$\rho_b = 500\ [kg\ m^{-3}] = 31.214\ [lb\ ft^{-3}]$$

The mass flow rate is 0.5 kg h^{-1} which corresponds to 0.001 m^3/hr or 0.03531 ft^3/hr.

The equivalent capacity is defined as:

$$Eq.Capacity\ [ft^3hr^{-1}] = Req.Capacity\ [ft^3hr^{-1}] \times CF_1 \times CF_2 \times CF_3$$

Standard pitch is the most common for most of the material and thus CF_1 = 1 .00 (2).



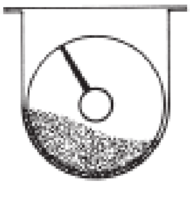
Shorter pitch is used in inclined applications (3).

A standard flight will be used and thus CF_2 is equal to 1.00

Since there are no mixing paddles CF_3 equals to 1.00 (2).

Therefore, $Eq.Capacity\ [ft^3hr^{-1}] = 0.03531\ \text{ft}^3/\text{hr}$

The load capacity for the material category is 30%(B type) (2)



The required rotational speed is calculated by the following:

$$N = \frac{Eq.Capacity \times CF_0}{cubic\ feet\ per\ hour\ at\ 1\ RPM}$$

Extrapolation of the capacity tables by CEMA (for ½ inch increment) gives that at 2.5 inches the capacity at 1 rpm is 0.049 ft^3/hr and thus

$$N = 1,57 \sim 1,6\ RPM$$

With maximum rotational speed of around 70 RPM.

Table 1 Summary of screw dimensions

D_{screw} [cm] / (inches)	6,35/ 2,5
D_{pitch} [cm] / (inches)	6,35 / 2,5
D_{shaft} [cm] / (inches)	1,59 / $^5/_8$
Clearance [mm] / (inches)	0,80 / $^1/_{32}$
Flight Thickness [mm] /(inches)	1,6 / $^1/_{16}$
Revolutions per min	1
Max. Revolutions per min	70
Trough Thickness [mm]	2,6

Determination of the auger length

Assumptions:

I. The auger length was considered as the required length to achieve 99,99% conversion of the organic fraction of the WEEE material.
II. The material is considered to behave as a moving bed in the reactor.
III. The reactor walls are kept at a constant temperature of 600°C.
IV. The ash was considered to be comprised of SiO_2.

