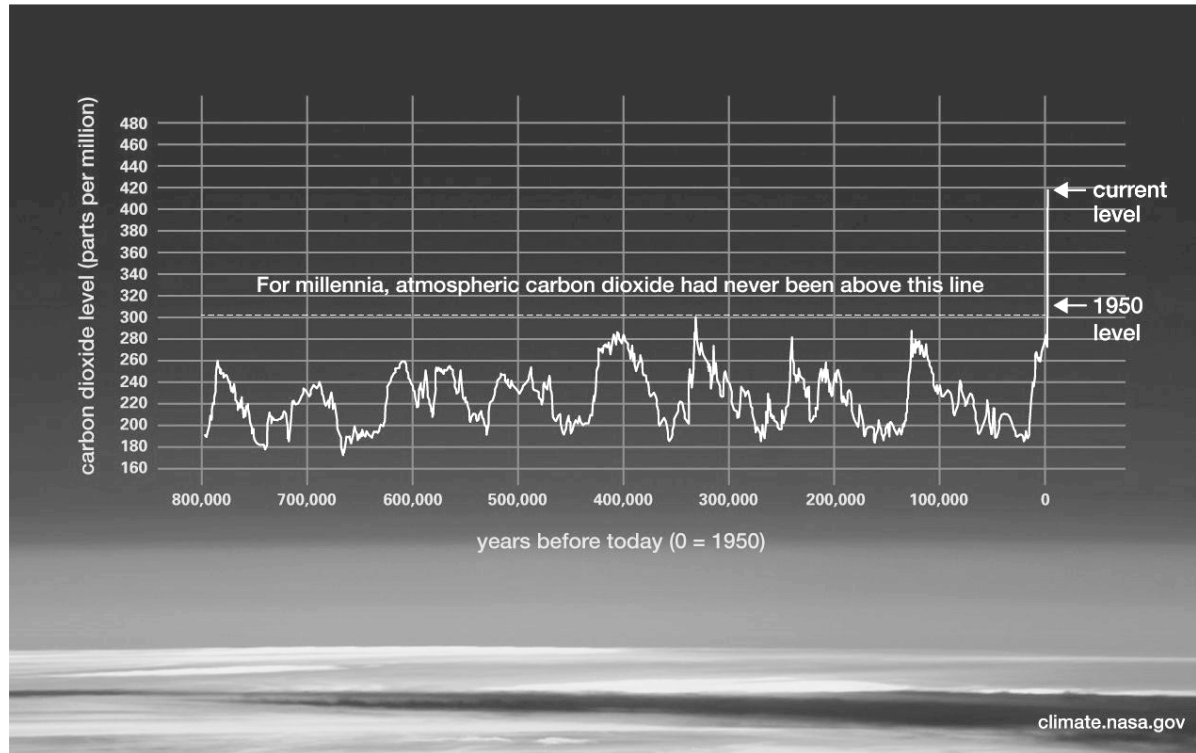


1 Jansen PhD thesis Figures

2

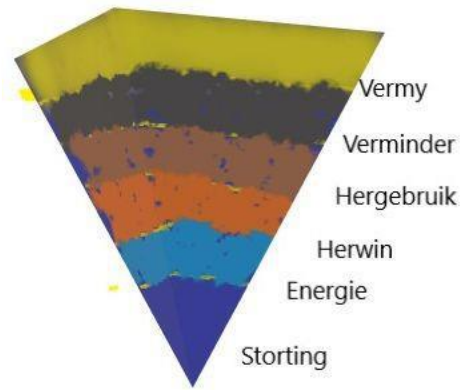
Hoofstuk 1.



3

4 Figuur 1-1: Gemete en geraamde atmosferiese CO₂-vlakke die afgelope 800 000 jaar soos uit verskillende bronne saamgestel deur NASA.

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Figuur 1-2: Illustrasie van die afvalhiërargie.

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Figuur 1-3: Voorbeeld van 'n bande-opslagplek.

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Figuur 1-4: Brandende bande-opslagplek, Koeweit, 2021



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2 Figuur 1-5: Voorbeeld van kommersiële bandesnippers, koordmateriaal nie verwyder.

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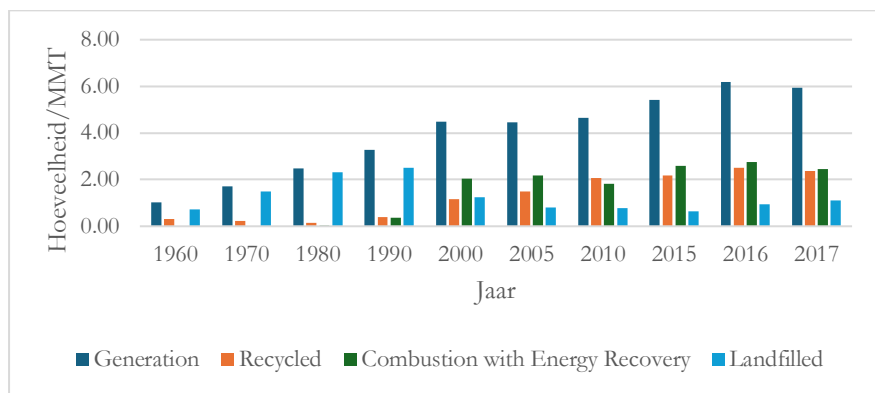
2

3 Figuur 1-6: Voorbeeld van bandrubber granules soos gebruik vir hierdie studie.

4

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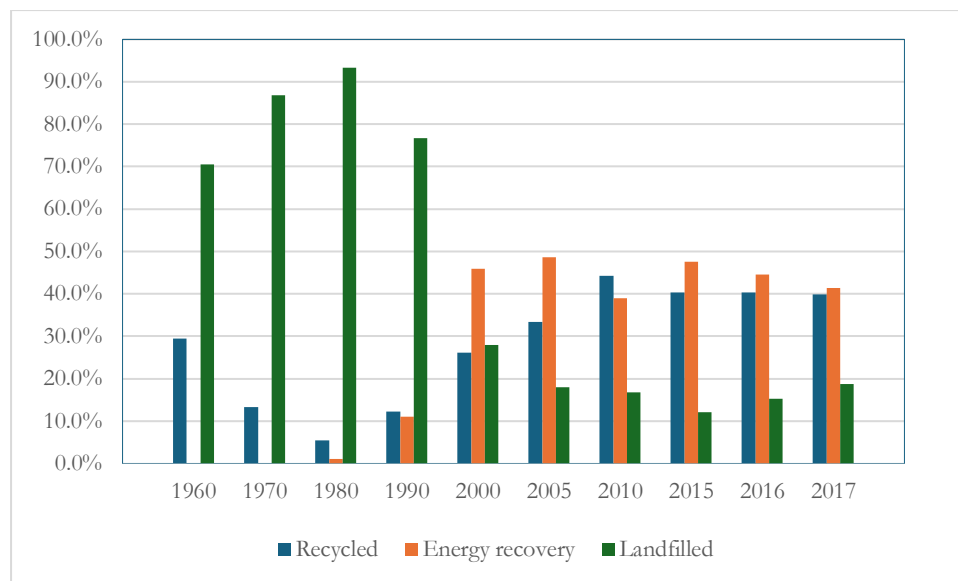
Hoofstuk 2.



2

3 Figuur 2-1: VSA Omgewingsbeskermingagentskap data vir bandevertaardiging, herwinning, energieherwinning en storting.

4



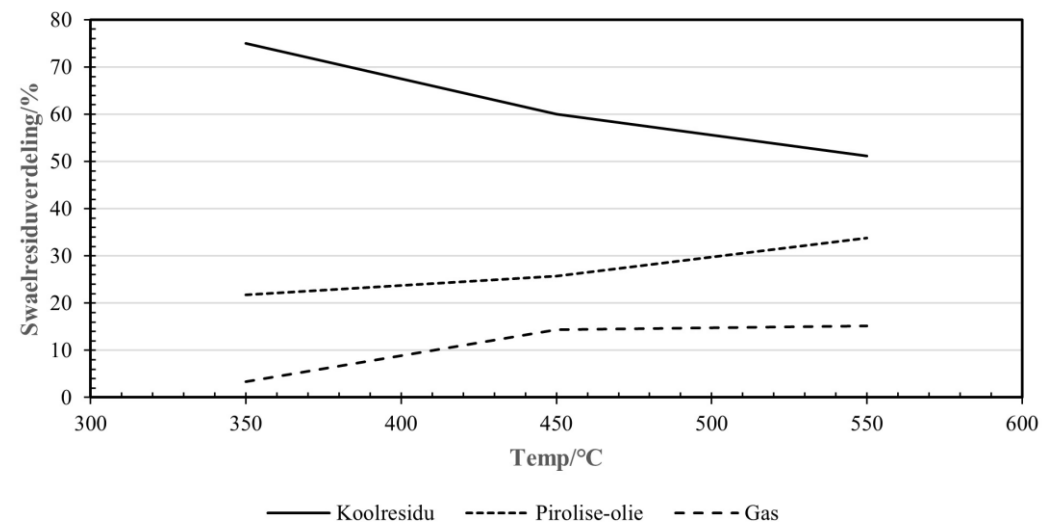
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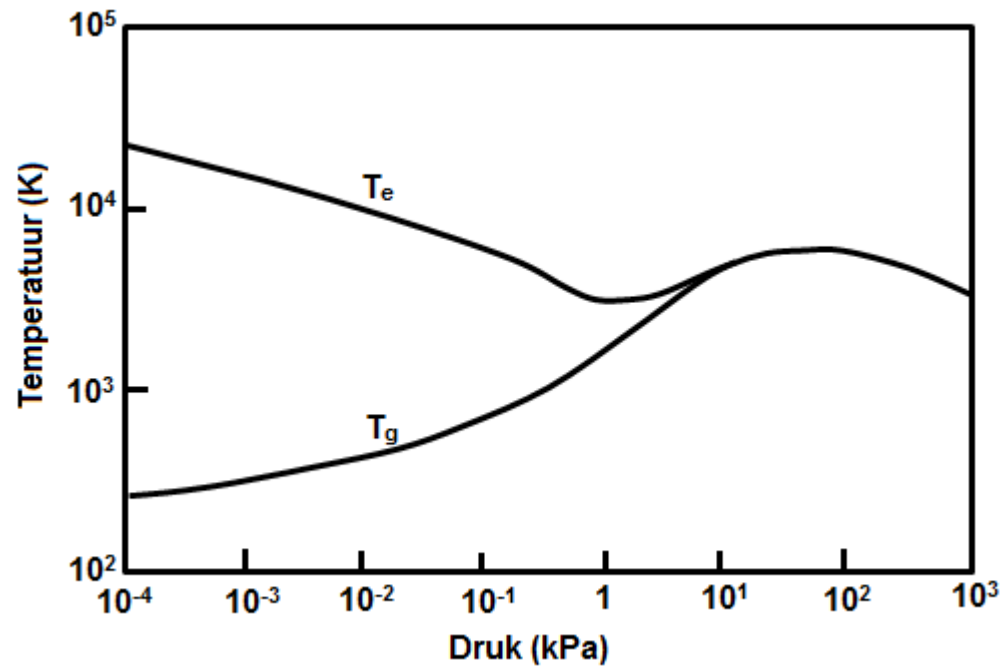
4

Figuur 2-2: VSA Omgewingsbeskermingagentskap data vir bandevervaardiging, herwinning, energiekeerwinning en storting as fraksie van die totaal vervaardig, 2016–2017.

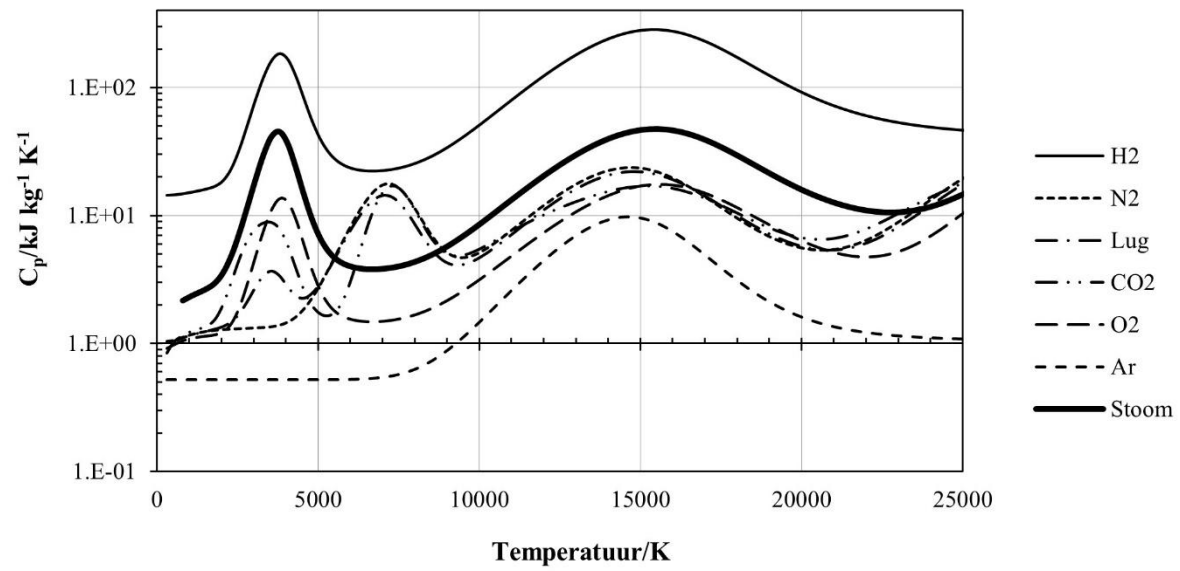


Figuur 2-3: Die effek van pirolisetemperatuur op die swaelinhoud van produkstrome.

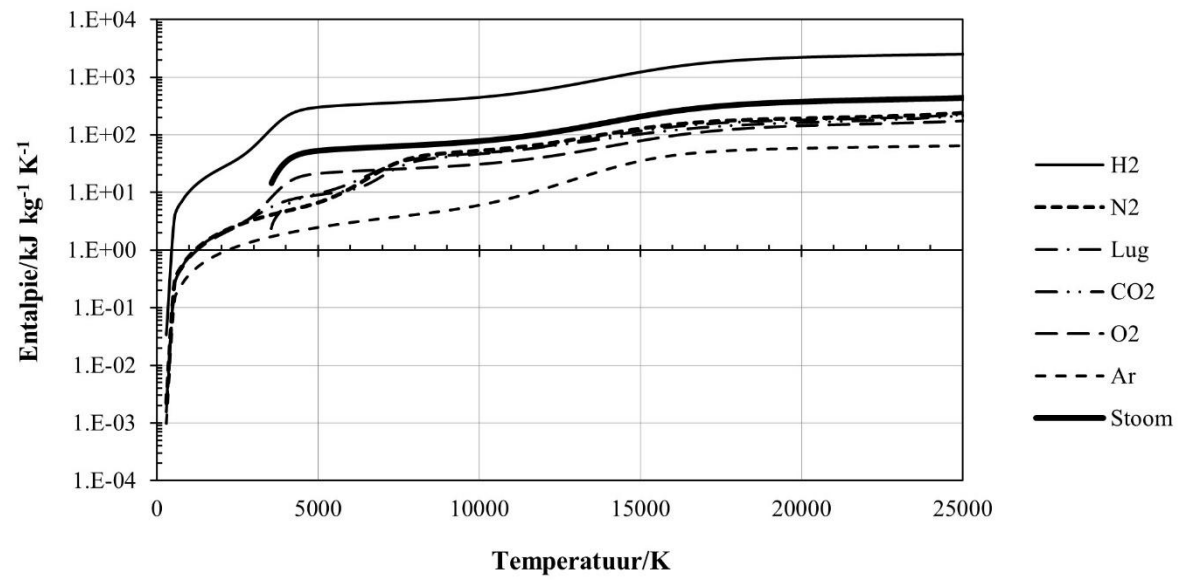
Hoofstuk 3.



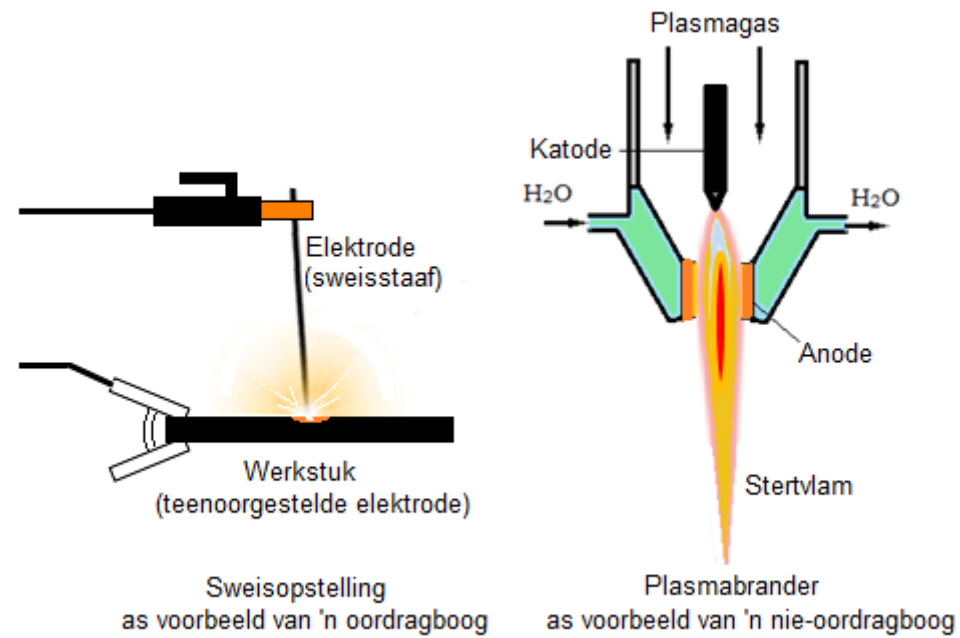
Figuur 3-1: Elektron- en gastemperatuur (K) van argon as funksie van absolute druk (kPa).



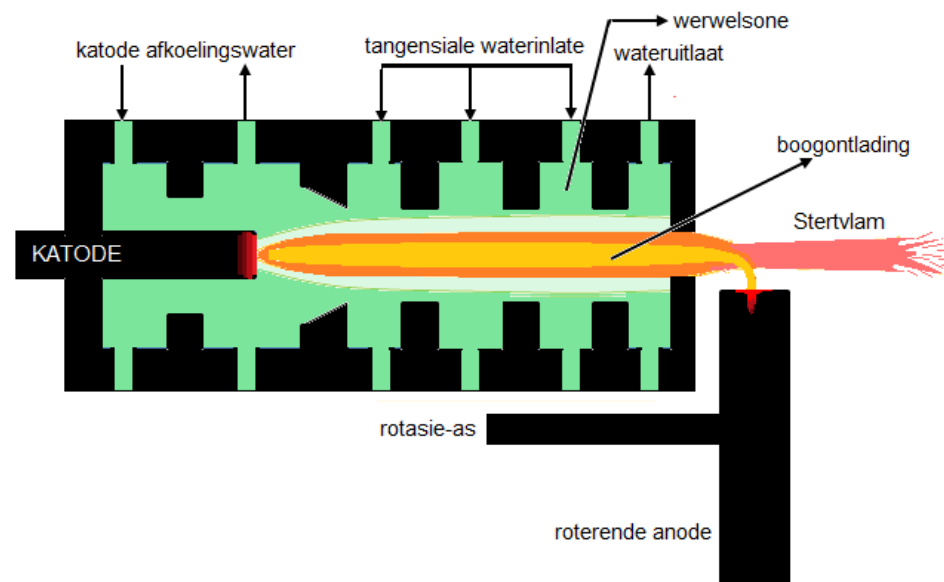
Figuur 3-2: Spesifieke warmtekapasiteit van H_2 en ander tipiese plasmagasse by atmosfersiese druk.



Figuur 3-3: Entalpie van H_2 en ander tipiese plasmagasse by atmosferiese druk.

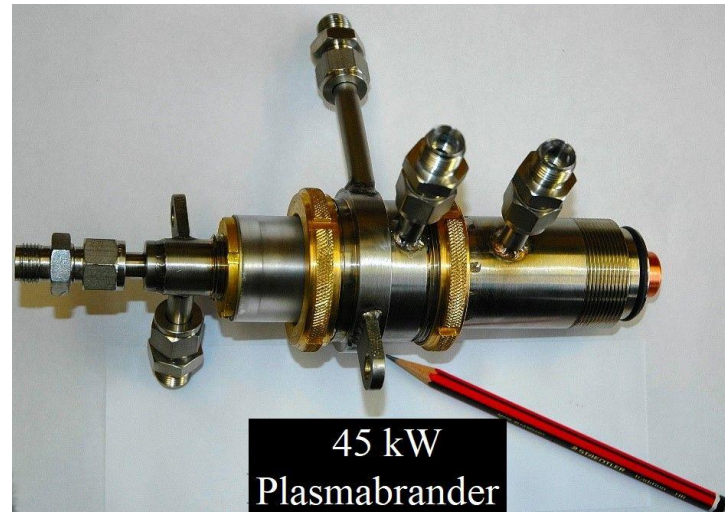


Figuur 3-4: Voorbeelde van 'n oordragboog en 'n nie-oordragboogplasma.



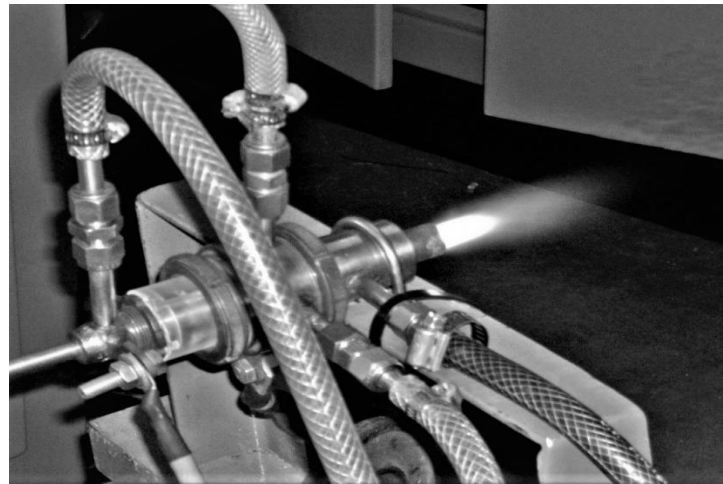
Figuur 3-5: Vloeistofgestabiliseerde plasmabranders.

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Figuur 3-6: 45 kW lug/N₂ plasmabrander.

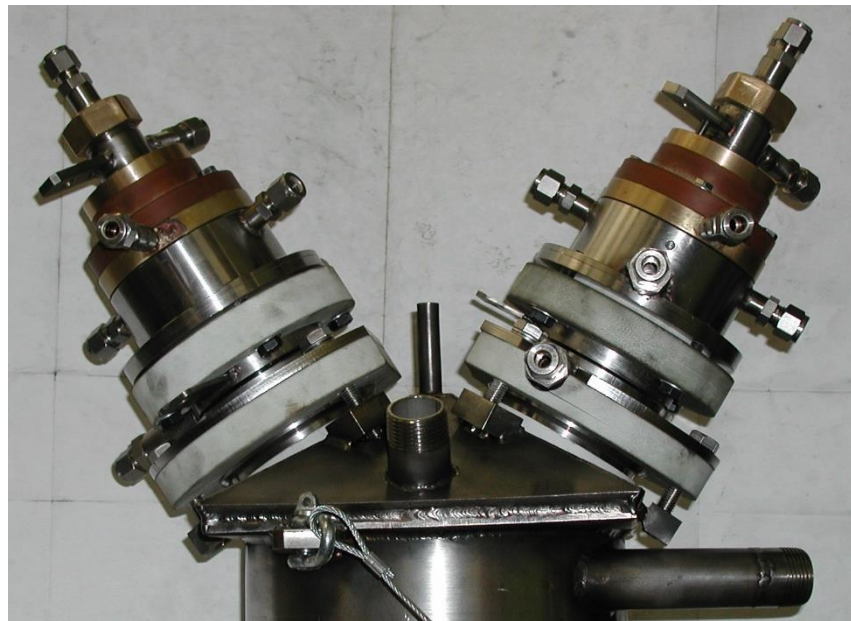
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Figuur 3-7: 20 kW(e) stikstofplasma.

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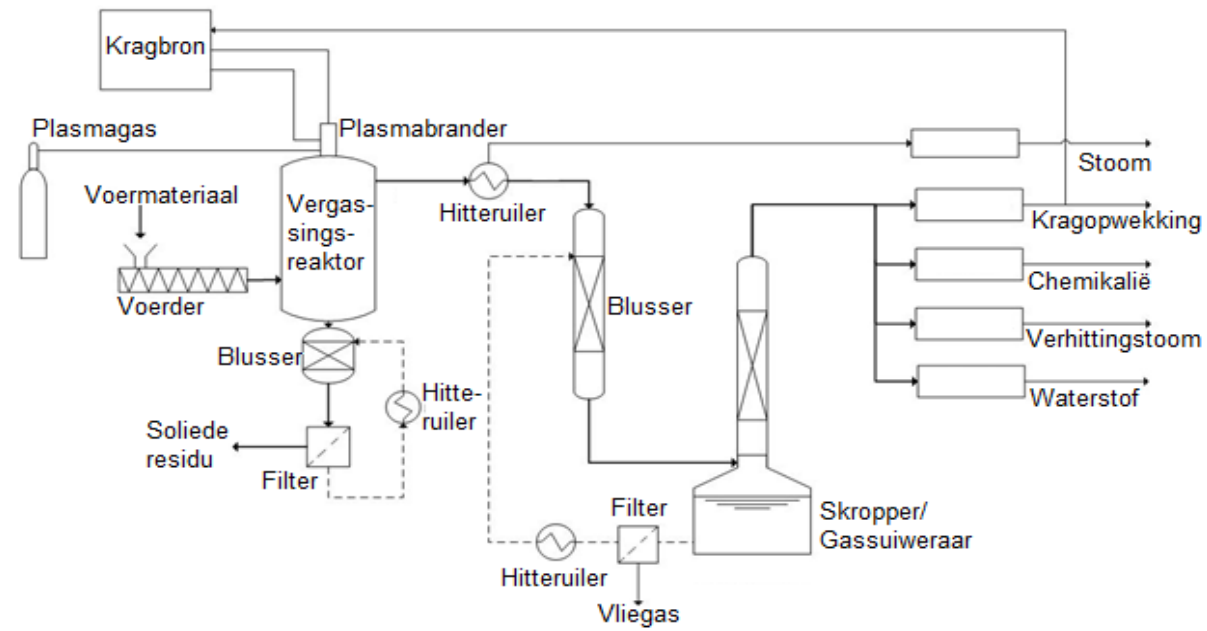


3

Figuur 3-8: V-vormige dubbelbrander opstelling.

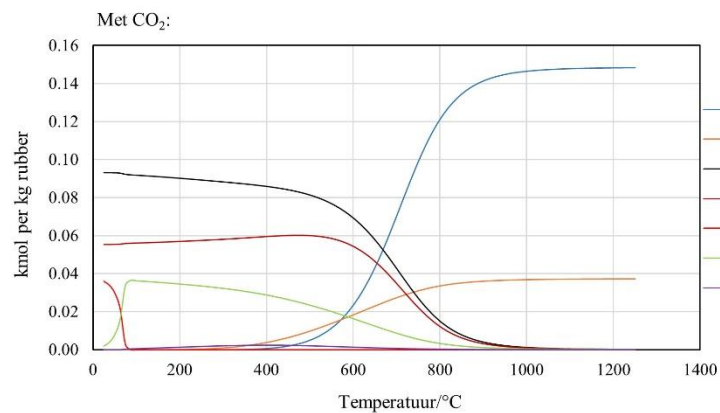
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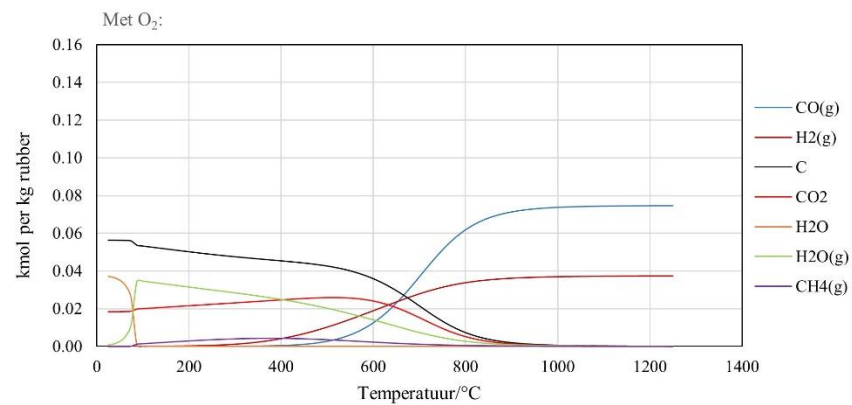


Figuur 3-9: Konseptuele skema vir 'n plasmavergassingstelsel.

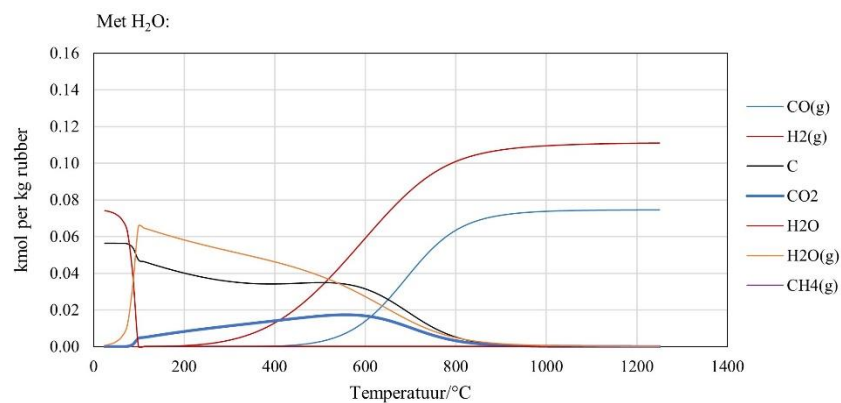
Hoofstuk 4.



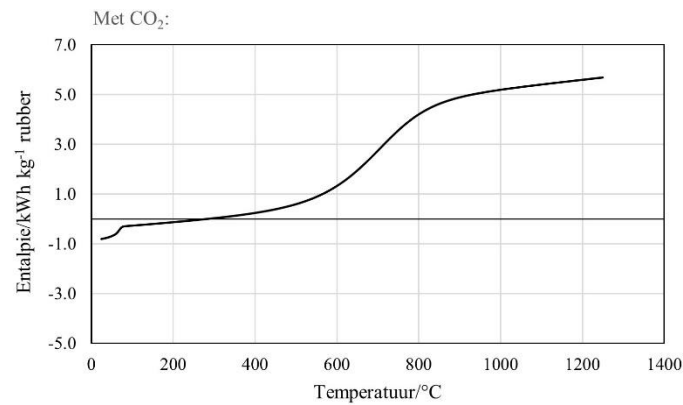
(a)



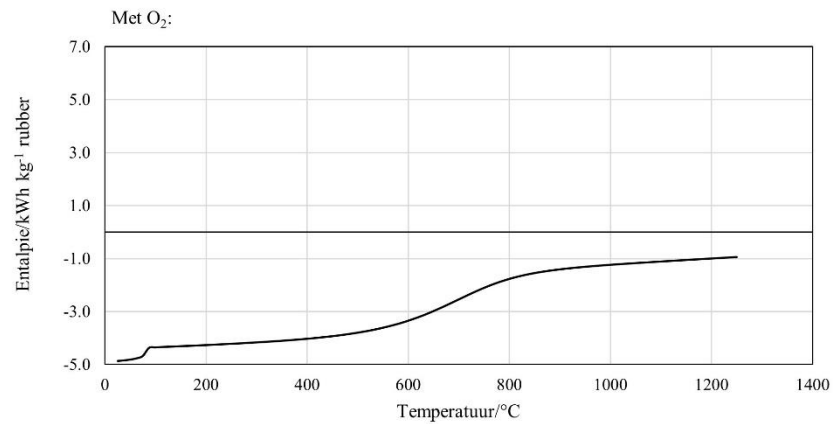
(b)



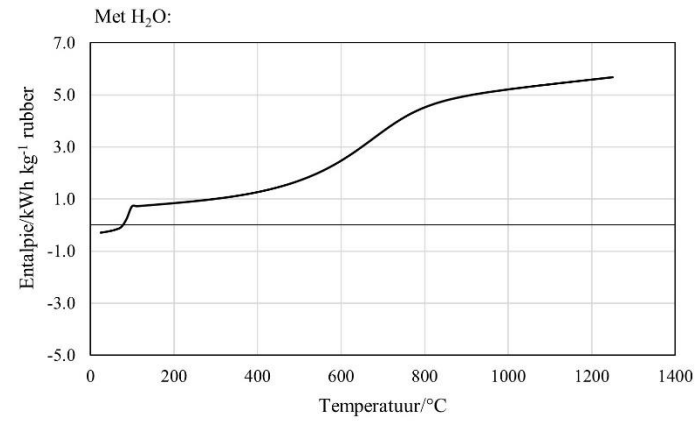
(c)



(d)



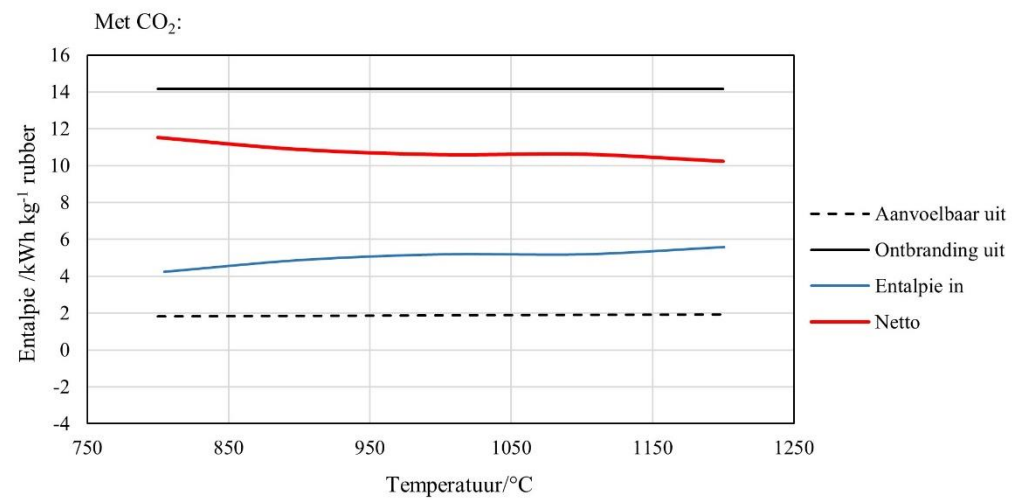
(e)



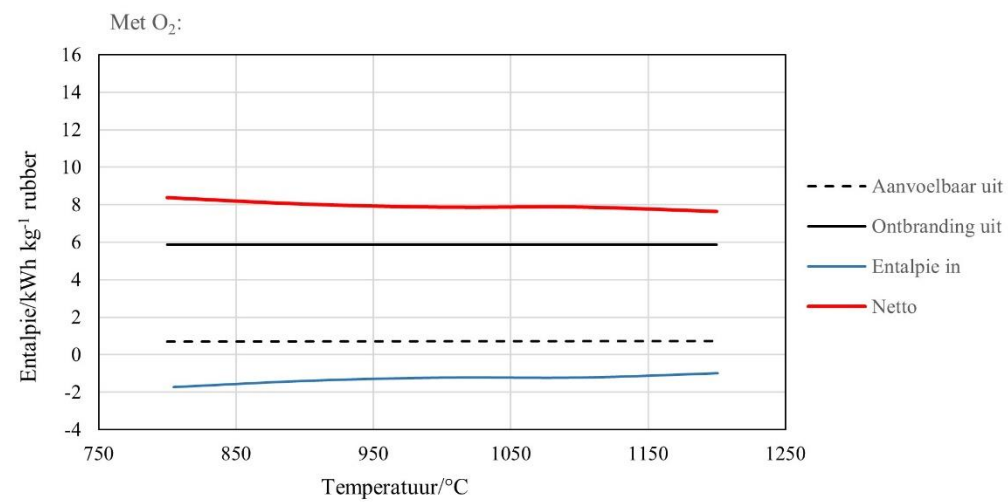
(f)

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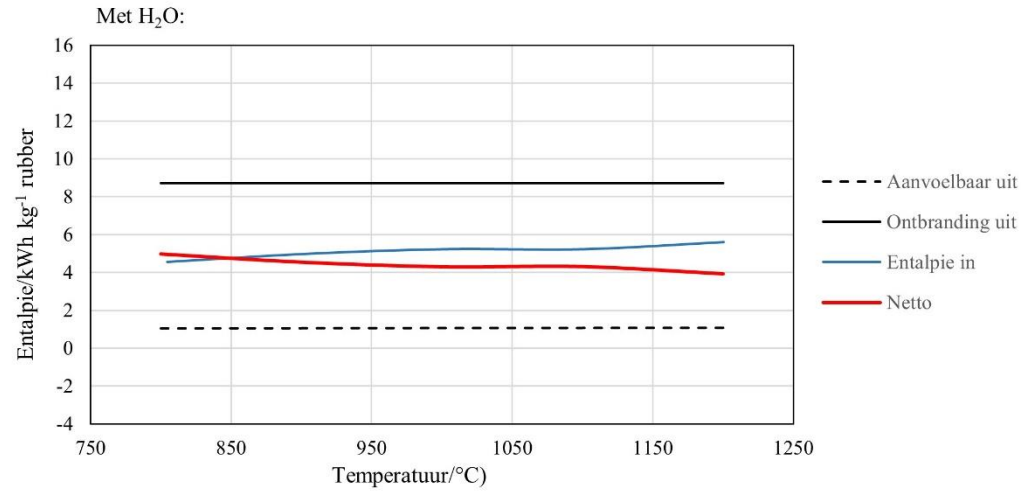
Figuur 4-1: Spesiëring tydens vergassing van 1 kg rubber met stoïgiometriese hoeveelhede (a) CO₂, (b) O₂, en (c) H₂O, en die energiebehoefte vir vergassing met (d) CO₂, (e) O₂, en (f) H₂O.



(a)



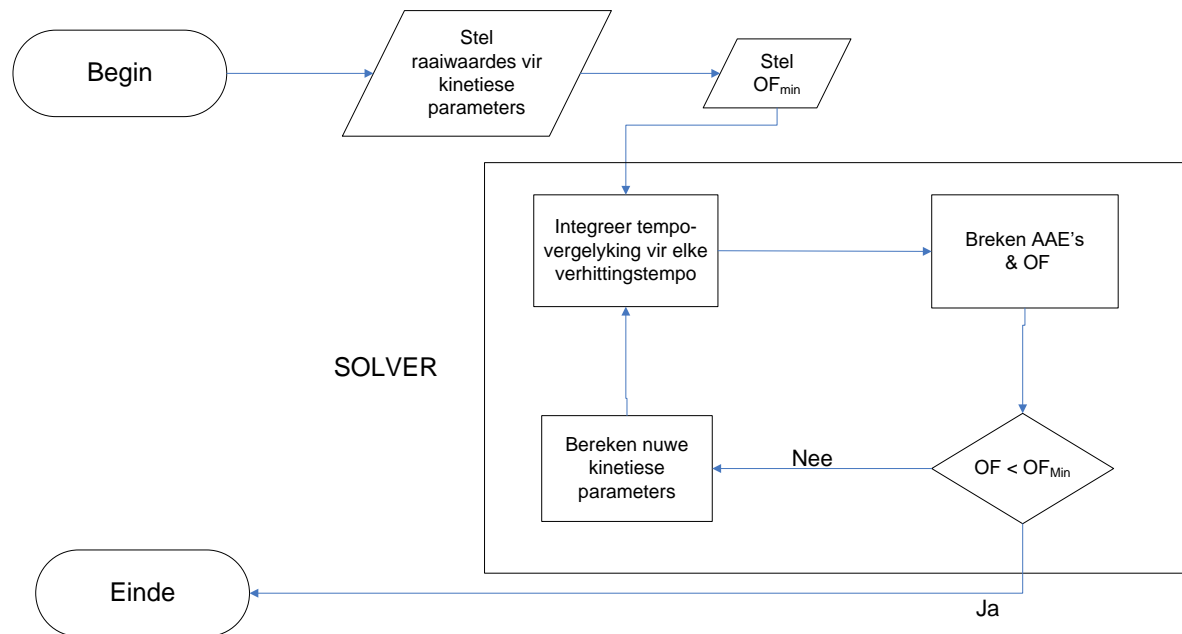
(b)



(c)
 Figuur 4-2: Entalpie-verdeling vir die vergassing van 1 kg rubber met (a) CO₂, (b) O₂, en (c) H₂O.

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Hoofstuk 5.

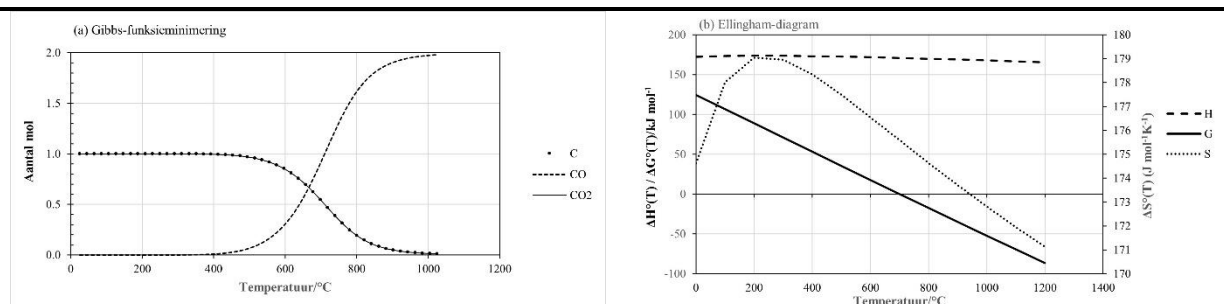


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Figuur 5-1: Vloedidiagram vir nie-lineêre krommepassing.

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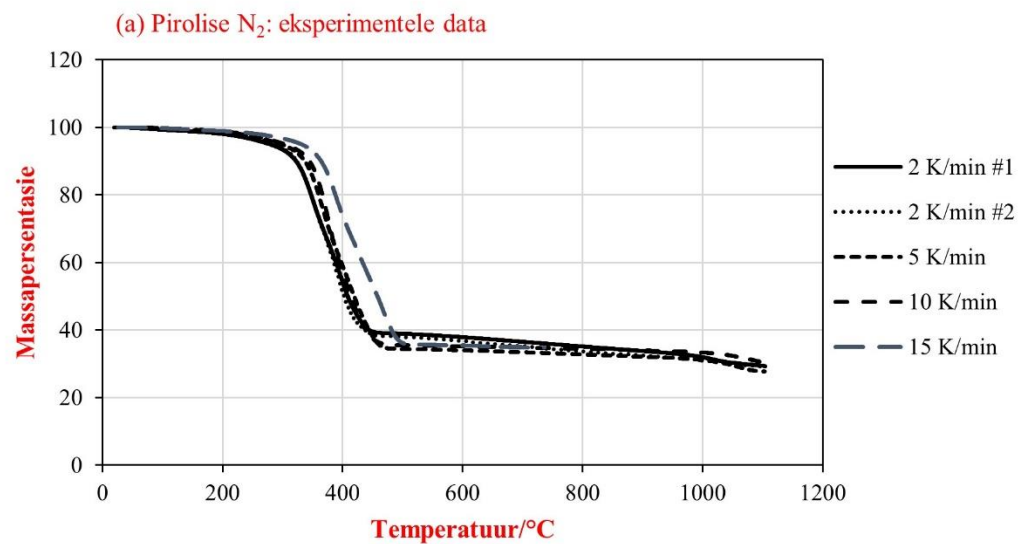


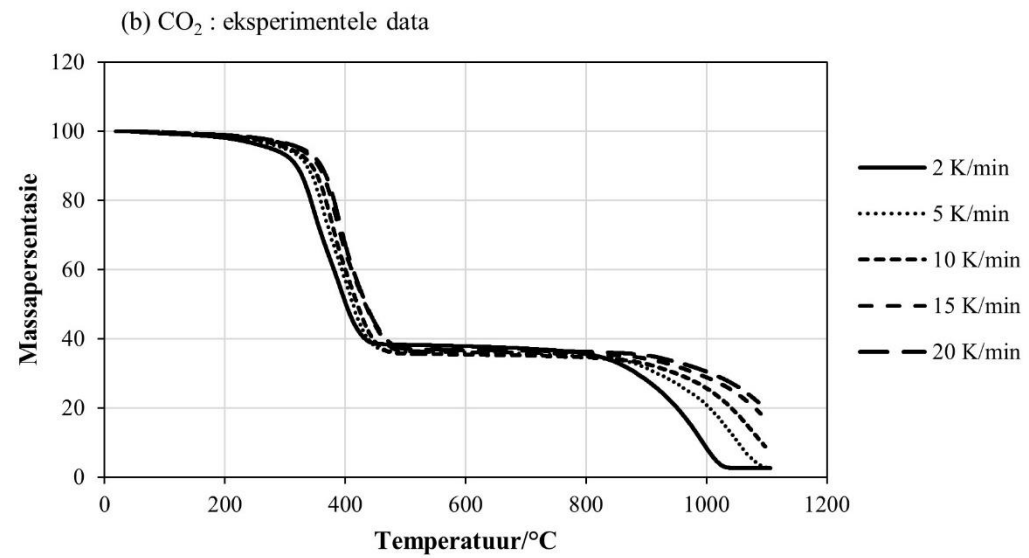
(a)

(b)

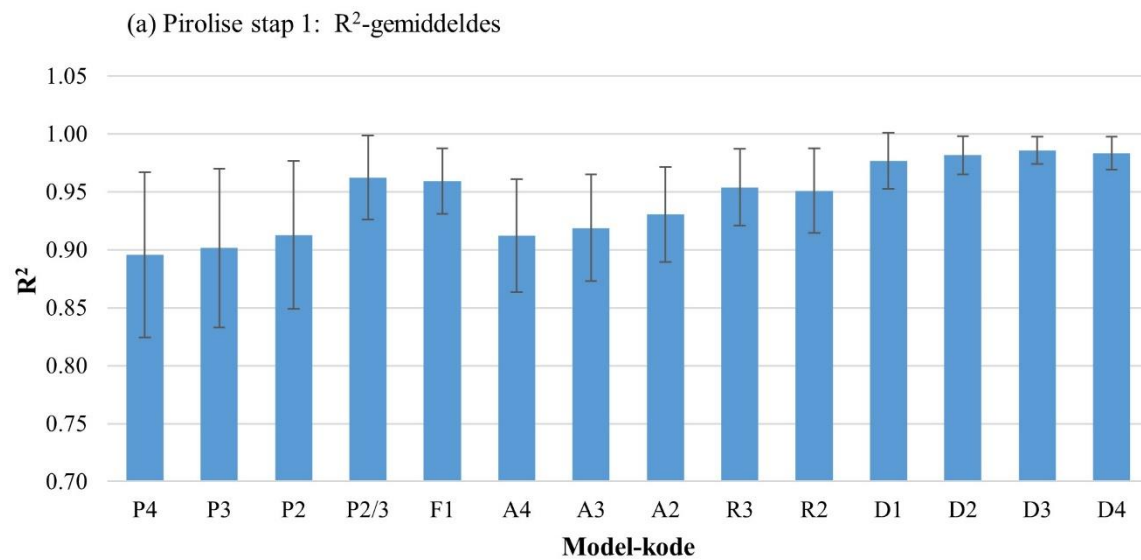
1 Figuur 5-2: Tru-Boudouardreaksie: (a) spesiëringsewewig kromme vir die stoigiometriese reaksie tussen CO_2 en grafiet en (b) die entalpie- en entropiebydraes
2 tot die veranderinge in die Gibbs-energie vir die reaksie.

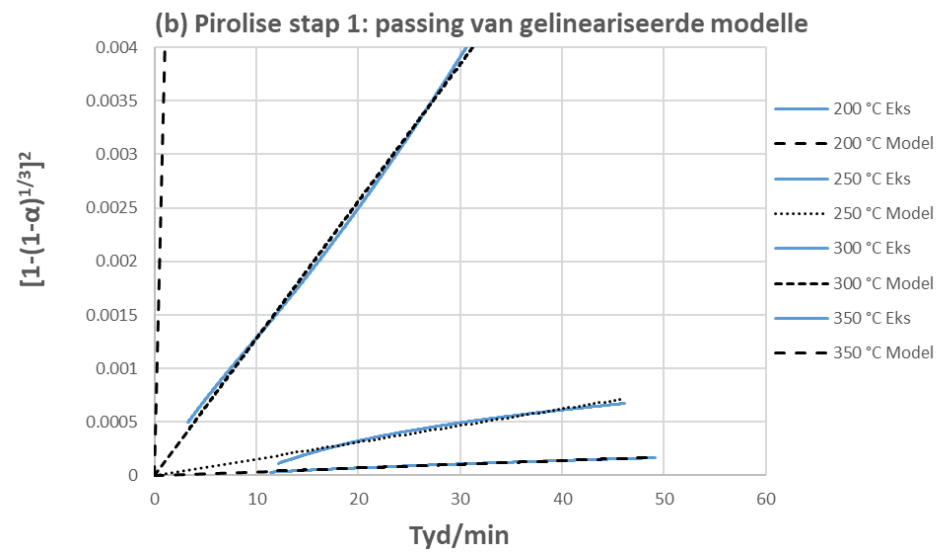
3

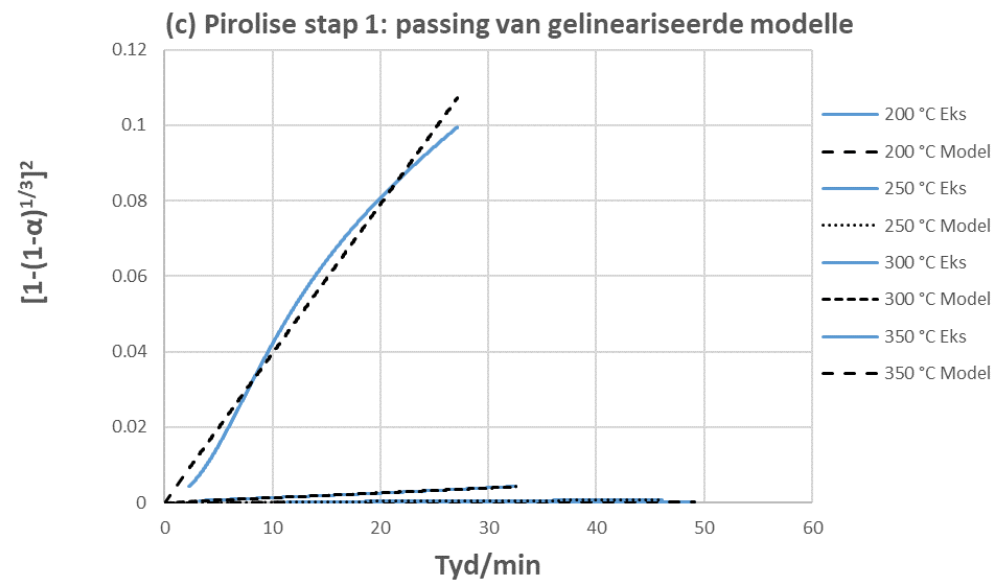


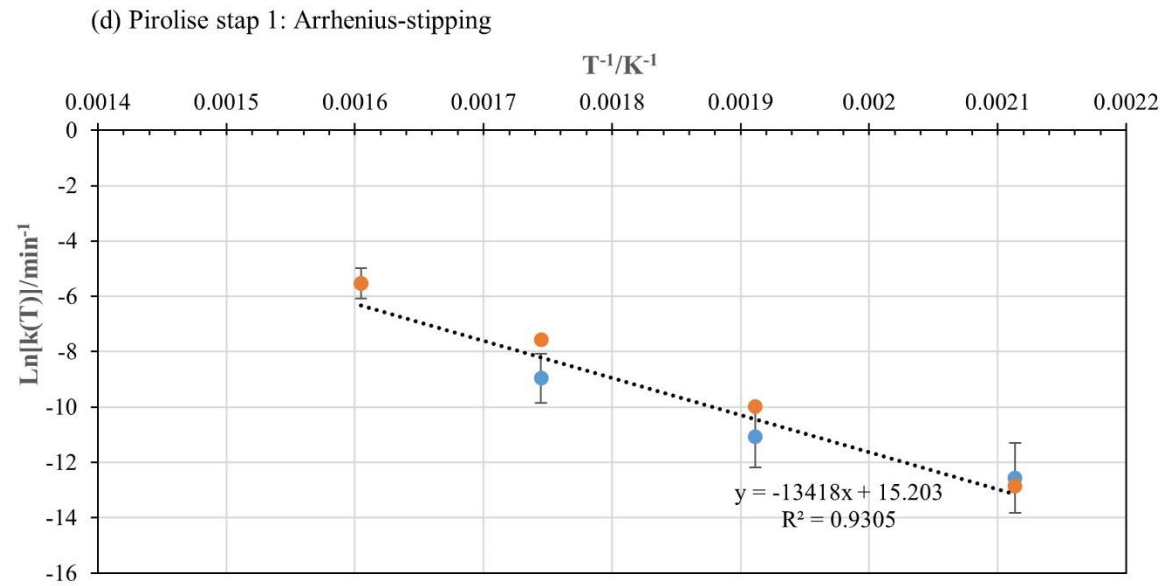


Figuur 5-3: TGA rou data onder (a) N₂ en (b) CO₂ vloeï.