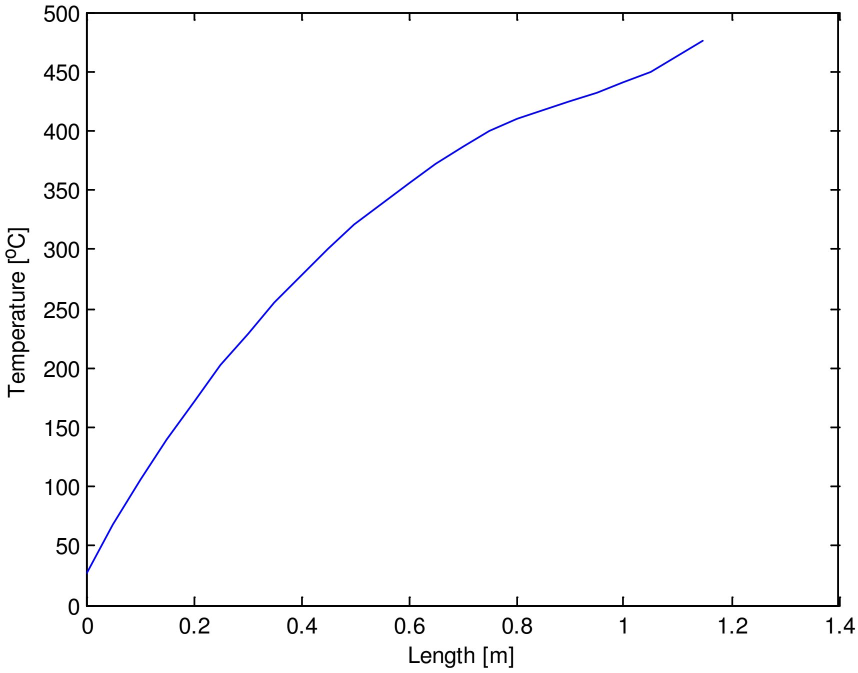


Figure 3 Temperature profile in the auger reactor

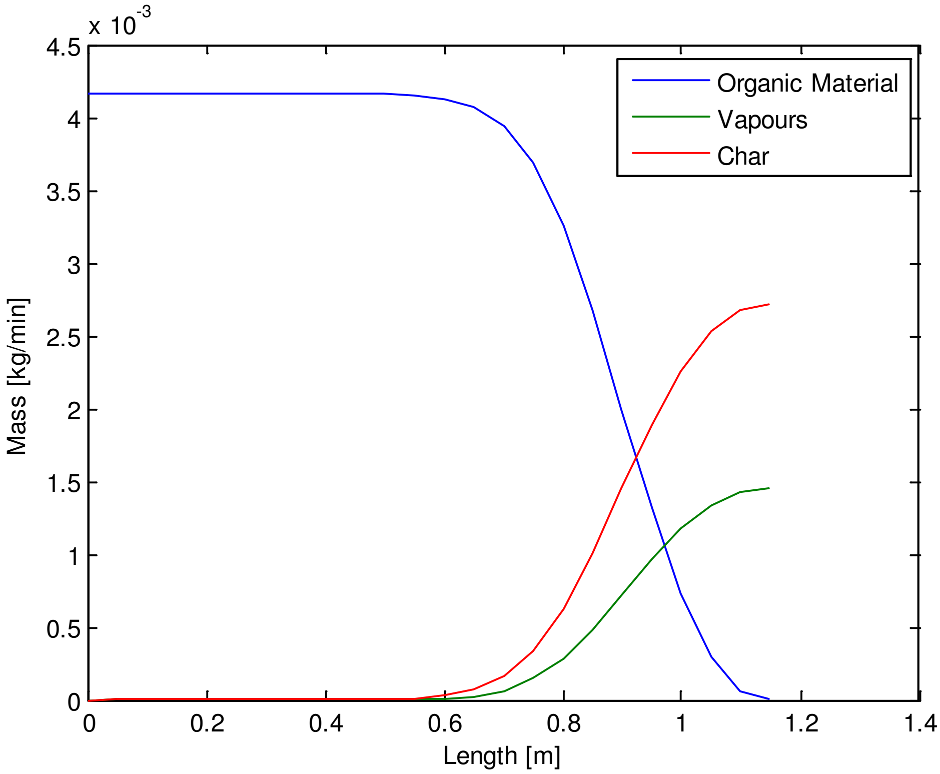
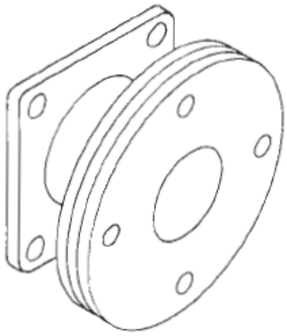


Figure 4 Products profile along reactor length

The required length for conversion of 0.5kg h^{-1} of WEE material is ~1.2 m. the overall reactor length should include a start-up length and feeding length as well as a discharge length and cooling length of the screw.

Thus the overall length of the auger reactor is approximately 1.7m. The overall heat duty for a capacity of 0.5 kg h^{-1} equals to 77 W.

A flanged gland shaft seal is the most positive shaft seal and can be used at the through end and is suitable for pressurized applications.



4. Materials of construction

Material selection is very important when working with high temperature. According to CEMA for operating temperatures up to 750 °C (1400°F) 316 SS should be used for the reactor (*4*).

5. Bibliography

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