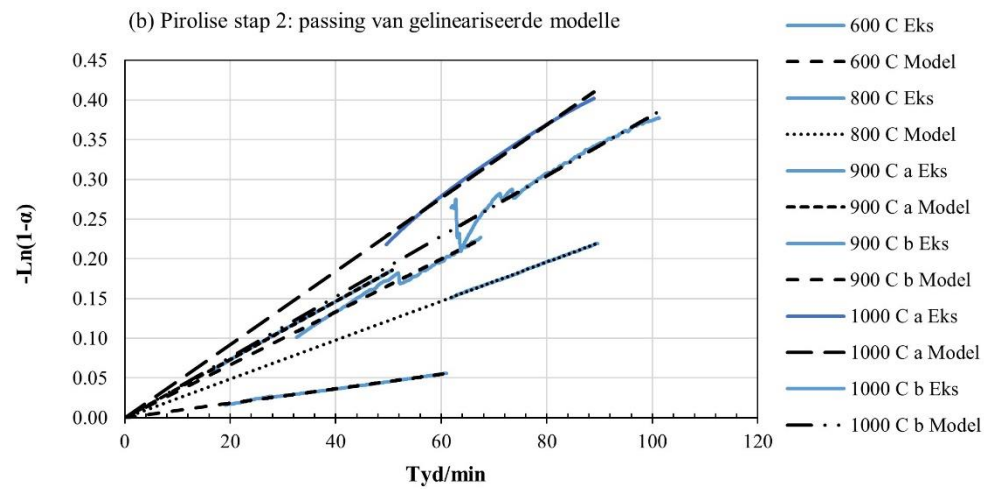
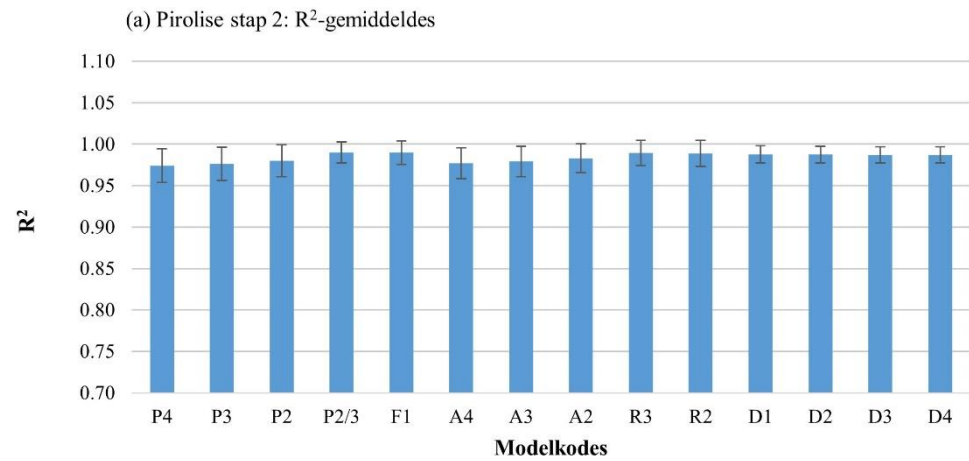


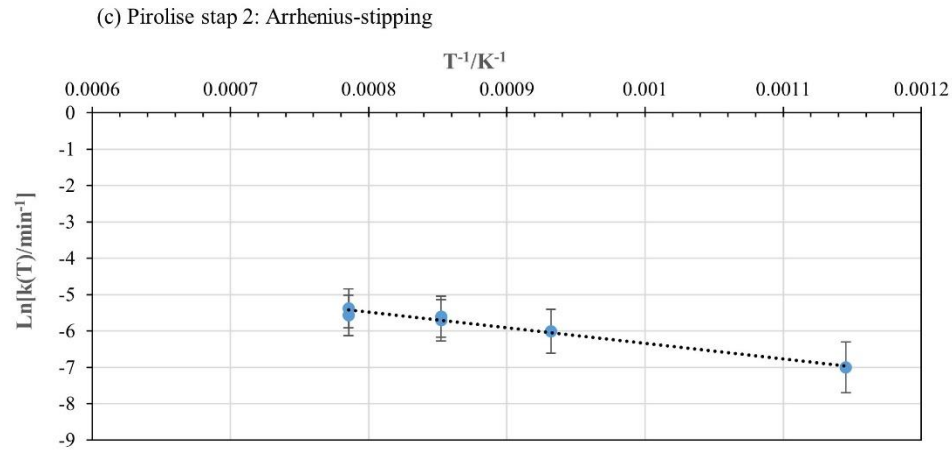




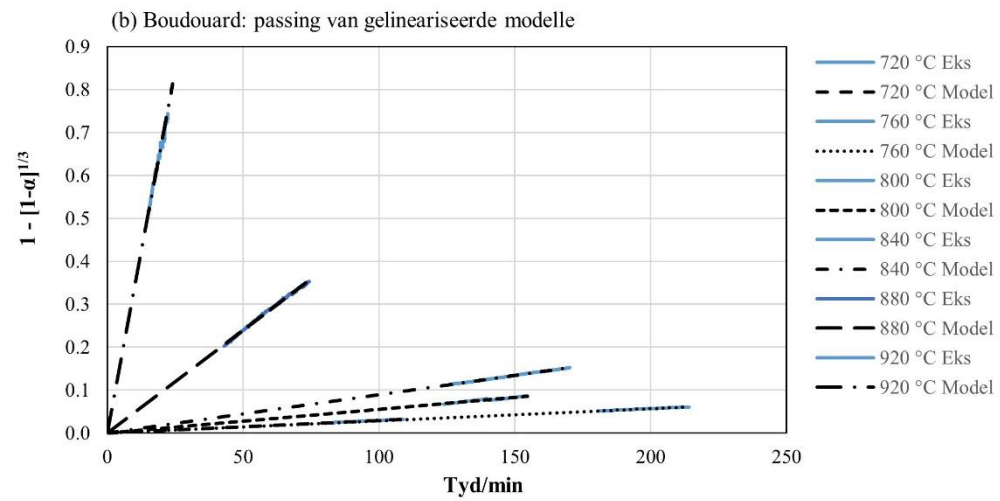
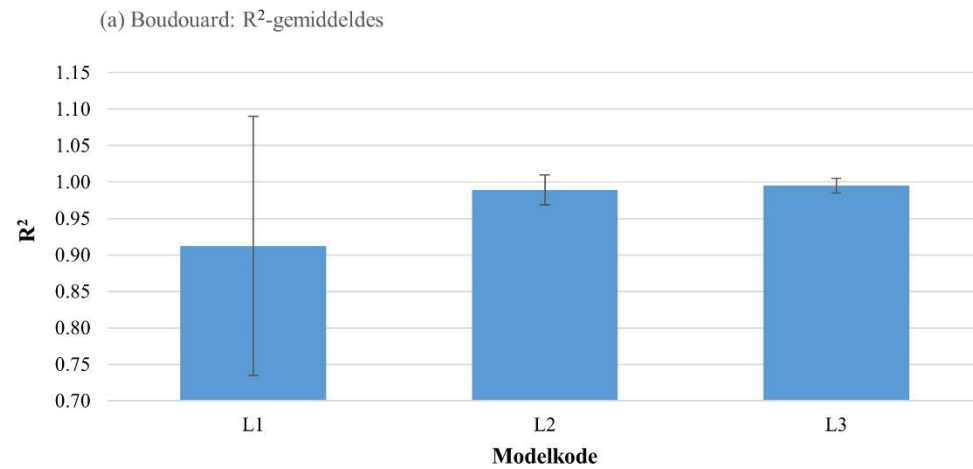


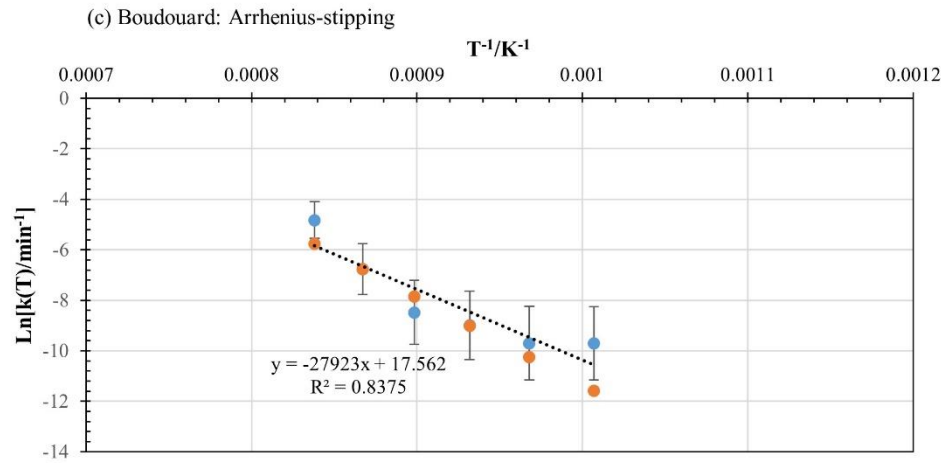
1 Figuur 5-4: Afleiding van die isothermiese kinetika van die eerste pirolisestap onder N_2 : (a) R^2 gemiddeldes oor die temperatuurgebied vir elke model; (b) en (c)
 2 eksperimentele data en modelpassing; en (d) Arrheniuskromme vir model D3.





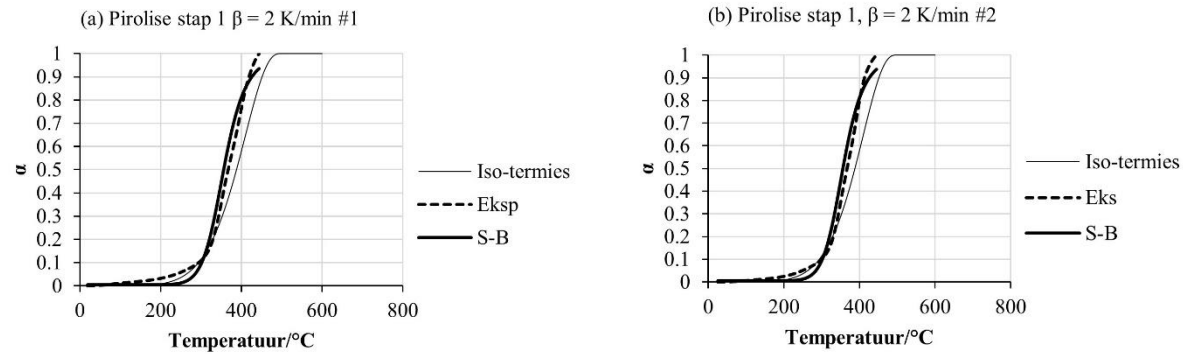
1 Figuur 5-5: Afleiding van die isotermiese kinetika vir die tweede piroliseverskynsel onder N_2 : (a) R^2 gemiddeldes en foutbalkies oor die temperatuurgebied vir
 2 elke model; (b) eksperimentele data en modelpassing; (c) Arrheniuskromme vir model F1.
 3

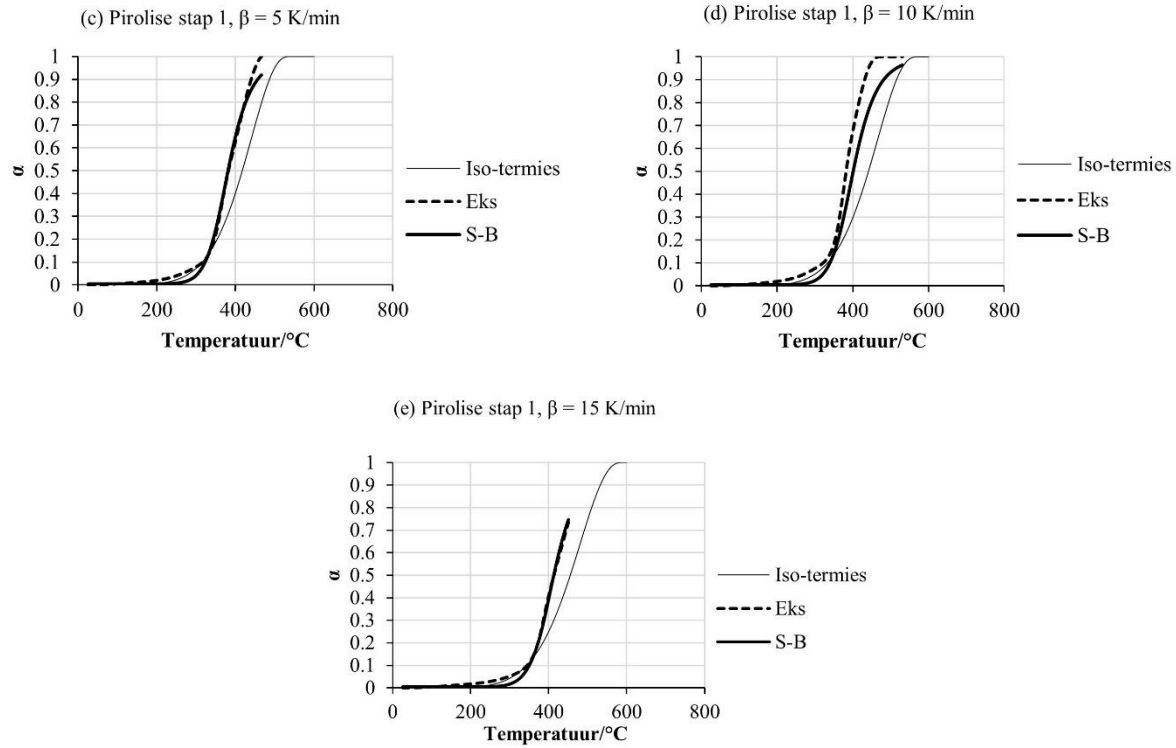




1 Figuur 5-6: Afleiding van die isothermiese kinetika vir die tru-Boudouardreaksie: (a) R^2 gemiddeldes en foutbalkies oor die temperatuurgebied vir elke model; (b)
 2 eksperimentele data en modelpassing; (c) Arrheniuskromme vir model L3.

3



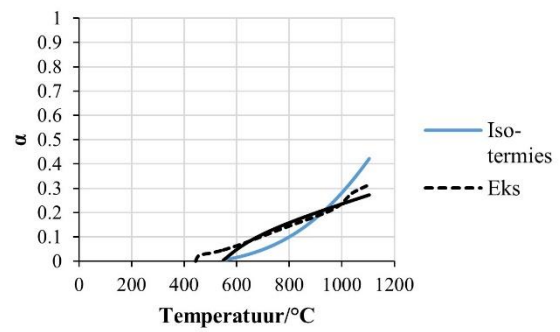


Figuur 5-7: Eerste termiese gebeurtenis onder suiwer N_2 . Krommes individueel gepas vir elke verhittingstempo.

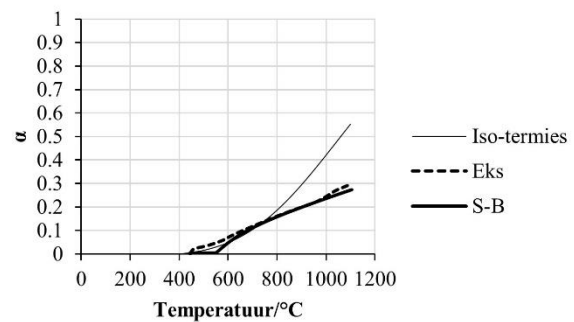
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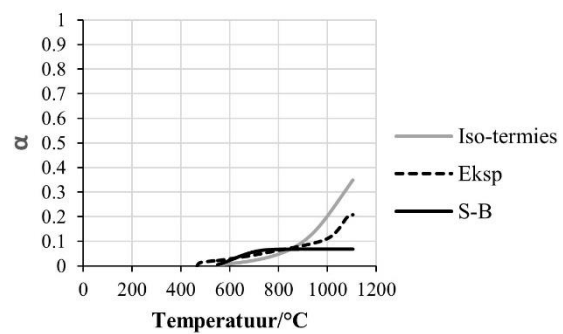
(a) Pirolise stap 2, $\beta = 2$ K/min #1



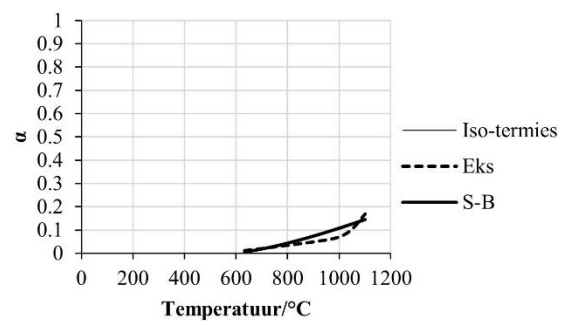
(b) Pirolise stap 2, $\beta = 2$ K/min #2

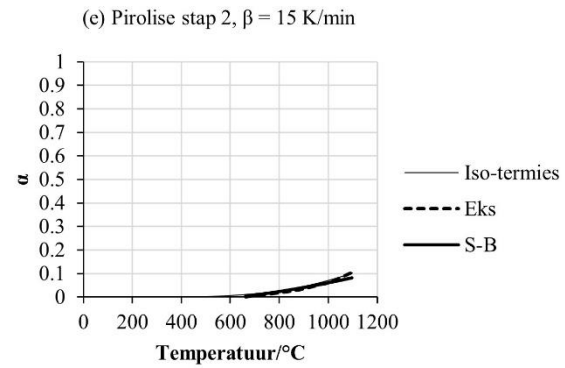


(c) Pirolise stap 2, $\beta = 5$ K/min



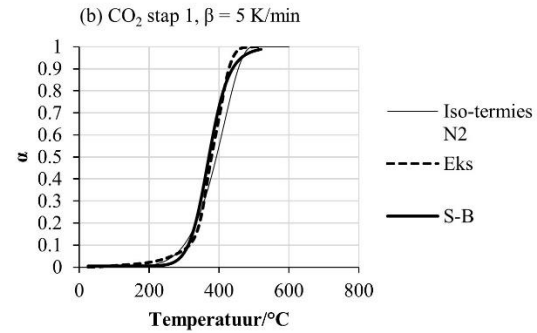
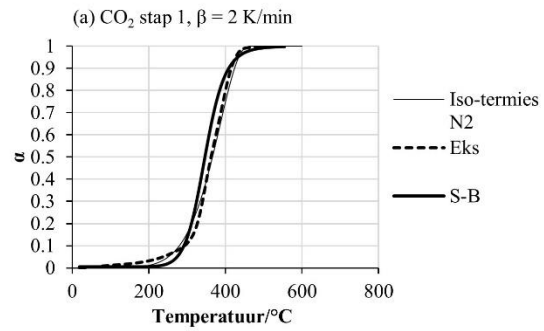
(d) Pirolise stap 2, $\beta = 10$ K/min

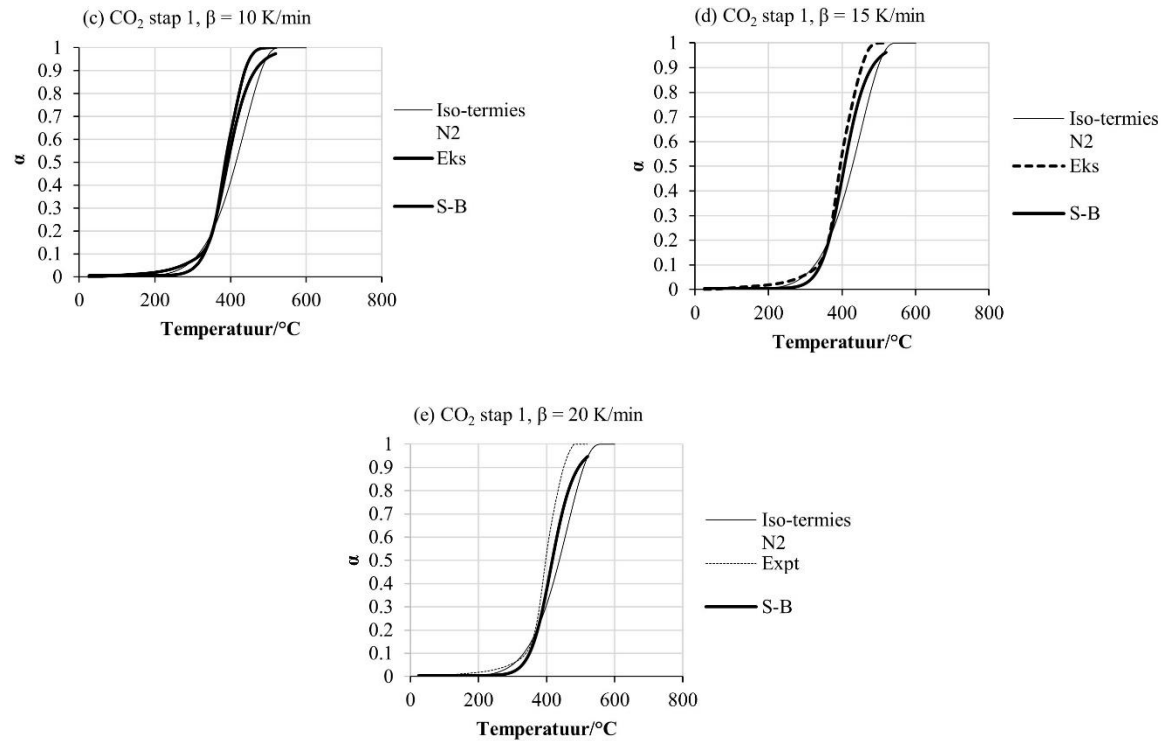




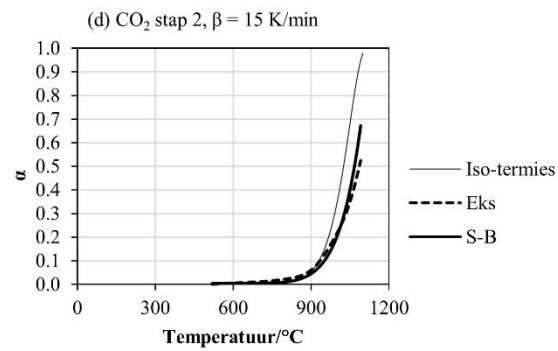
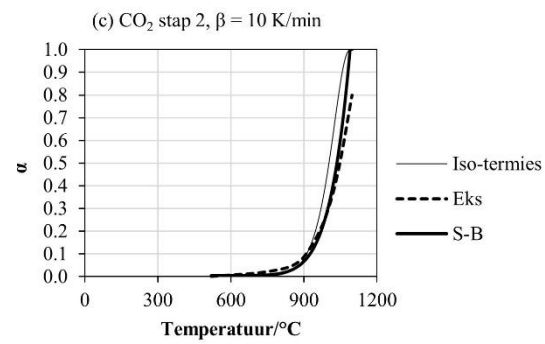
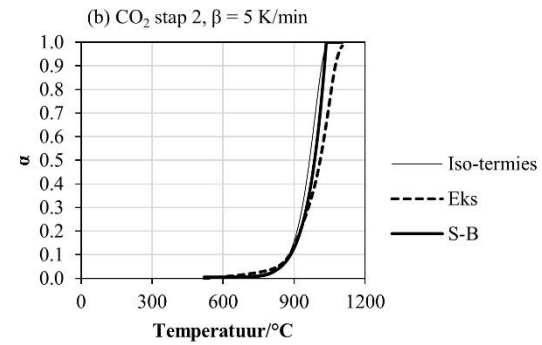
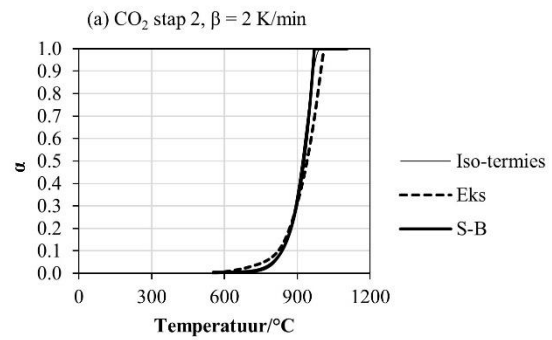
1 Figuur 5-8: Tweede termiese gebeurtenis onder suiwer N_2^* .

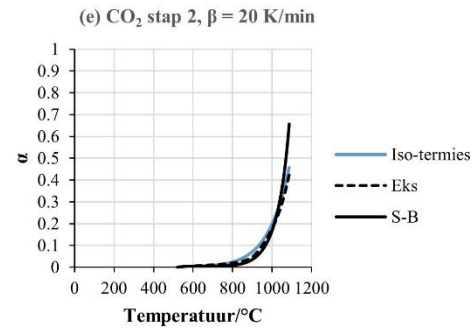
2 *Krommes individueel gepas vir elke verhittingstempo.





- 1 Figuur 5-9: Eerste termiese gebeurtenis onder CO₂*.
- 2 *Verkry deur direkte passing. Die lyne gemerk 'Iso-termies N₂' is verkry deur direkte nie-lineêre modelpassing van die ooreenstemmende N₂ pirolisedata. Krommes
- 3 is individueel gepas vir elke verhittingstempo.
- 4

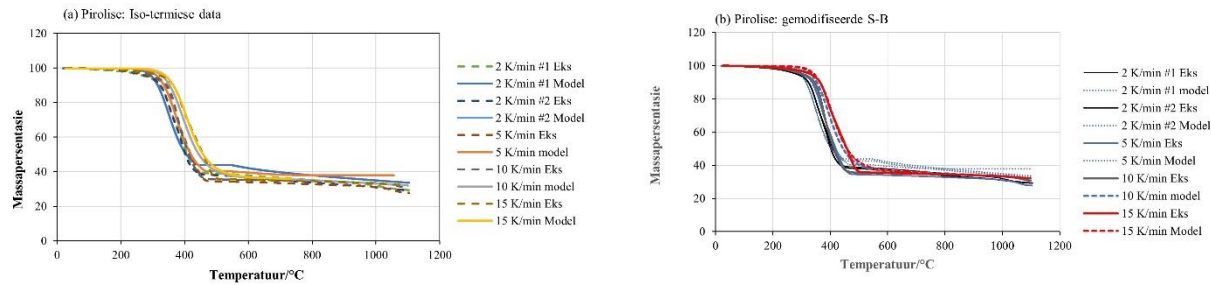


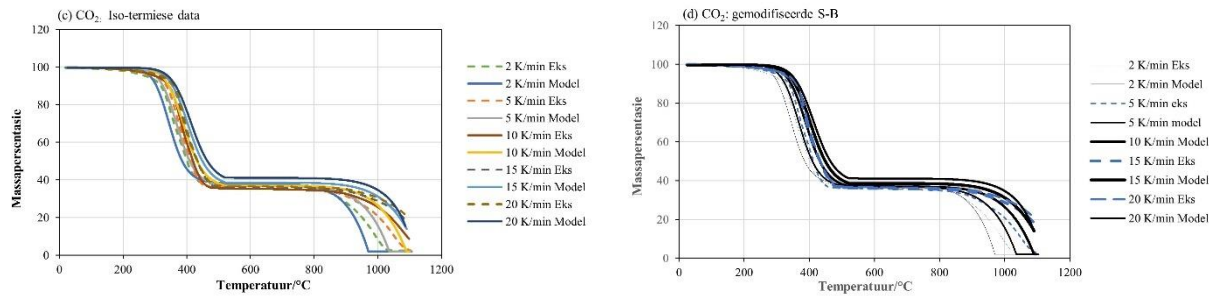


1 Figuur 5-10: Tweede termiese gebeurtenis, vergassing met CO₂ deur die tru-Boudouardreaksie, by verskillende verhittingstempo's*.

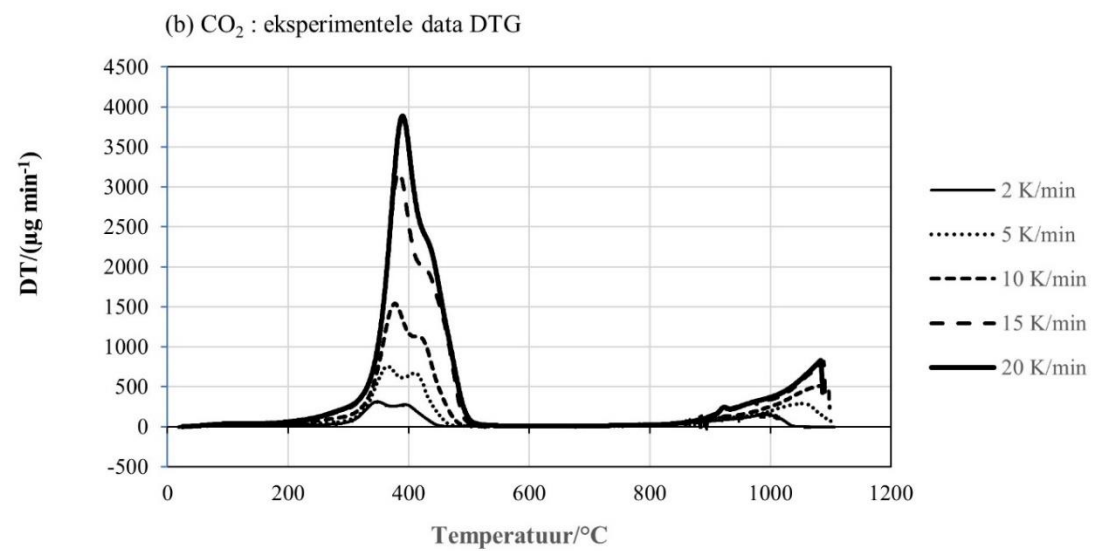
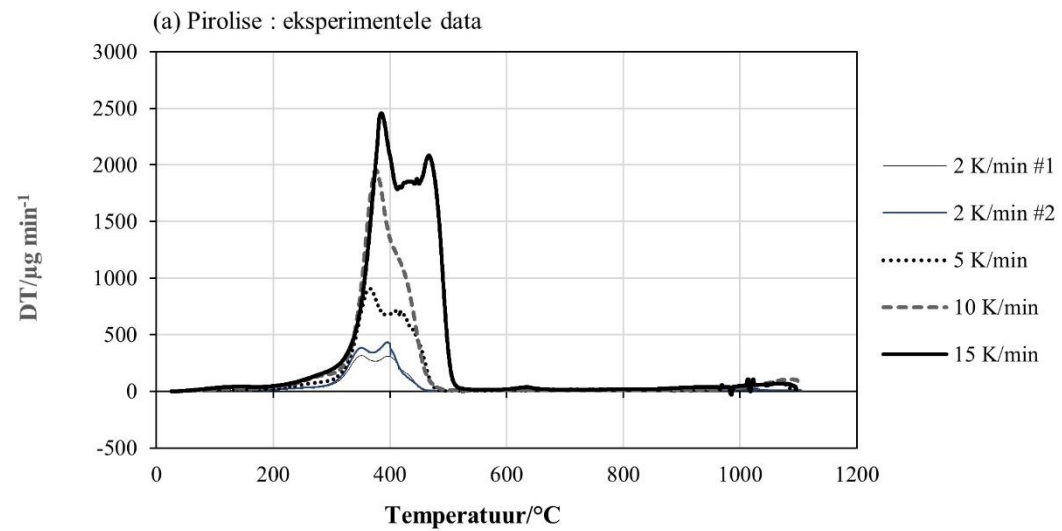
2 *Krommes is individueel gepas vir elke verhittingstempo.

3



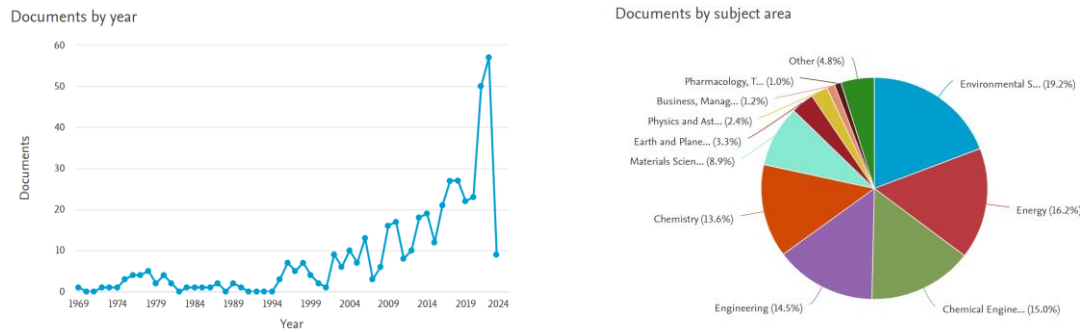


Figuur 5-11: Simulasiekrommes onder suiwer N₂ en suiwer CO₂, met gebruik van isokinetiese parameters (boonste ry) en die gemodifiseerde Sestak-Berggren model (onderste ry).

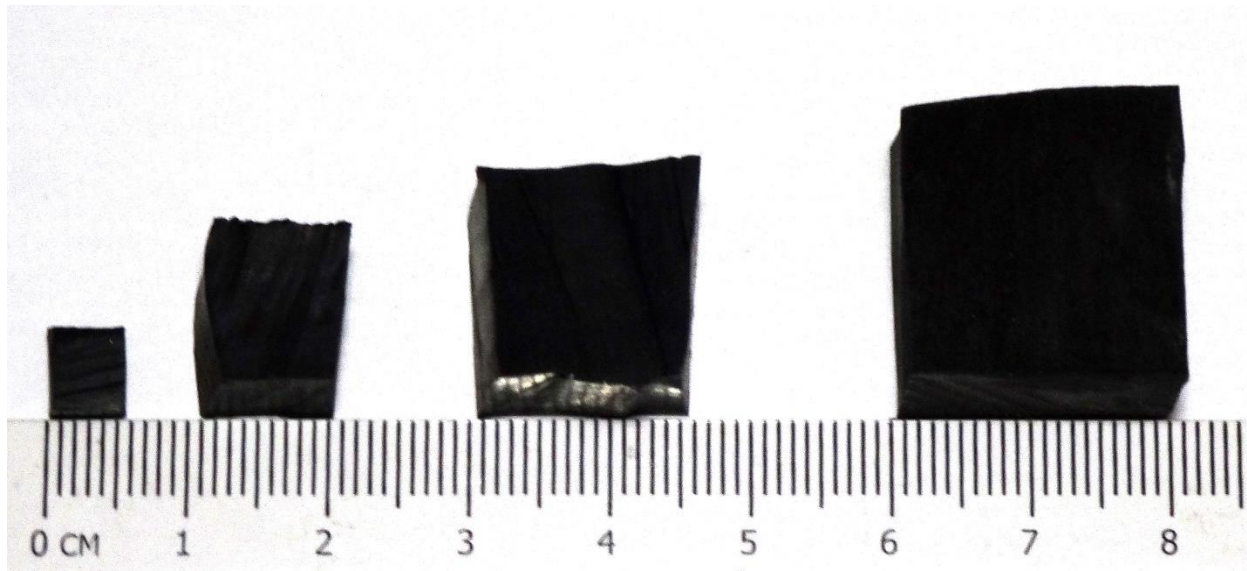


Figuur 5-12: DTG krommes van die (a) pirolise and (b) tru- Boudouard termogramme.

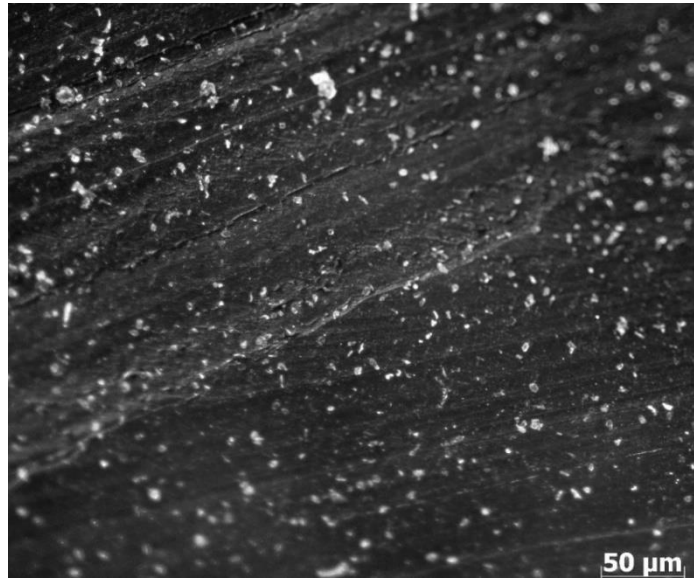
Hoofstuk 6.



Figuur 6-1: Scopus-analise van portuurbeoordeelde artikels in reaksie op die sleutelwoorde 'waste' EN 'tyre' EN 'rubber' EN 'pyrolysis'.



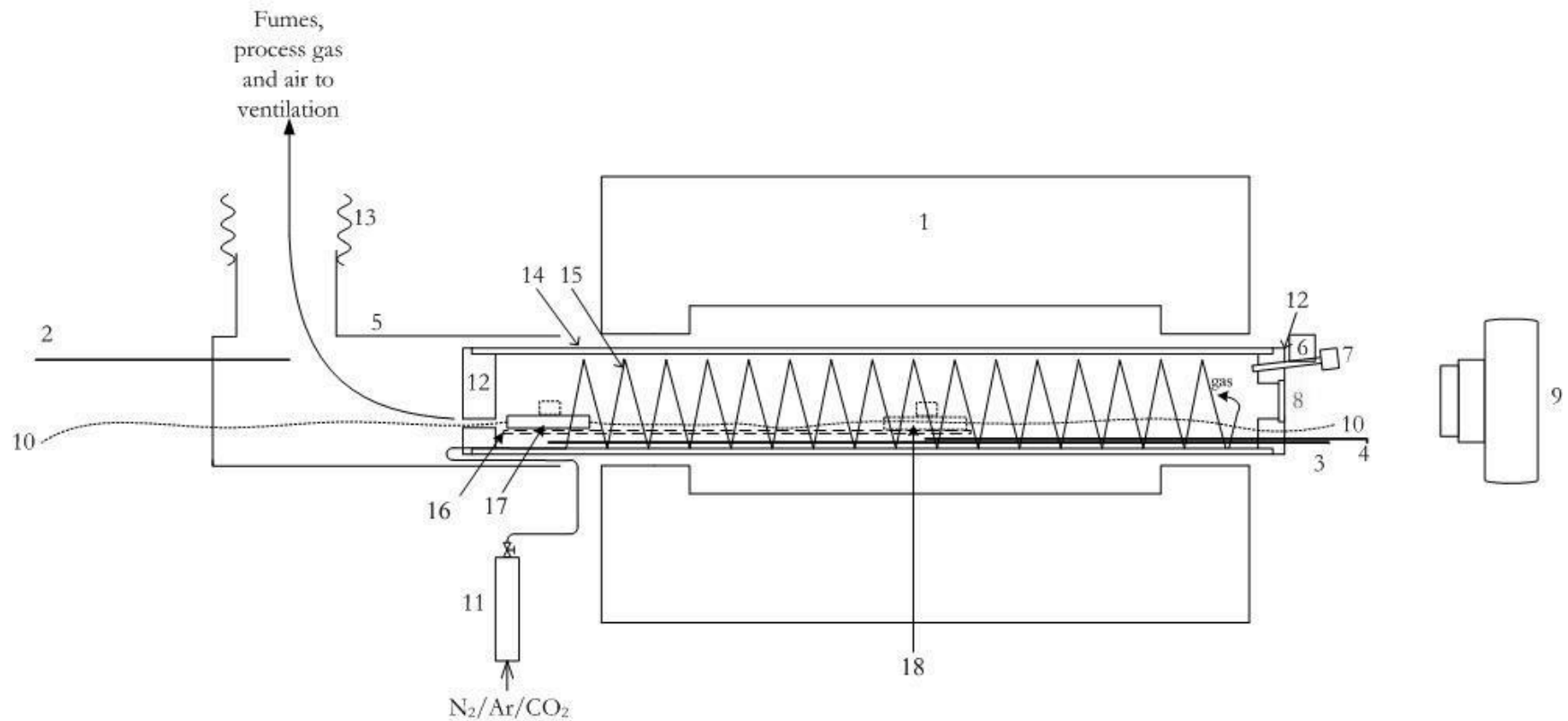
Figuur 6-2: Tipiese voorbeelde van kubiese rubberblokkies uit trekkerband loopvlak gesny.



1

2 Figuur 6-3: Snyvlak van trekkerband loopvlak (10× optiese vergroting)

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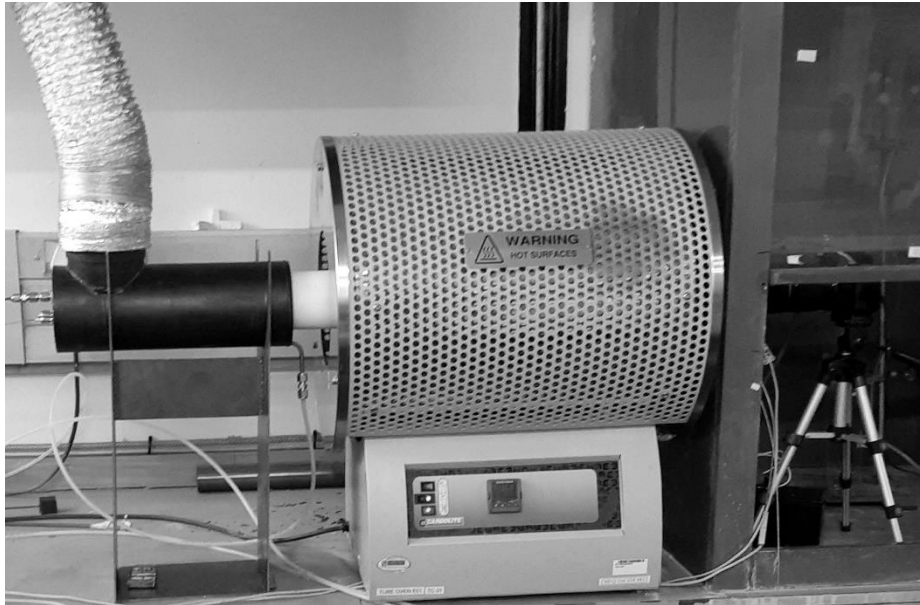
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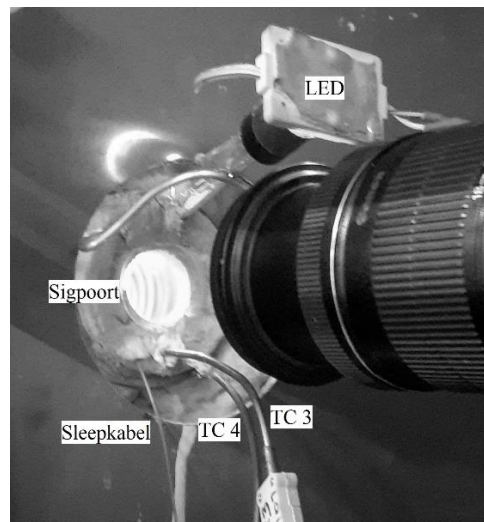
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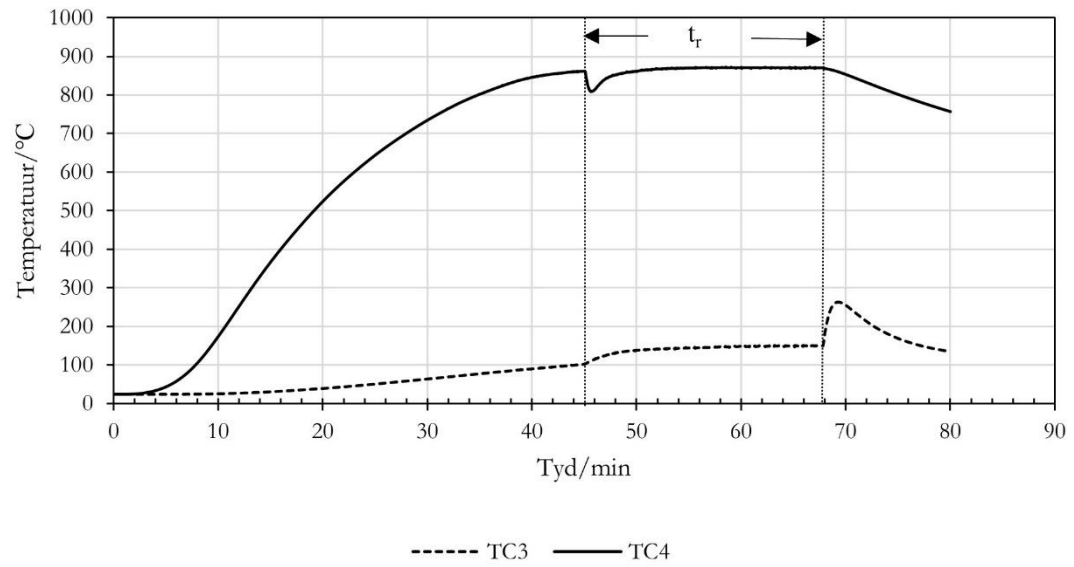
Figuur 6-4: Skets van die oond-opstelling. Nie volgens skaal nie. Dataregistreerder nie getoon nie. (1) Buisoond; (2) (3) (4) termokoppels verbind aan aan 'n multikanaal dataregistreerder. (5) ventilasiebuis; (6) boorsilikaatglas staaf; (7) 12 V LED lampie; (8) kwartsglas sigpoort; (9) kamera; (10) gevlegte staalkabel; (11) rotameter; (12) isolasiestein eindprop; (13) buigsame ventilasiebuis; (14) oondbuis; (15) gasverhittingspiraal; (16) steunrooster, (17); monsterpan (aanvangsposisie); (18) monsterpan (werkposisie); (19) eindprop (koue einde).



Figuur 6-5: Algemene aansig van die eksperimentele opstelling.



Figuur 6-6: Aansigte van die kamera-opstelling.



Figuur 6-7: Effect van die in- en uittrek van 'n monster op die temperatuur.



0 s (a)



10 s (b)



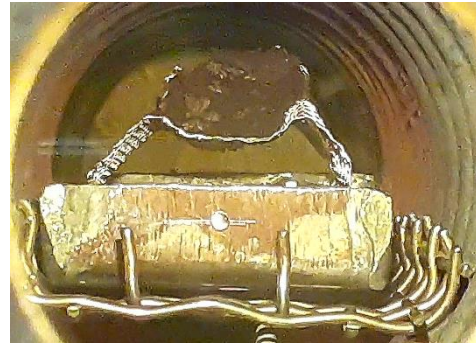
15 s (c)



18 s (d)



21 s (e)

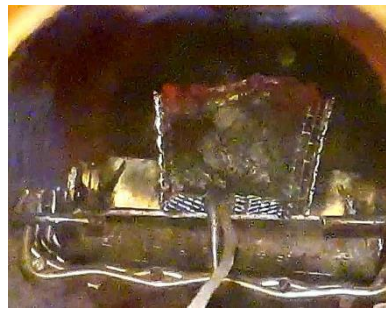


120 s (f)

Figuur 6-8: Tydsprong-beelde vir die pirolise van 'n 10 mm rubberblokkie by 635 °C onder N₂ vloei (Eksp. 220224_1).



0 min (a)



1 min (b)



1.5 min (c)



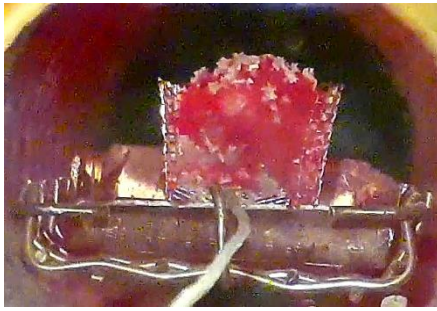
2.5 min (d)



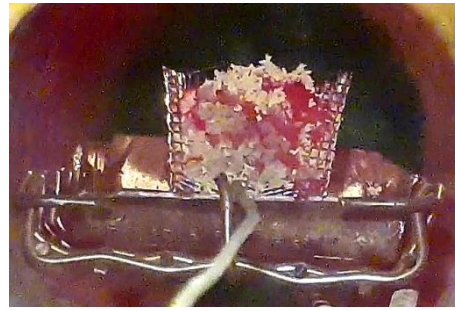
3 min (e)



5 min (f)

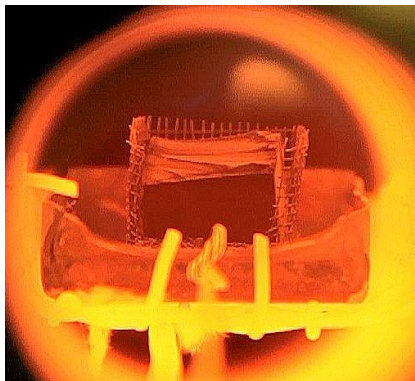


13 min (g)

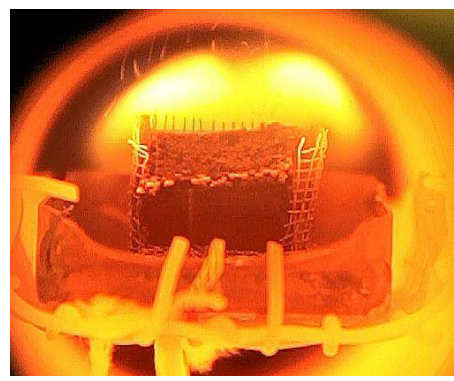


20 min (h)

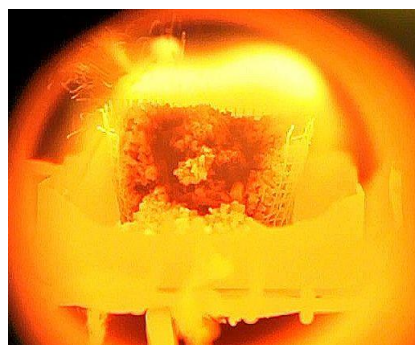
Figuur 6-9: Tydsprong-beelde van 'n 15 mm monster gedurende pirolise by 635 °C onder CO₂ vloei (Eksp. 220302_2).



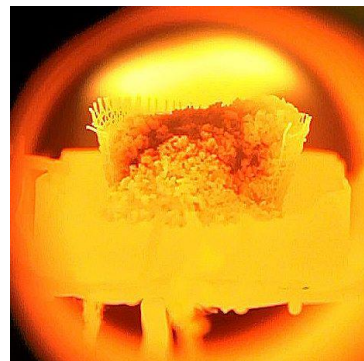
0 s (a)



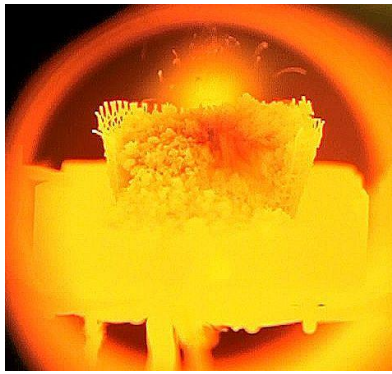
9 s (b)



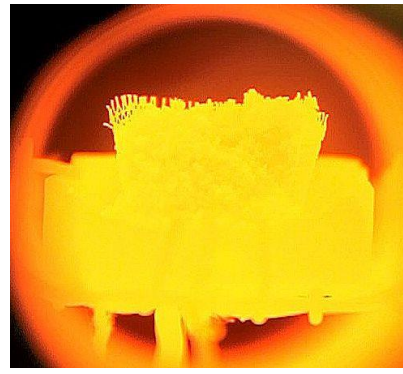
74 s (c)



124 s (d)

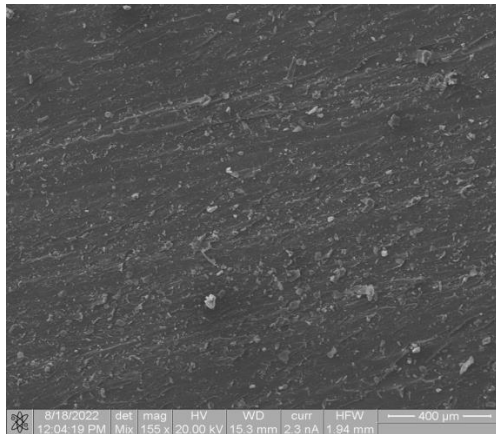


154 s (e)

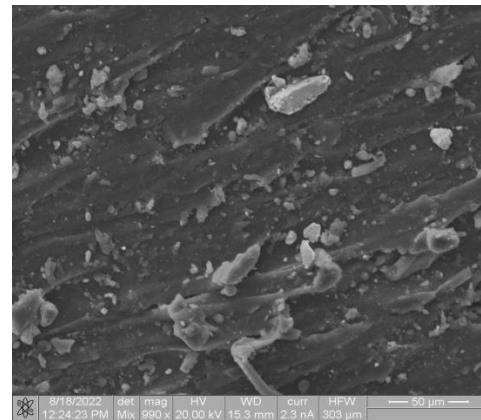


182 s (f)

Figuur 6-10: Tydsprong-beelde van pirolise en vergassing van 'n 15 mm rubberblokkie onder CO₂ by 990 °C (Eksp. 220505_1).

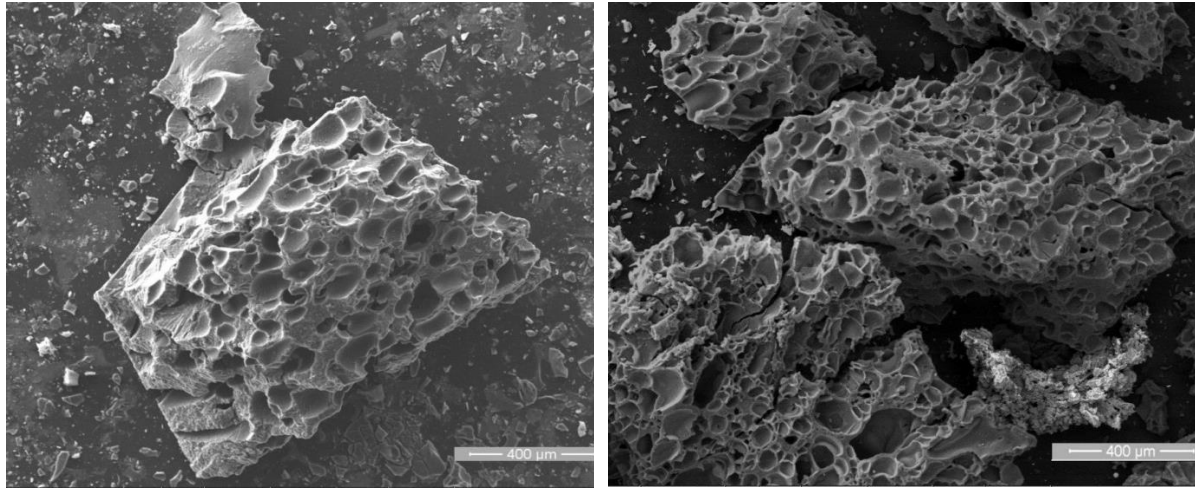


(a)

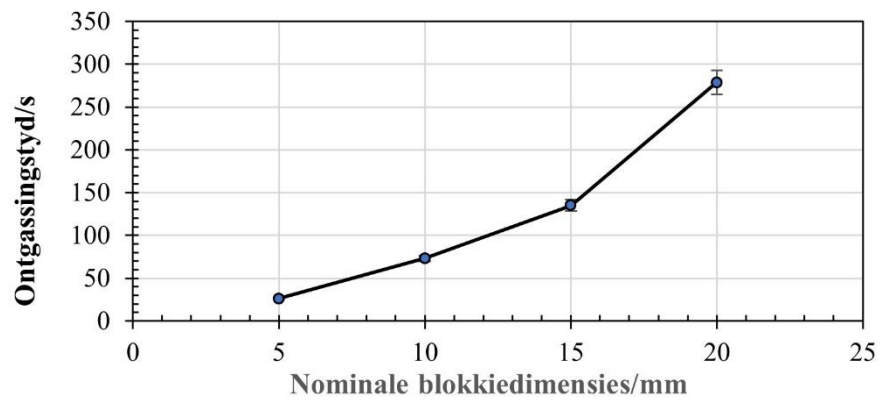


(b)

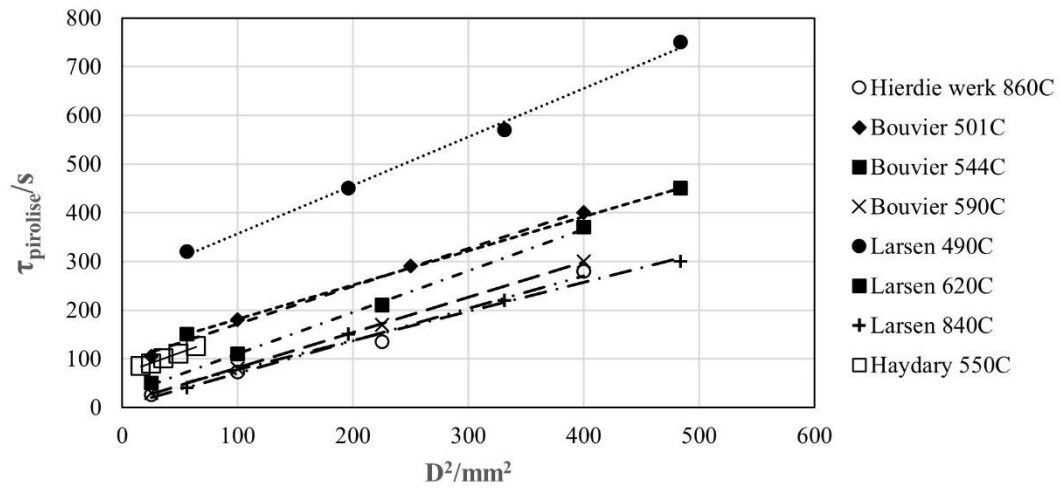
Figuur 6-11: Oppervlakmorfologie van 'n onbehandelde rubbermonster. Gekombineerde sekondêre-elektron- en tru-verstrooide elektron SEM beelde (a) by $\times 155$ and (b) by $\times 1\,000$ vergroting.



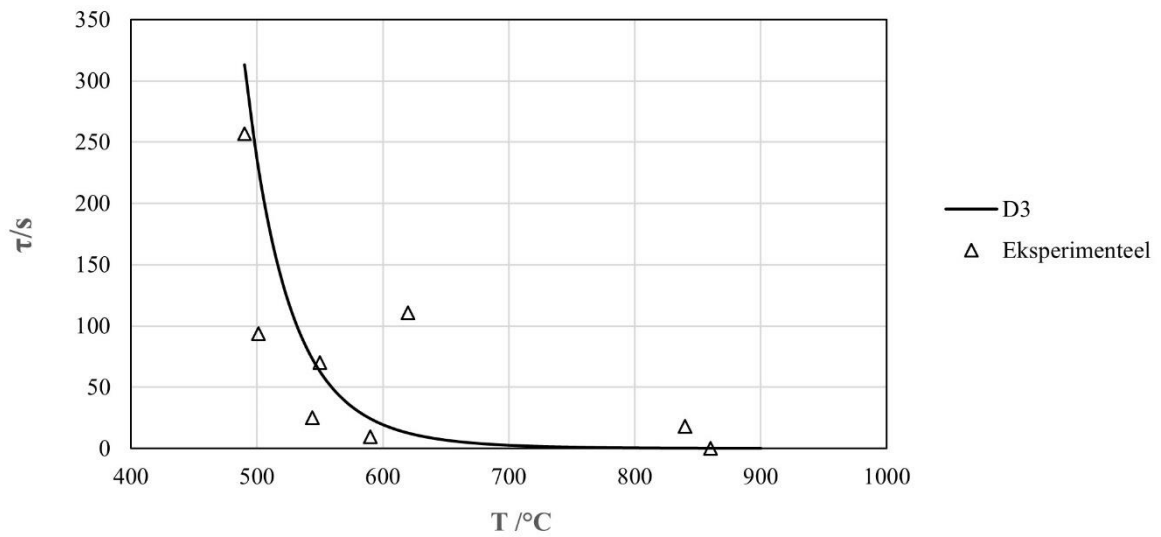
Figuur 6-12: SEM beelde van die oppervlakmorfologie van die residu (a) na 20 min by 650 °C onder N₂ vloei, en (b) na 20 min by 990 °C onder CO₂. Beide is by ×155 vergroting (Eksp. 220301_1).



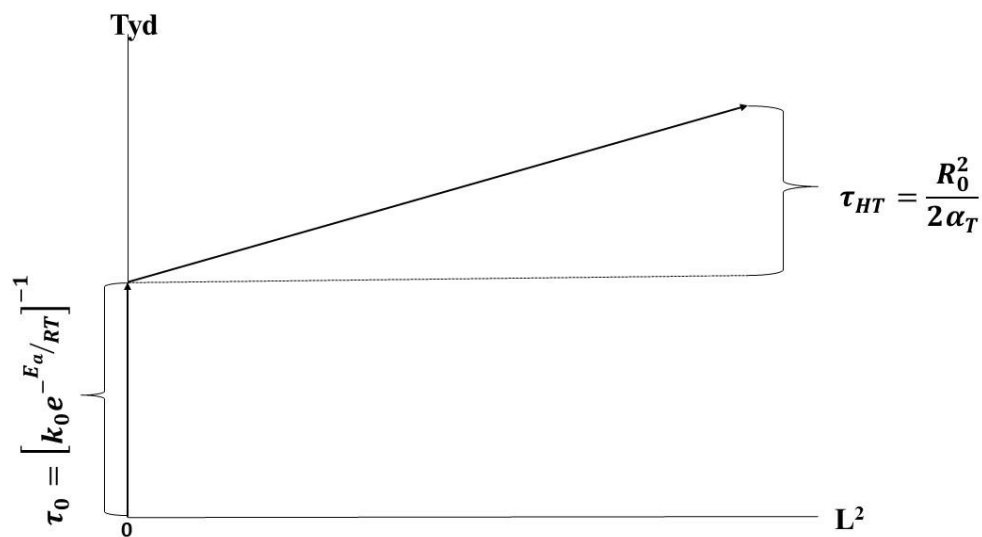
Figuur 6-13: Afhanklikheid van vervlugtigingstyd van nominale blokkie-afmetings by 860 °C.



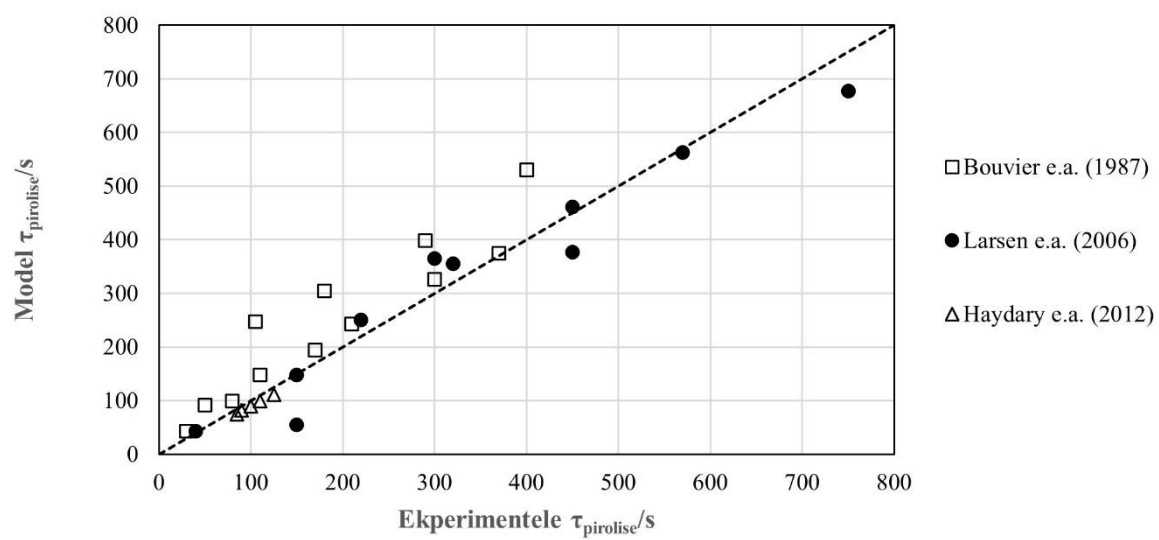
Figuur 6-14: Rou pirolisedata geneem uit die literatuur en huidige werk.



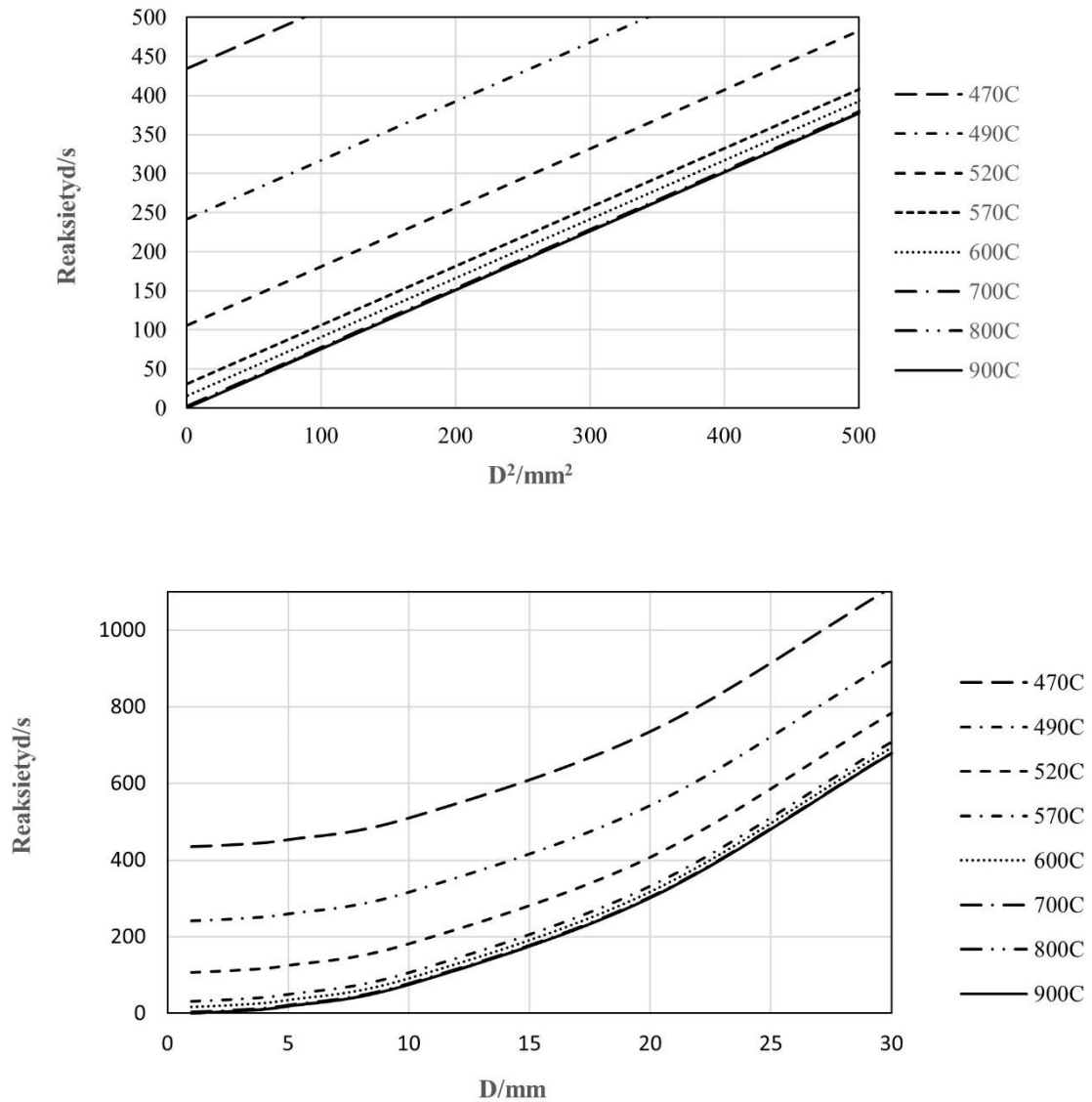
Figuur 6-15: Model- en eksperimentele pirolisetye vir $D \sim 0$ mm.



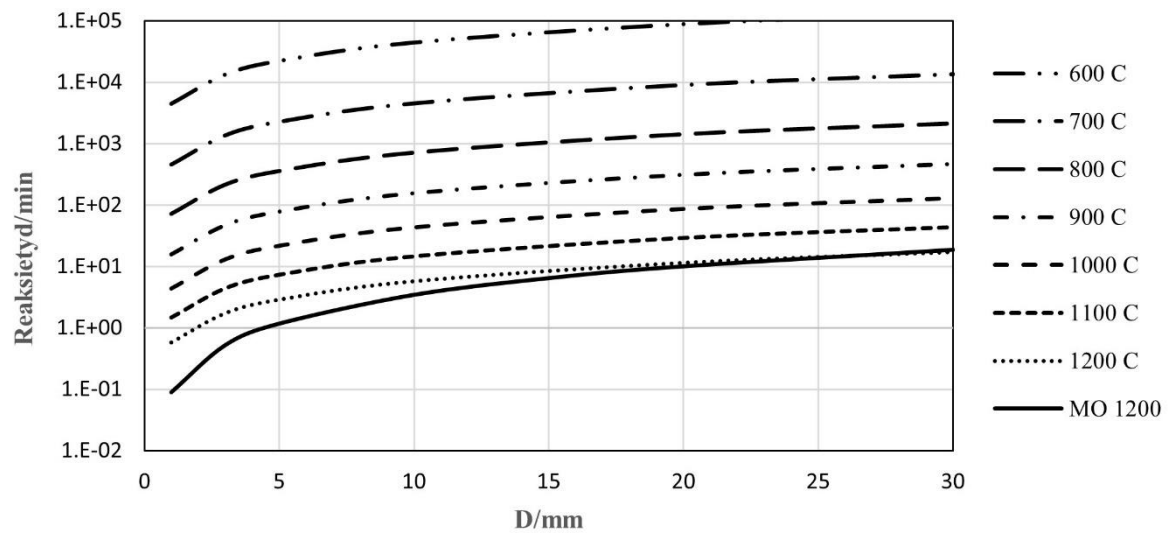
Figuur 6-16: Heuristiese skatting van rubberpirolisetyd.



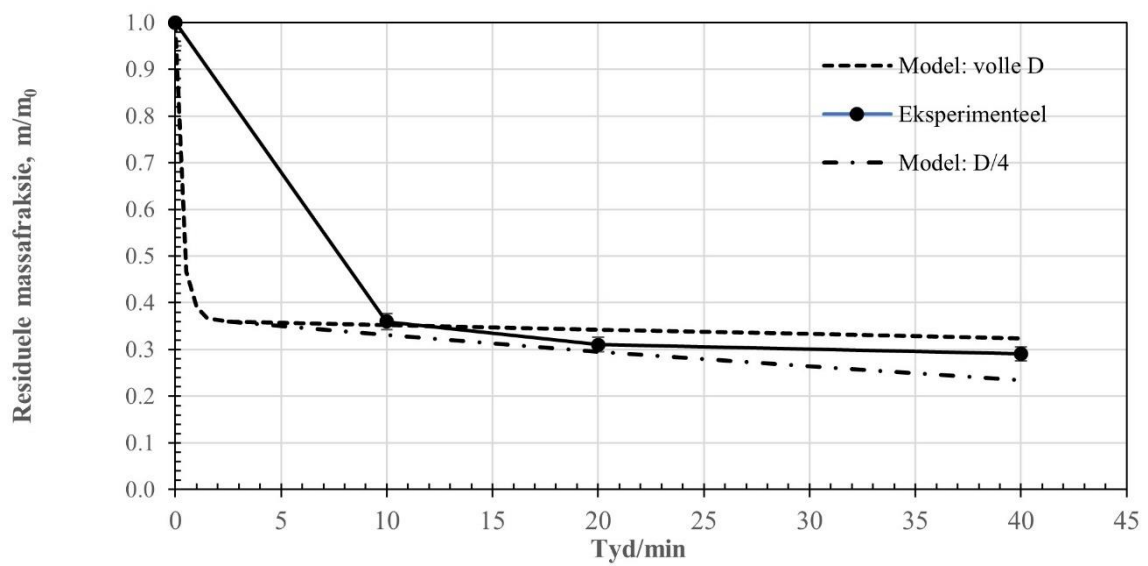
Figuur 6-17: Skattings van pirolisetye vir eksperimentele waardes uit die literatuur $T \geq 490$ °C.



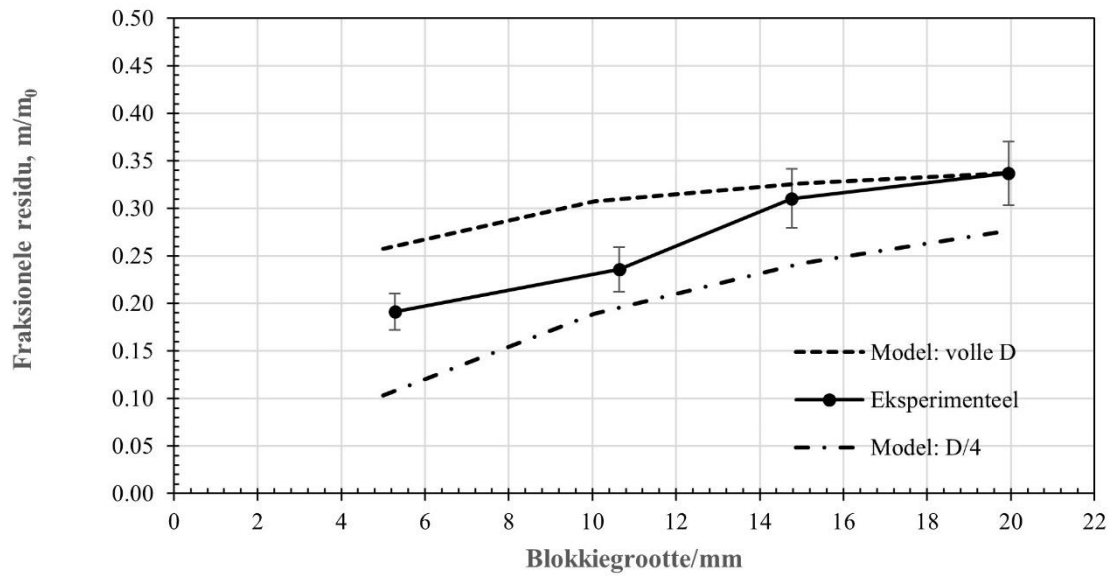
Figuur 6-18: Pirolisereaksie bereike vir banderubber: gemengde chemiese-reaksie- en hitte-oordragbeheer bokant die soliede (900 °C) lyn; effektiewe hitte-oordragbeheer slegs onder die lyn



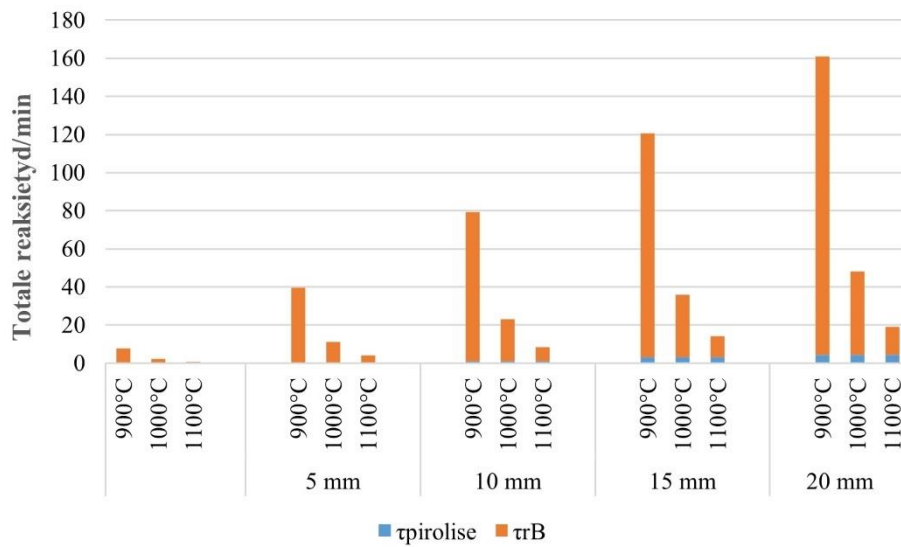
Figuur 6-19: Voorspelde reaksietye vir verskillende rubbermonstergroottes vir krimpende partikels onder chemiese-reaksie- en massa-oordrag (MO) beheer.



Figuur 6-20: Tydafhanklike residufraksie vir 15 mm rubberblokkies onder CO_2 vloei by 860 °C.



Figuur 6-21: Afmetingafhanklike residufraksie na 20 min onder CO_2 vloei by 860°C .

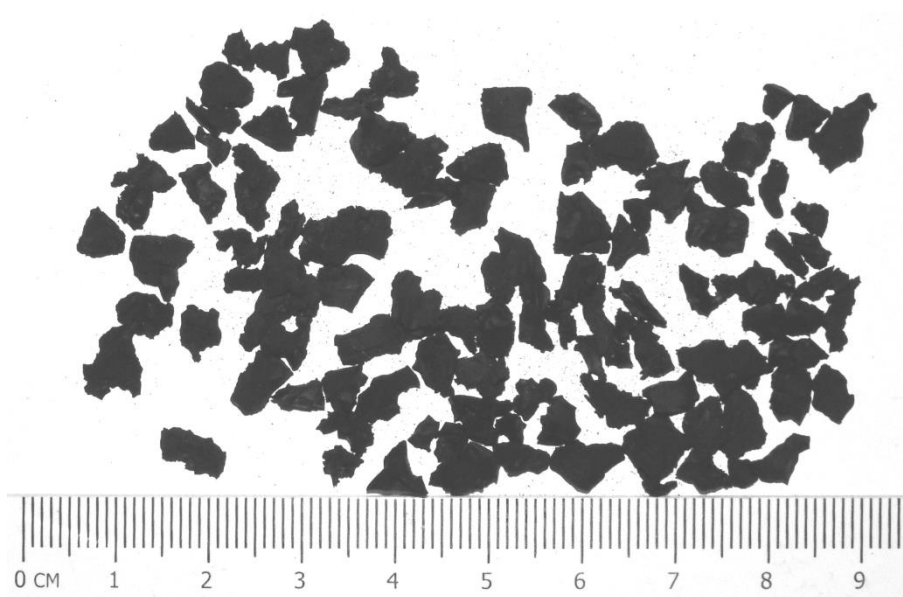


Figuur 6-22: Totale voorspelde pirolise-vergassingstye vir verskillende groottes rubberpartikels in die temperatuurbereik $900\text{--}1\,000^\circ\text{C}$.

Hoofstuk 7.



Figuur 7-1: Rubberskaafsels.

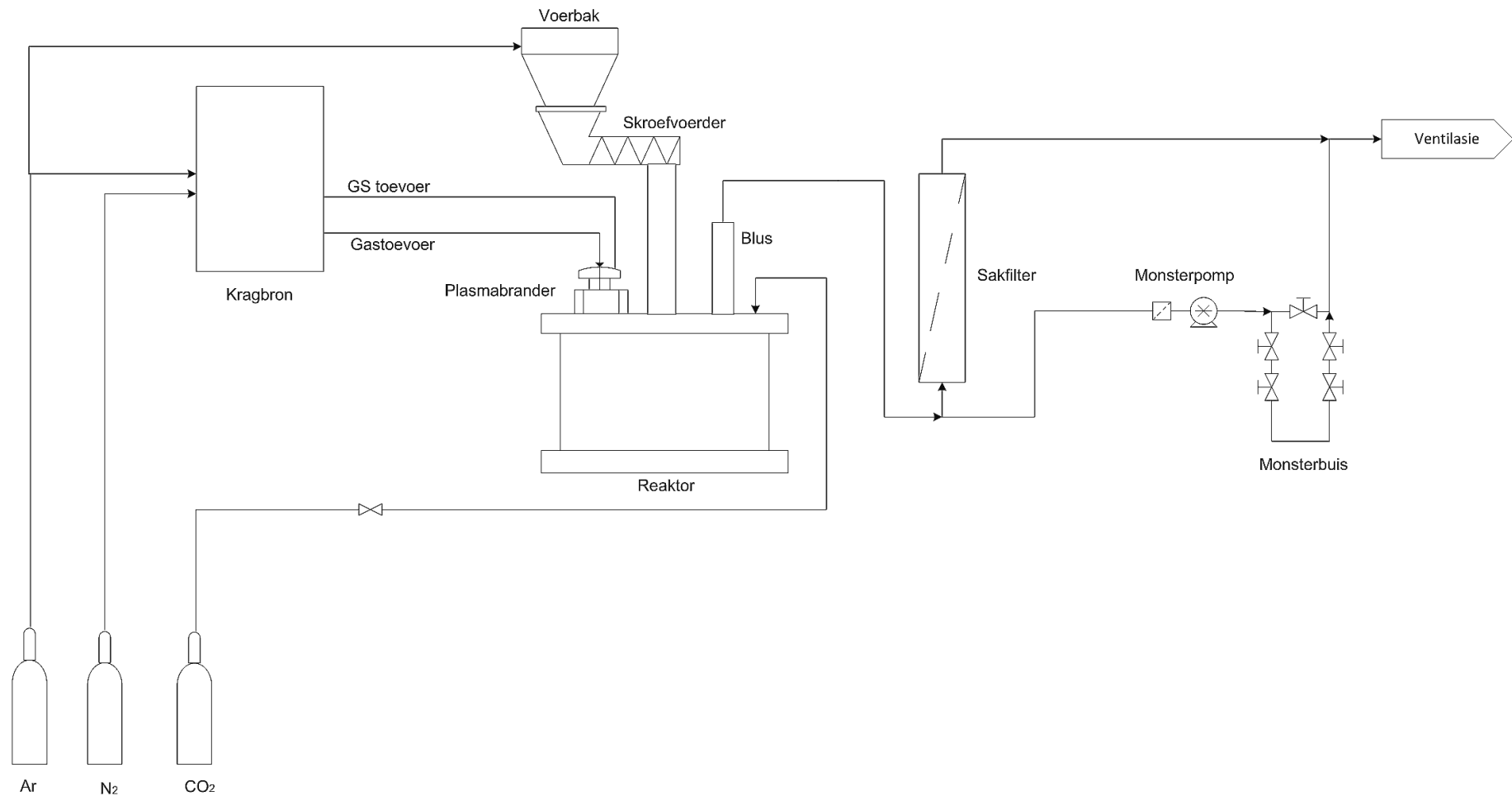


Figuur 7-2: Rubberkorrels.



Figuur 7-3: Rubbersnippers.

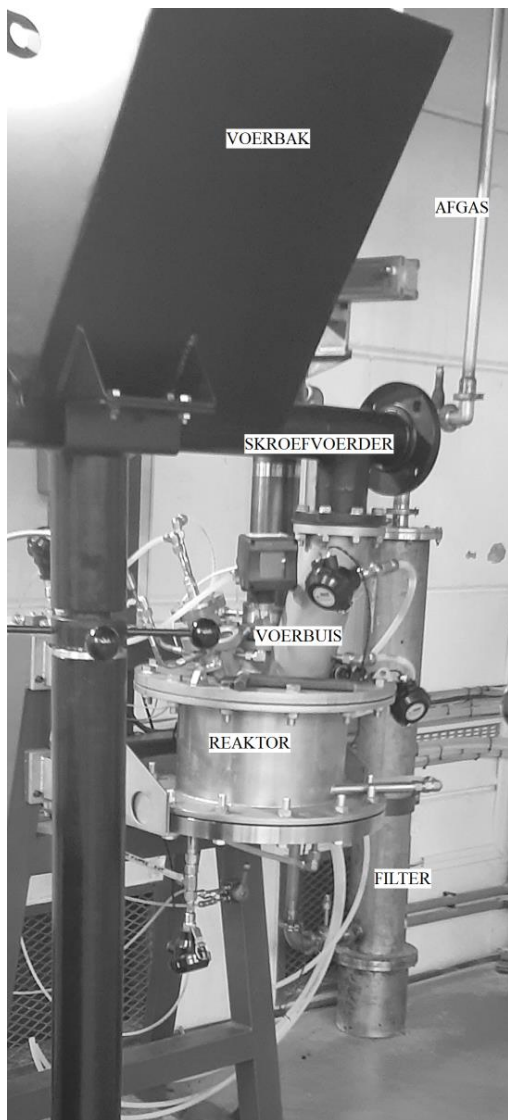
1



2

3

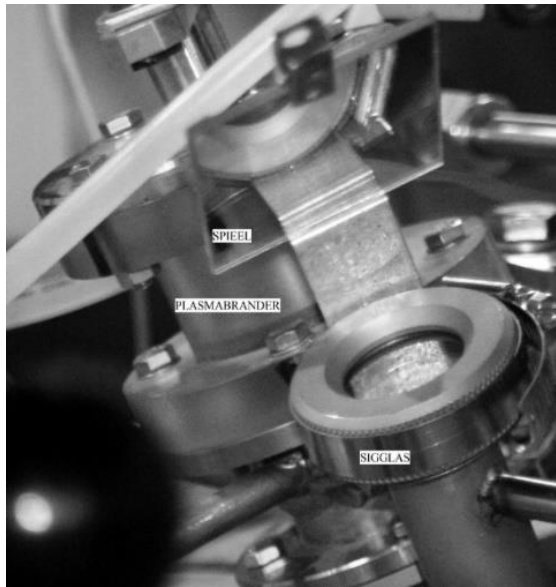
Figuur 7-4: Vereenvoudigde vloedigram van die eksperimentele plasmavergasserstelsel.



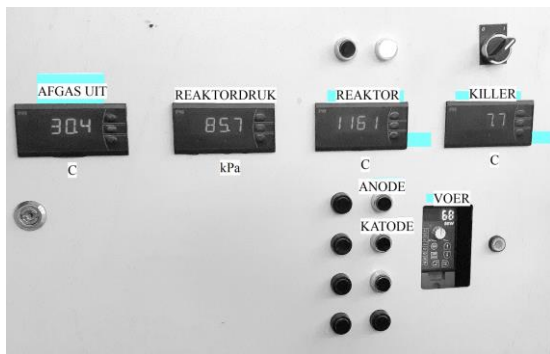
(a)



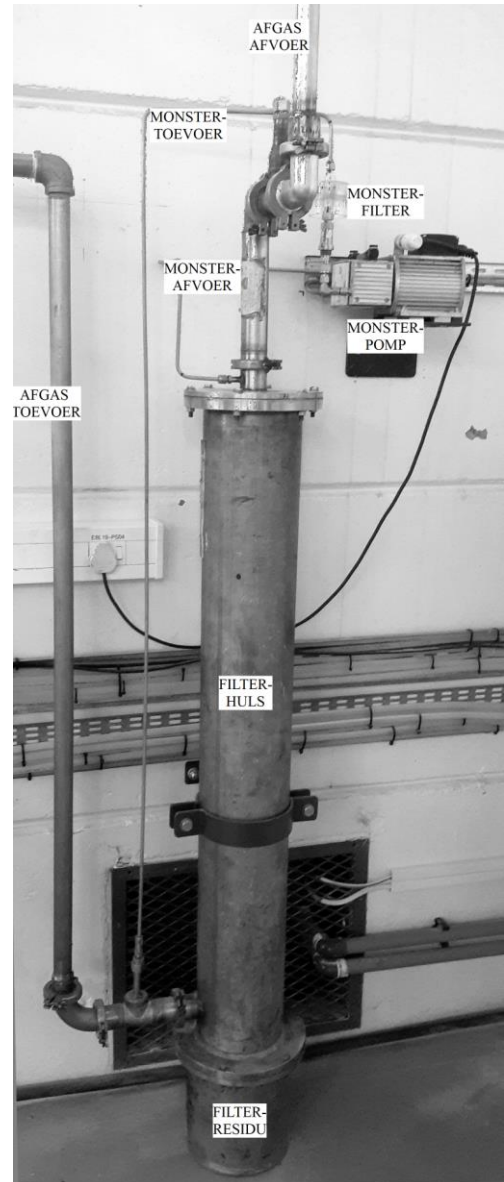
(b)



(c)

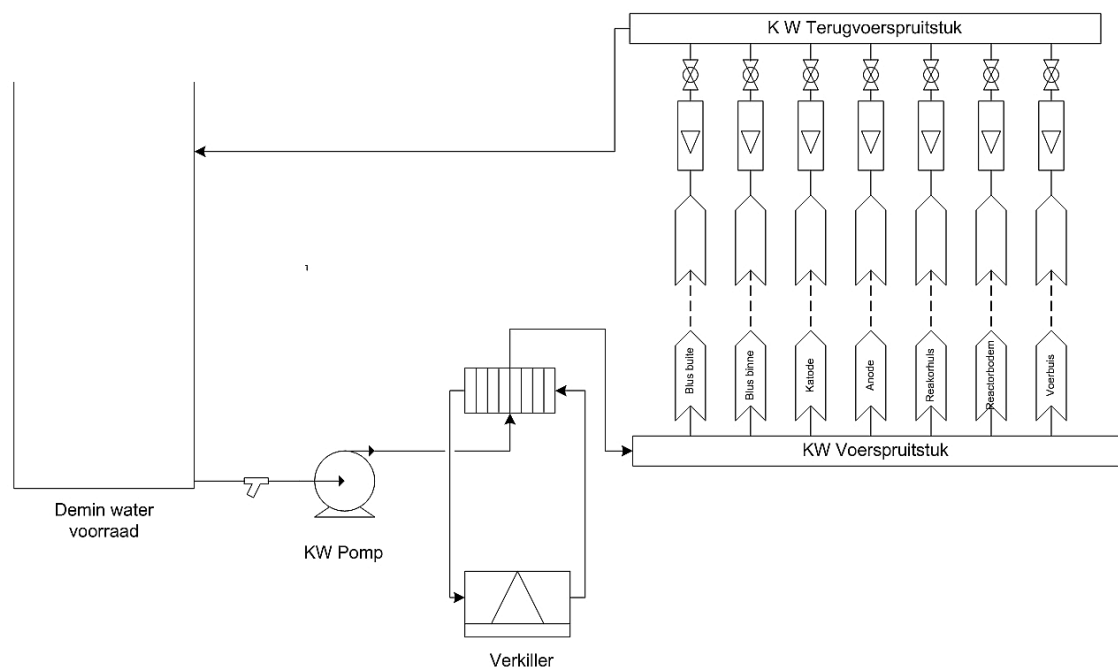


(d)



(e)

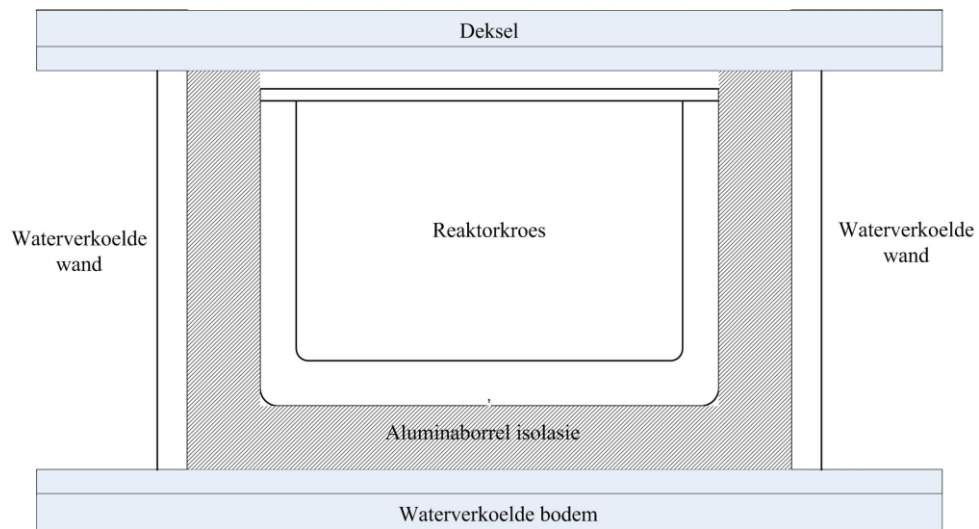
Figuur 7-5: Aansigte van de plasmavergassingtoerusting (a), (b) plasmareaktor en voerbak (c) sigpoort met spieël (d) Instrumentasiepaneel (e) Afgasfilter en monsterpomp.



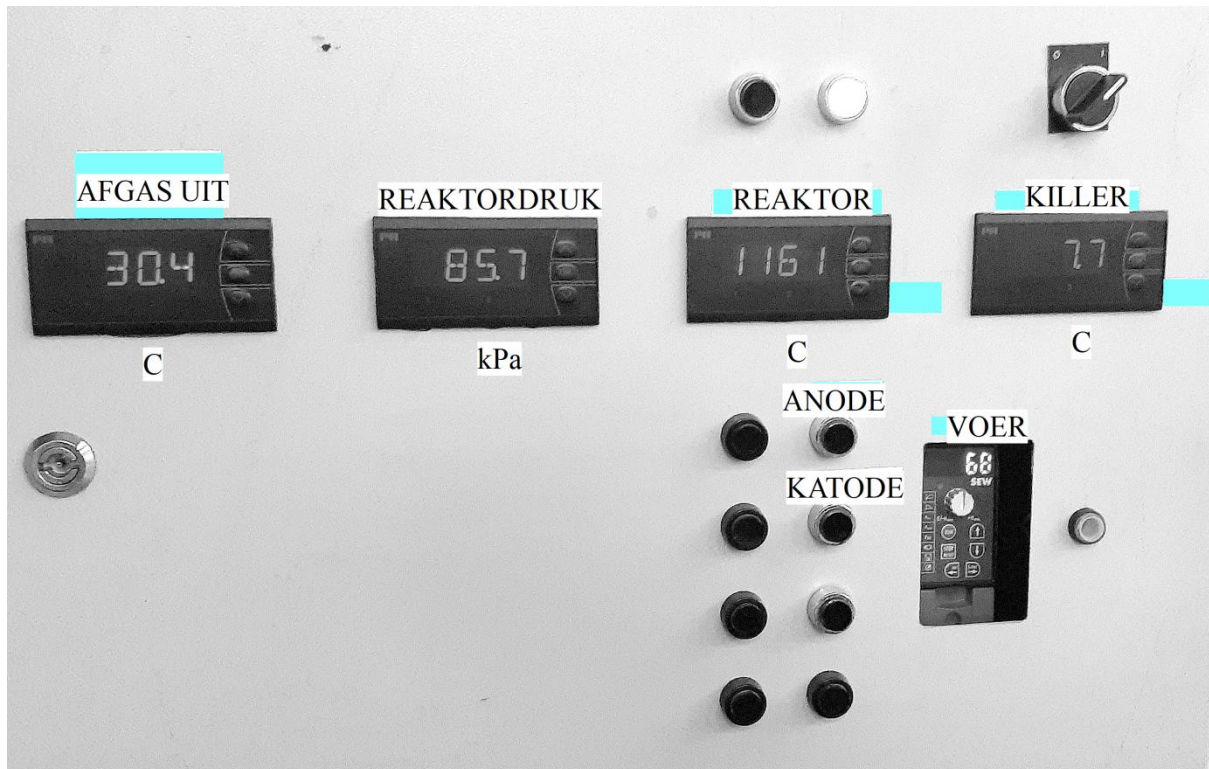
Figuur 7-6: Vereenvoudigde koelwatervloeiagram.



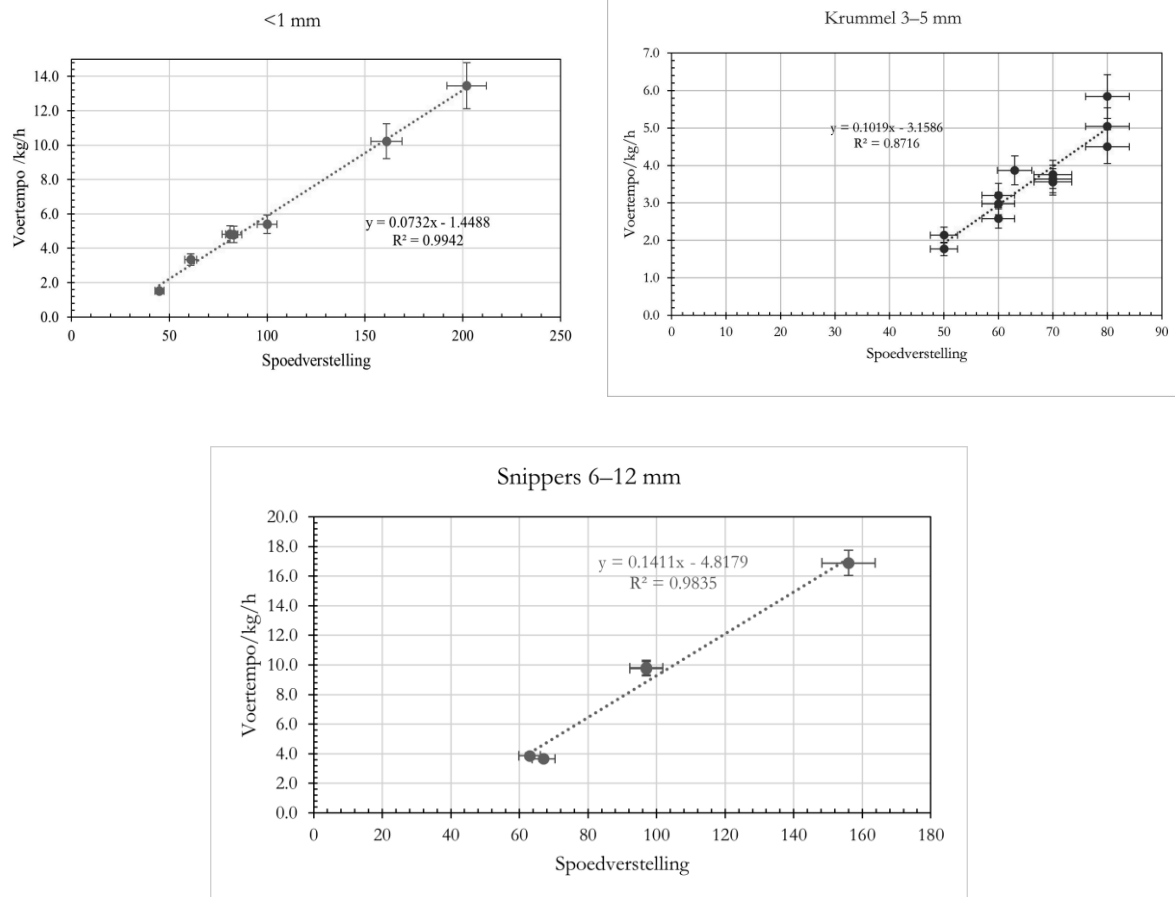
Figuur 7-7: Koelwaterbeheer.



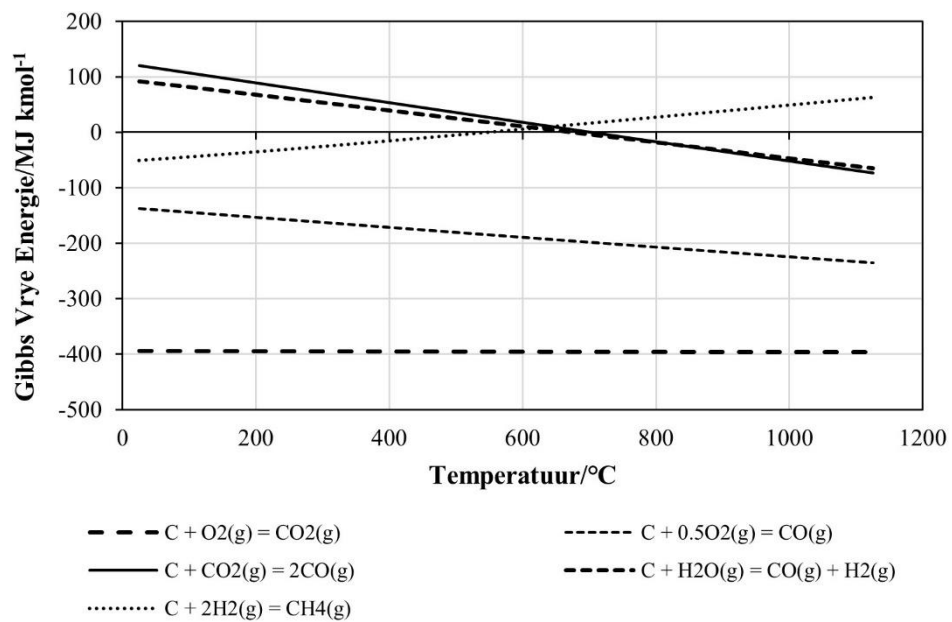
Figuur 7-8: Skematiese deursnit van die plasmareaktor.



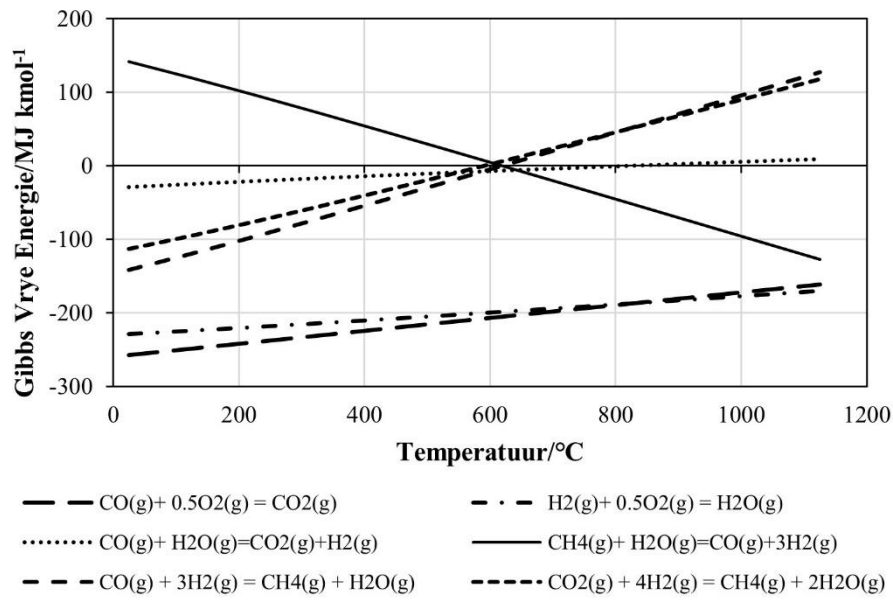
Figuur 7-9: Instrumentasie- en beheerpaneel



Figuur 7-10: Voerderkalibrasiekrommes vir verskillende partikelgroottes.

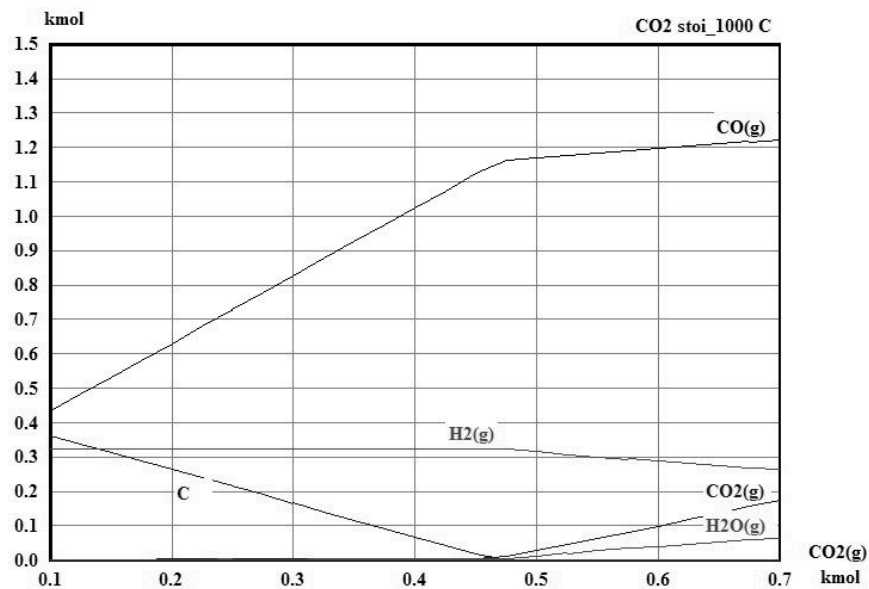


(a)

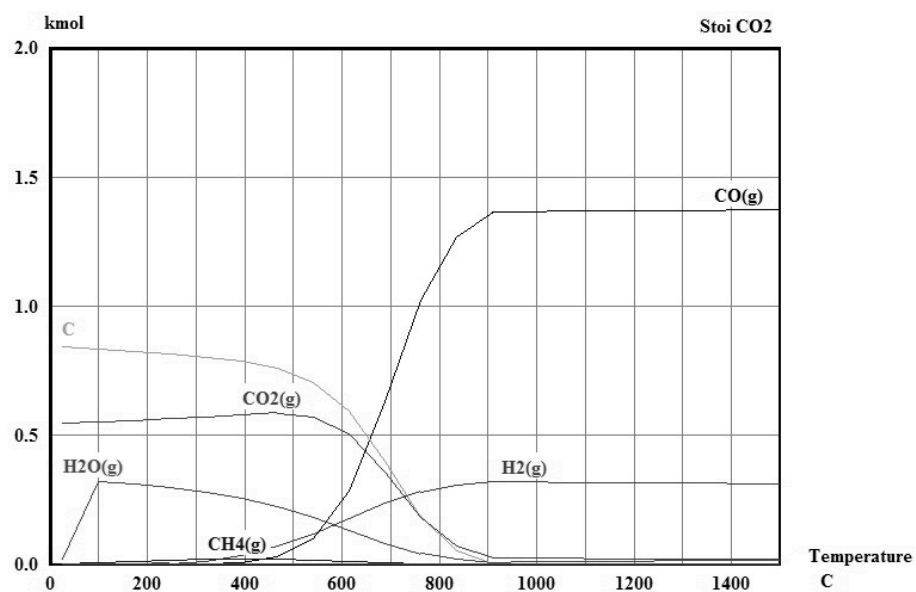


(b)

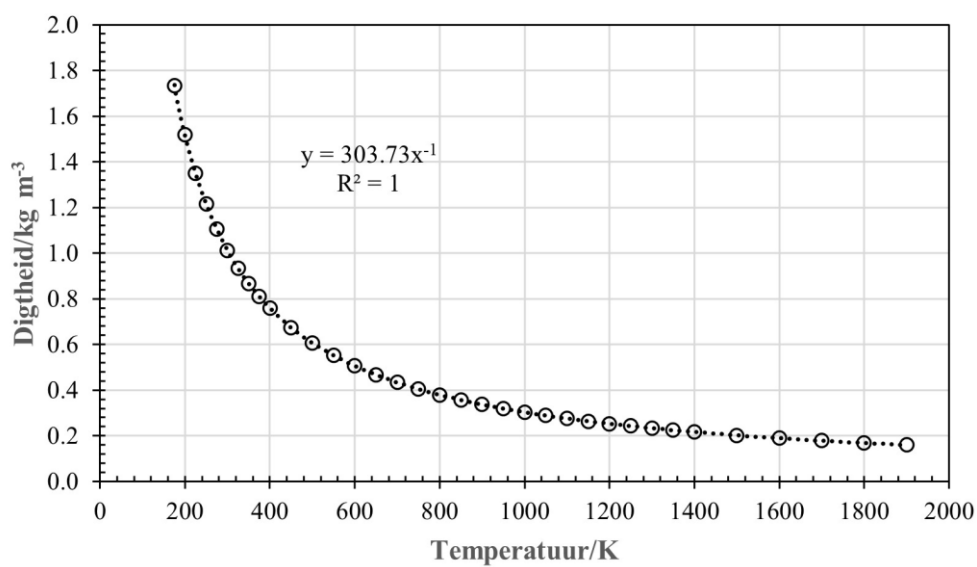
Figuur 7-11: Ellinghamdiagramme van vergassingsreaksies



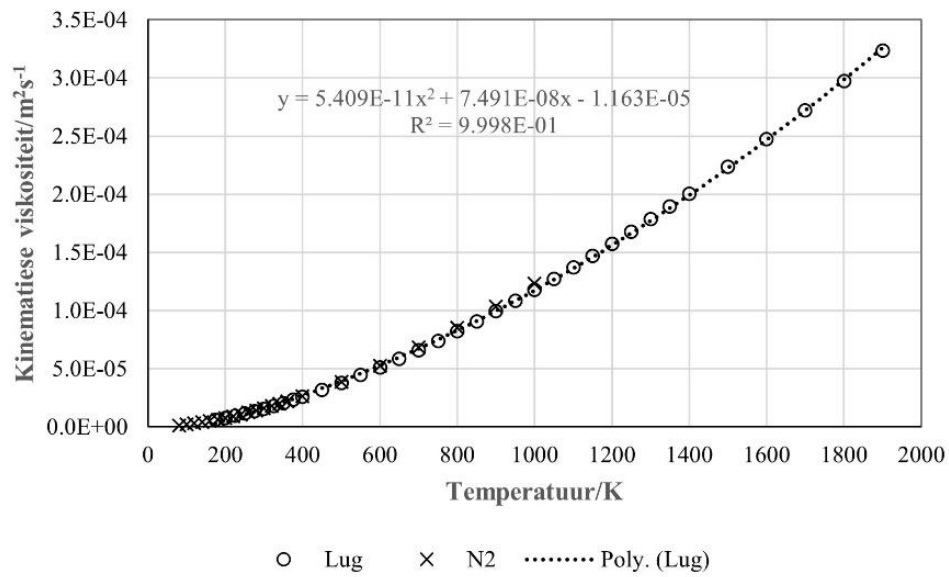
Figuur 7-12: Modelling vir bepaling van die stoigiometriese CO_2 voer by 1 000 °C



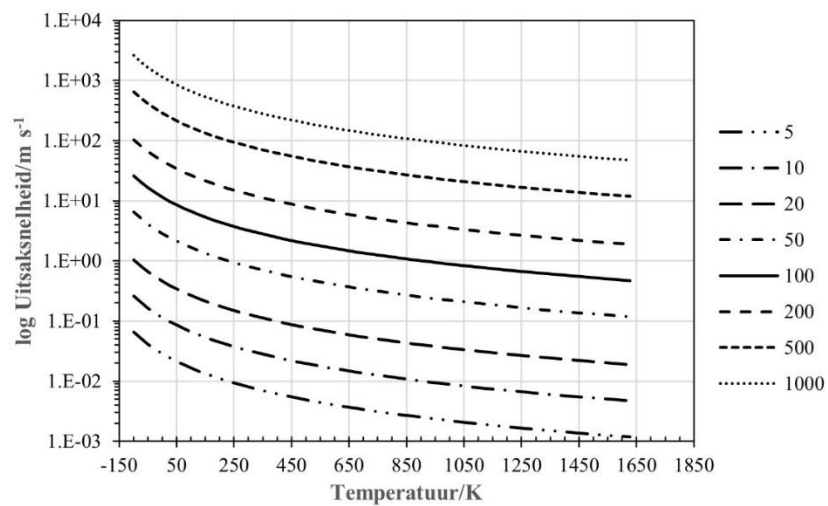
Figuur 7-13: Ewewigsamestelling van hoofkomponente.



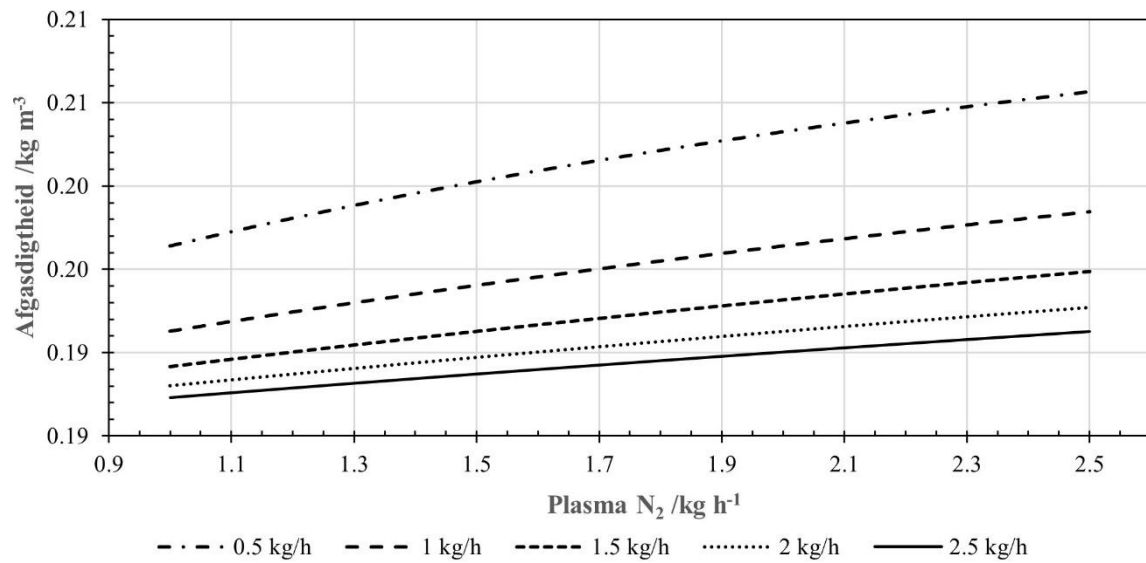
Figuur 7-14: Digtheid van lug by 86 kPa (0.85 atm).



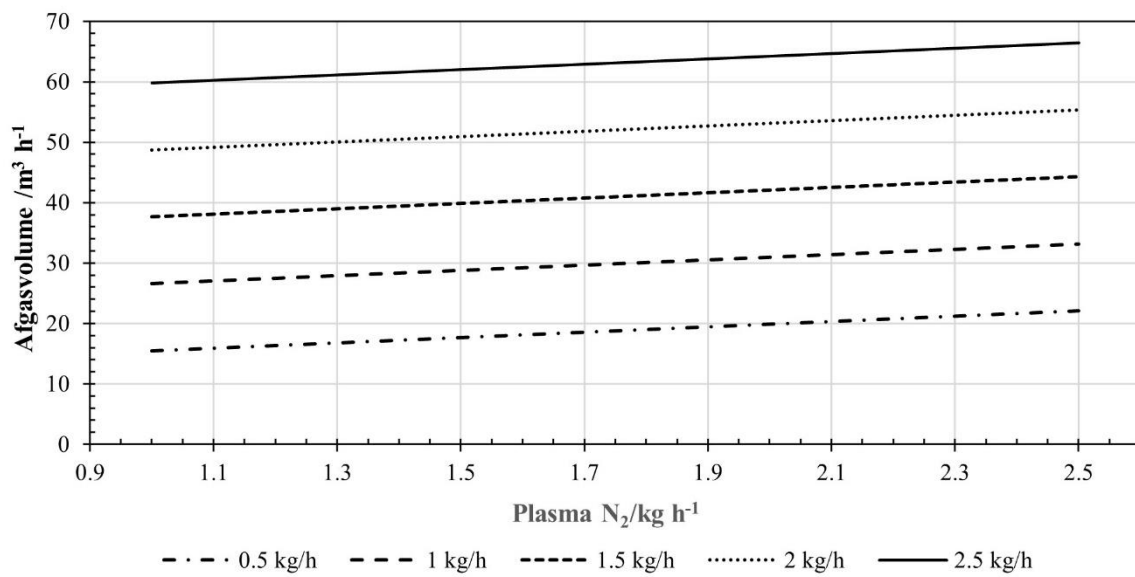
Figuur 7-15: Kinematiese viskositeit van lug, N₂.



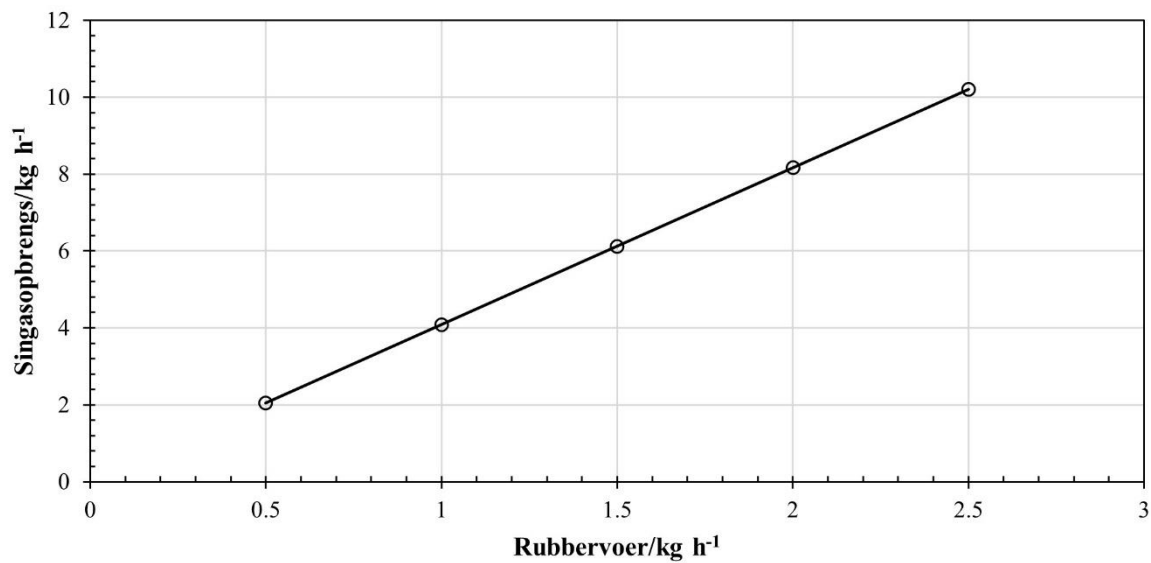
Figuur 7-16: Die verband tussen uitsaksnelheid, temperatuur en partikelgrootte (μm) by 0.85 atm.



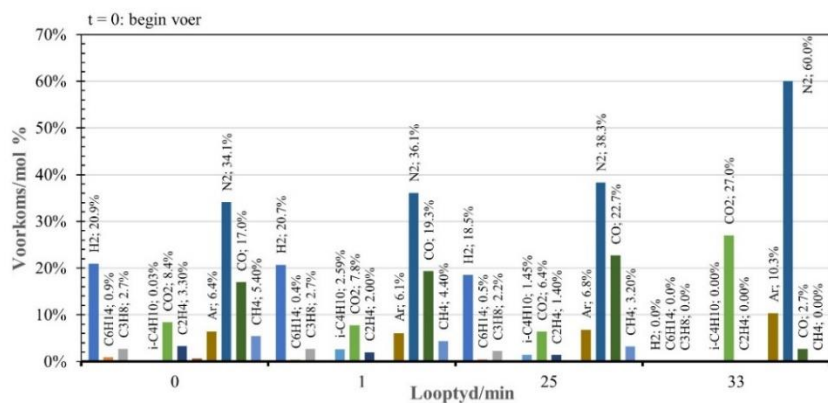
Figuur 7-17: Berekende afgasdigtheid as funksie van plasmagas vloeï by verskillende rubbervoertempo's.



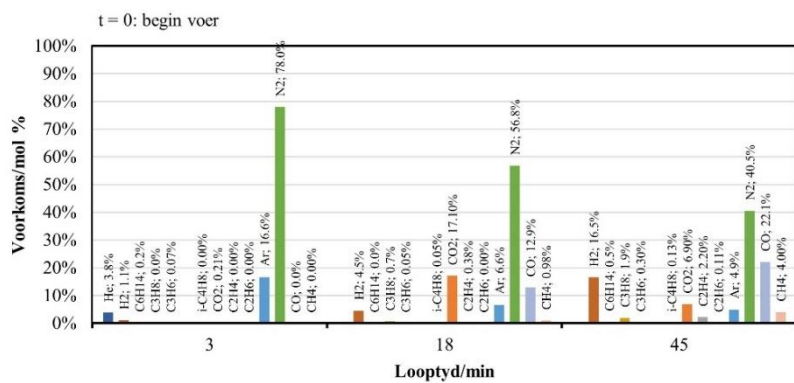
Figuur 7-18: Afgasvolume. Afhanklikheid van plasmagasvloei en rubbervoertempo's.



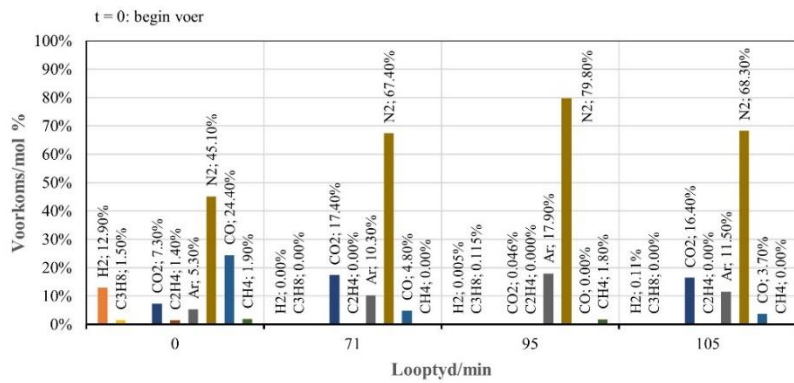
Figuur 7-19: Berekende sintesegasopbrengs as funksie van rubbervoertempo.



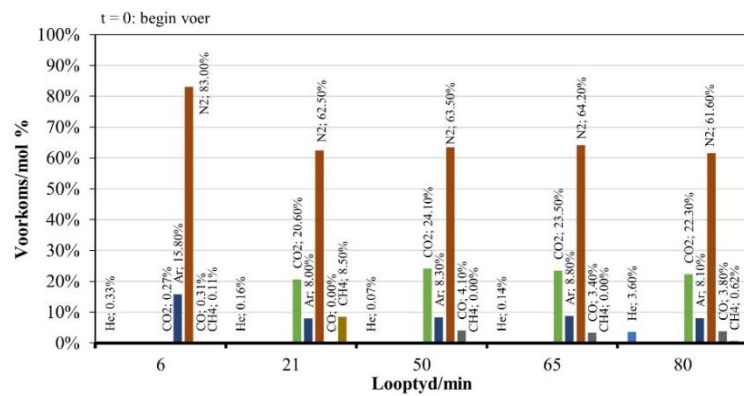
(a) Eksp. 220915_1



(b) Eksp. 220922_1

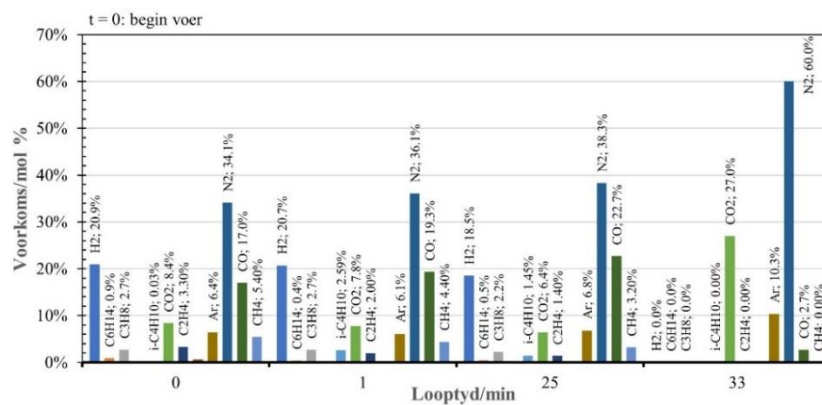


(c) Eksp. 220928_1

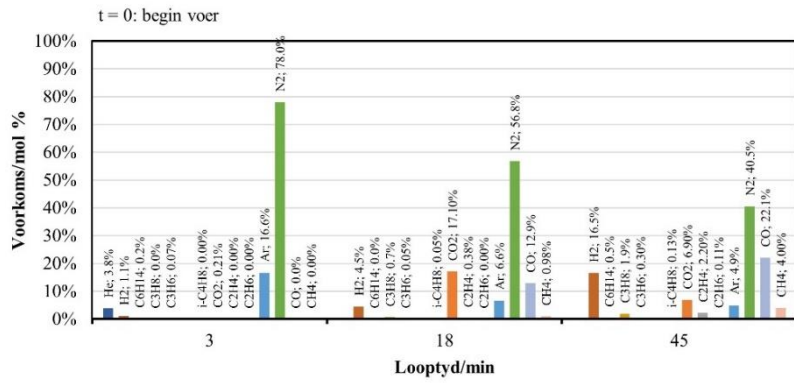


(d) Eksp. 221005_1

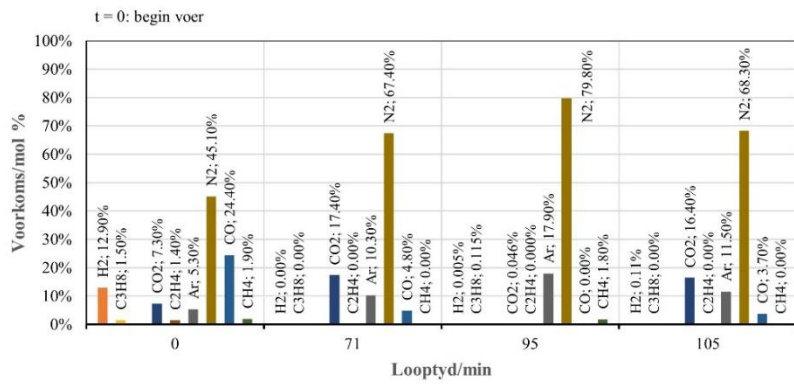
Figuur 7-20: Tydafhanklike gassamestellings, rubberskaafsel-vergassing.



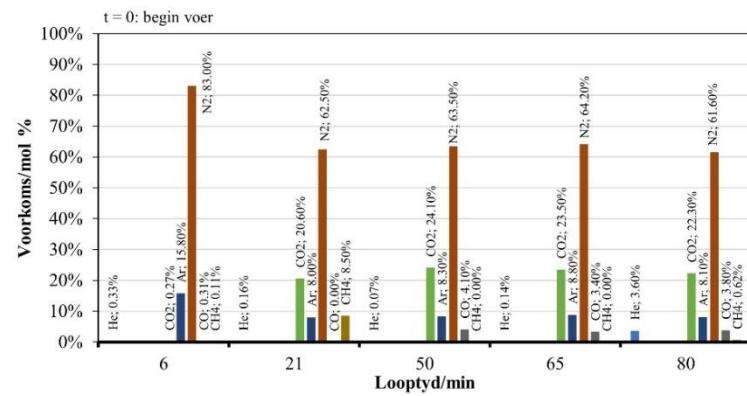
(e) Eksp. 220915_1



(f) Eksp. 220922_1

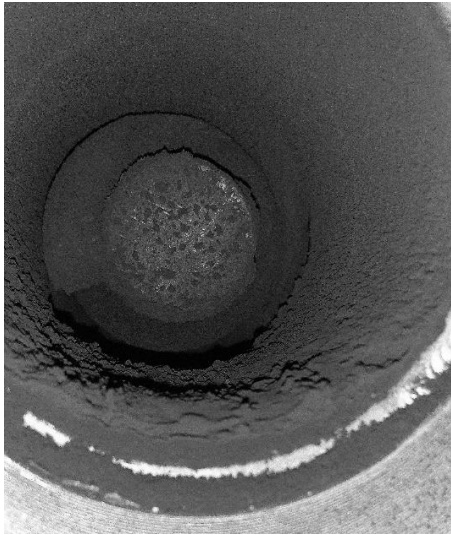


(g) Eksp. 220928_1



(h) Eksp. 221005_1

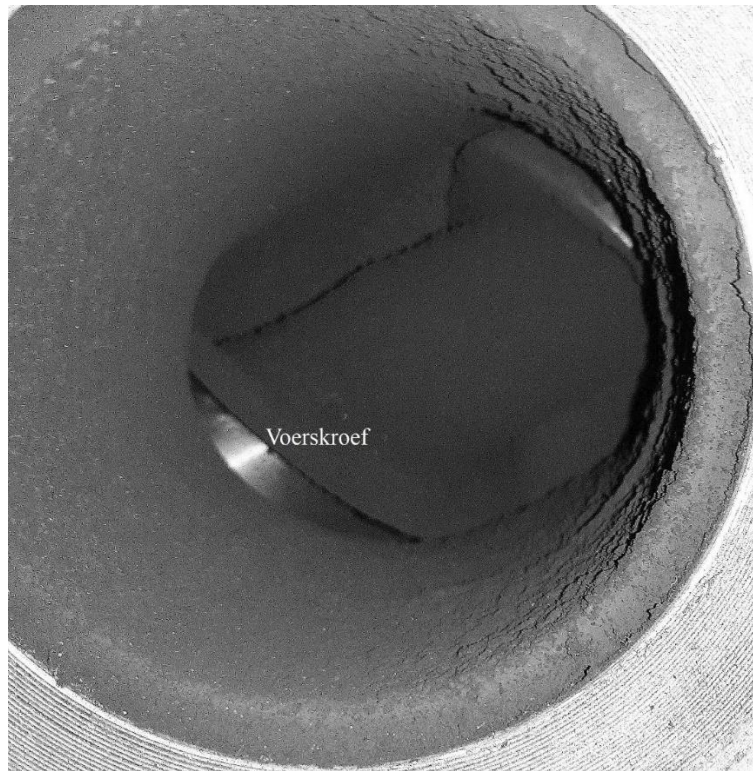
Figuur 7-21: Tydafhanklike gassamestellings, rubberskaafsel-vergassing.



(a)

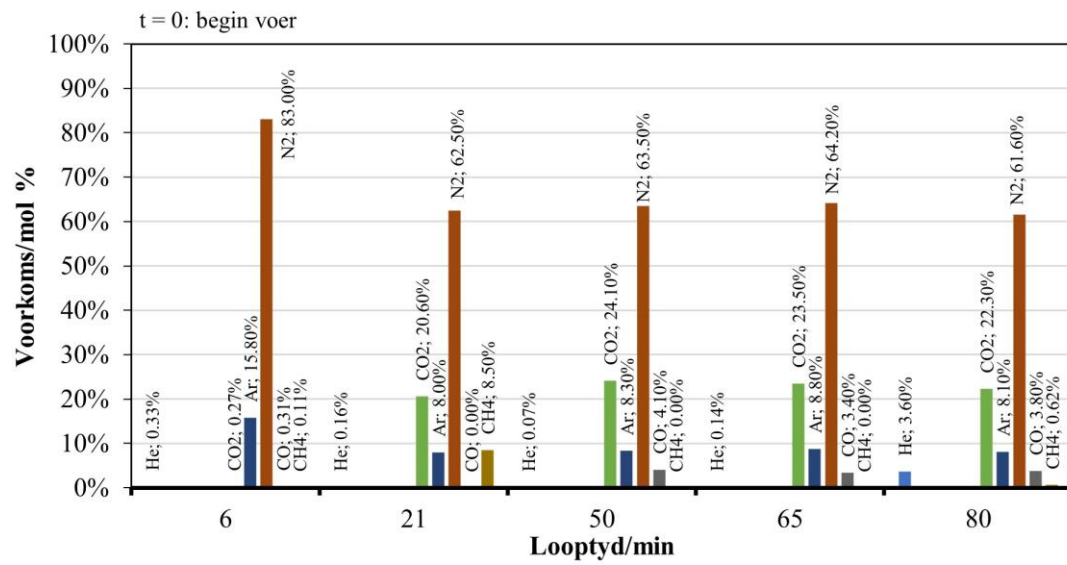


(b)

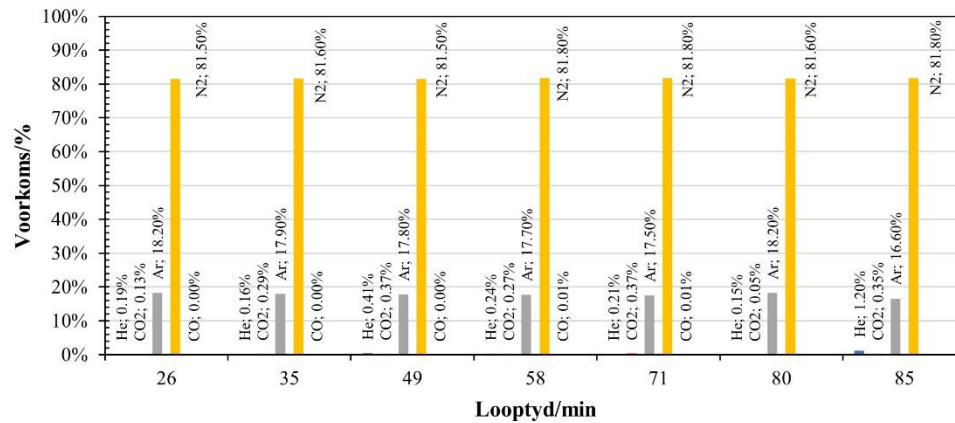


(c)

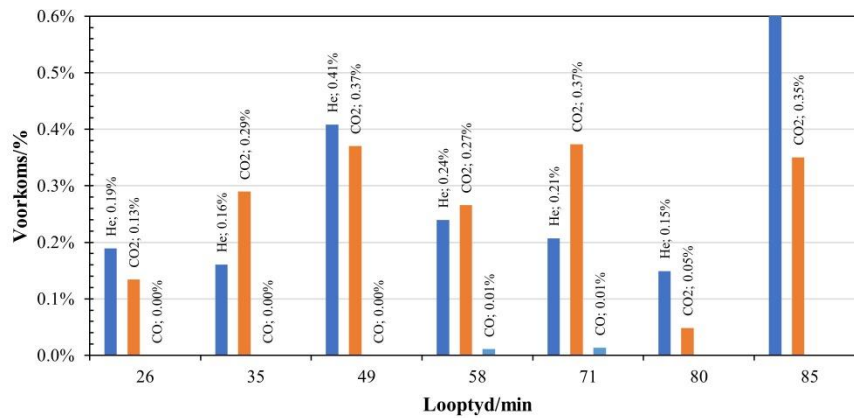
Figuur 7-22: Kooksneerslae in die toerusting. (a), (b) neerslag in die voerbuis; (c) neerslag op die voerskroef.



Figuur 7-23: Gassamestelling, $0.75 \text{ kg h}^{-1} < 1 \text{ mm}$ partikels (Eksp. 221005_1).

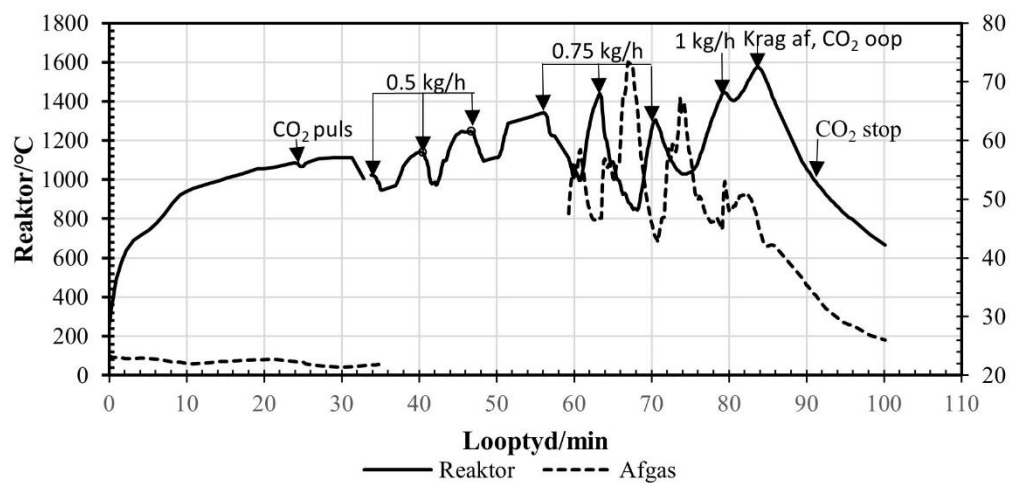


(a) Hoofkomponente

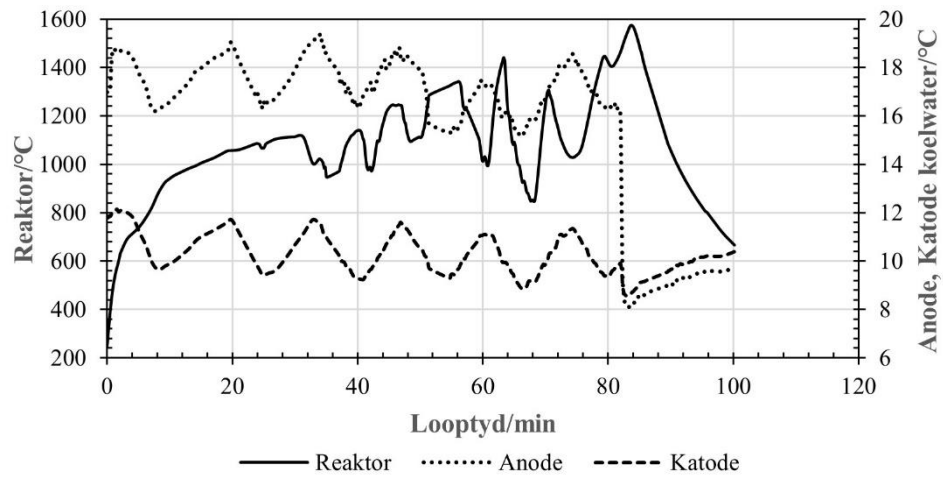


(b) Singaskomponente

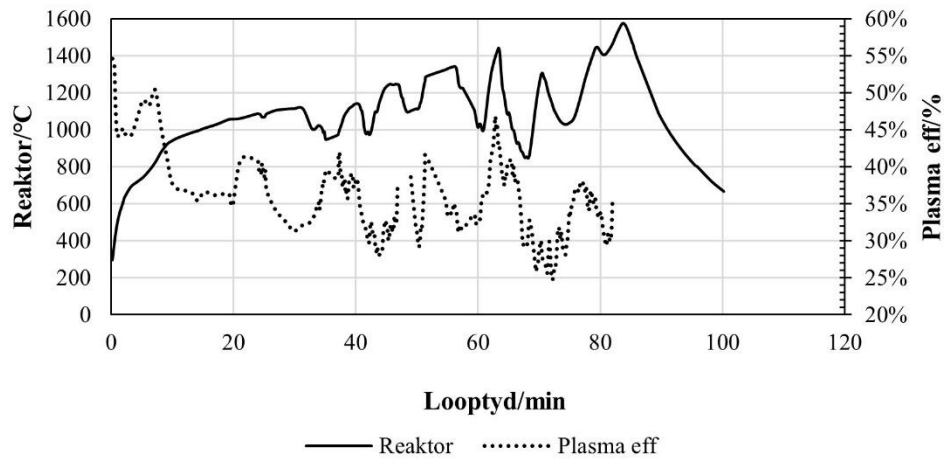
Figuur 7-24: Gasanalyse: piroliseproducte (Eksp. 221020_1).



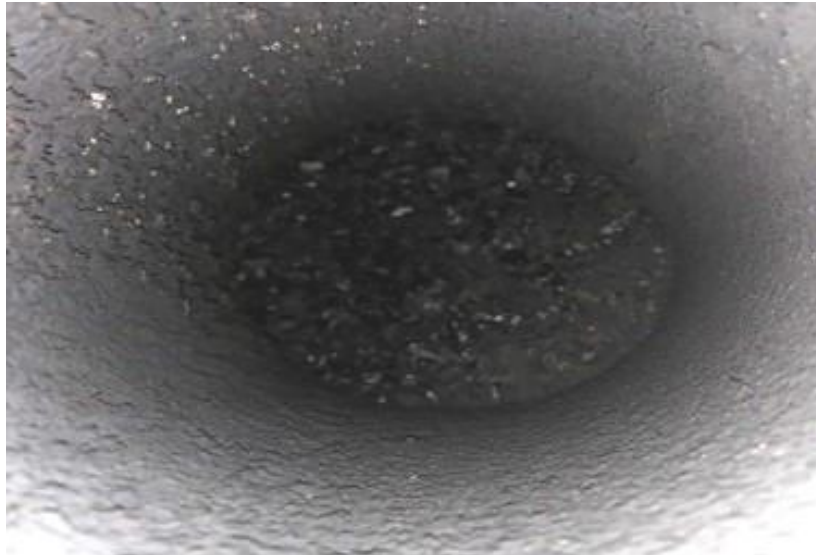
Figuur 7-25: Pirolise- en afgas temperatuur by verskillende voertempo's. (Eksp. 221020_1).



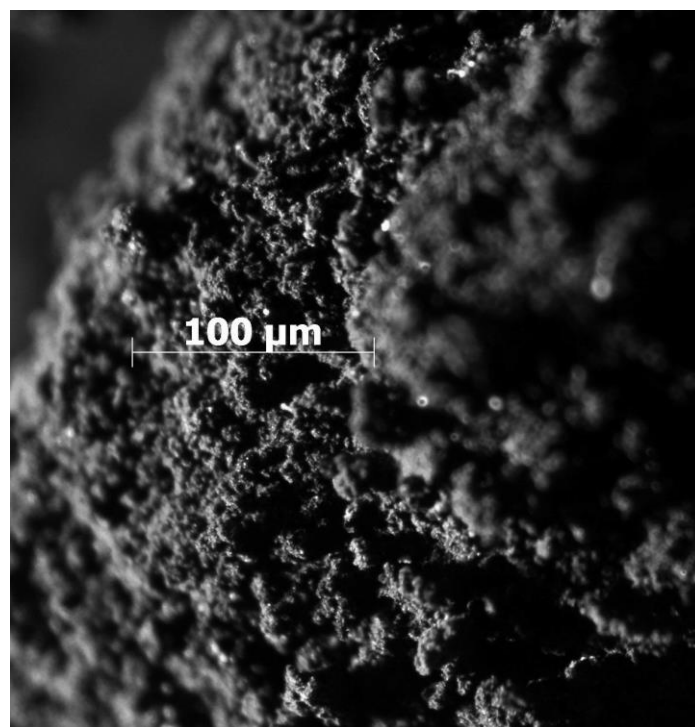
Figuur 7-26: Verband tussen reaktortemperatuur en plasmaverkoelwater temperature. (Eksp. 221020_1)



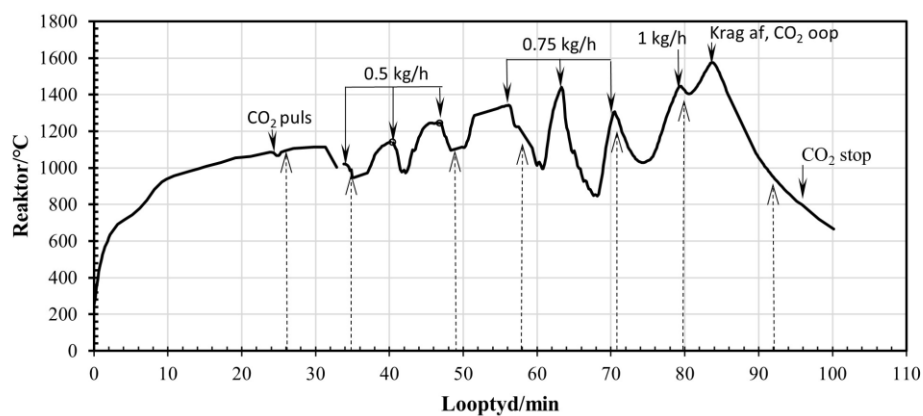
Figuur 7-27: Verband tussen reaktortemperatuur en plasma termiese effektiwiteit (Eksp. 221020_1)



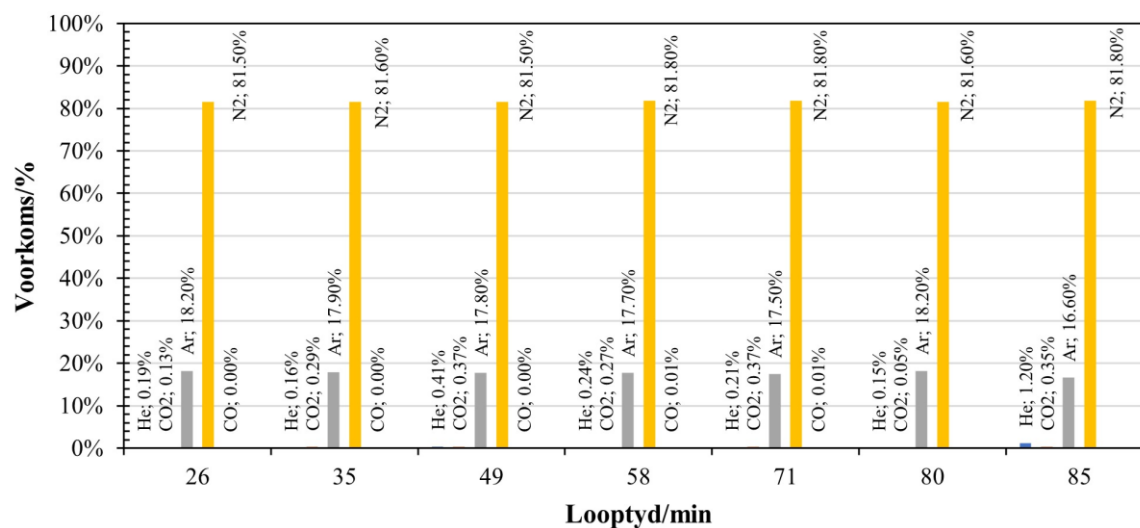
Figuur 7-28: Die vol reaktor na afloop van plasmapirolise (Eksp. 221020_1).



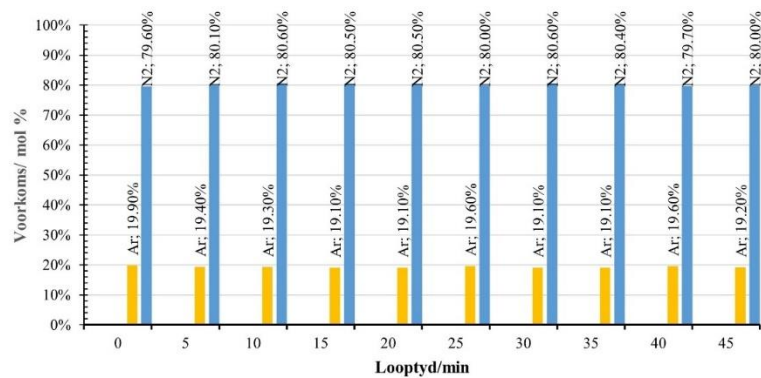
Figuur 7-29: Materiaal uit die reaktor herwin na plasmapirolise (Eksp. 221020_1).



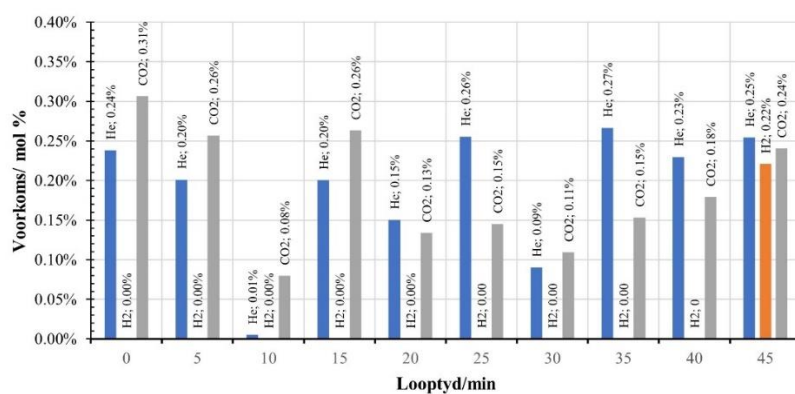
Figuur 7-30: Plasmapirolise – monsterneming (Eksp. 221020_1)



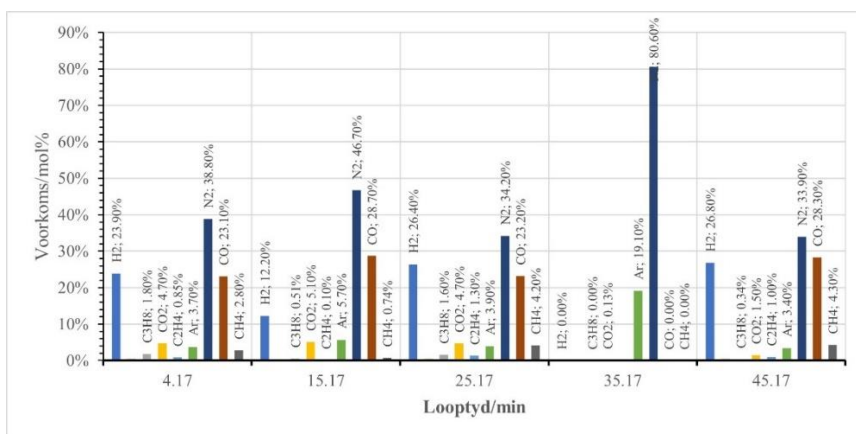
Figuur 7-31: GC analyses – plasmapirolise (Eksp. 221020_1)



(a)

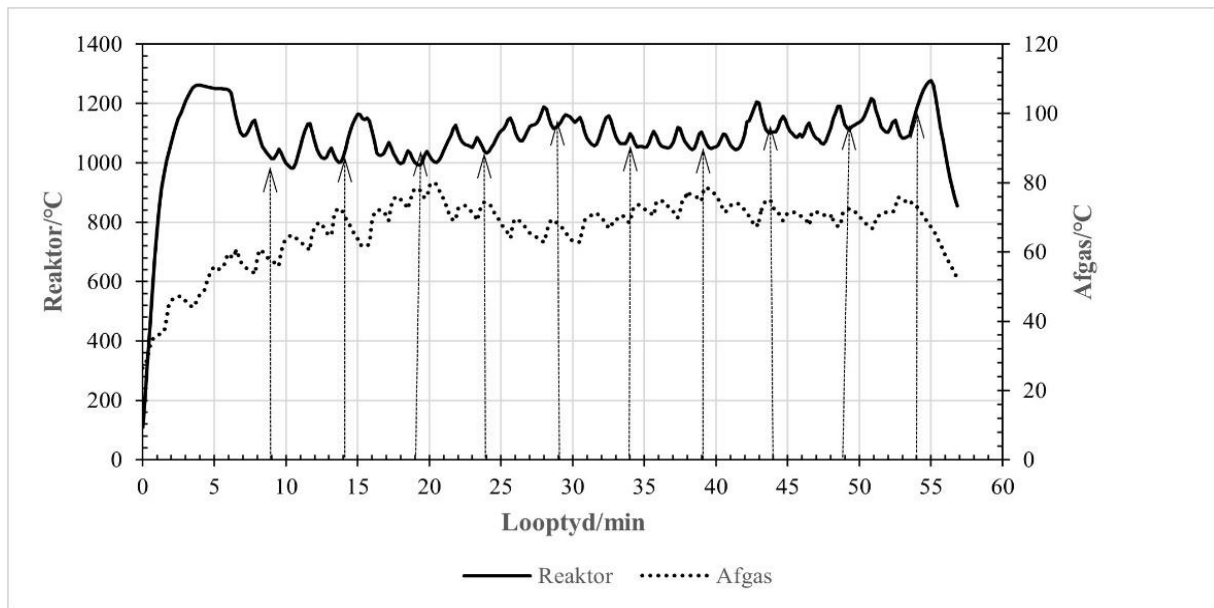


(b)

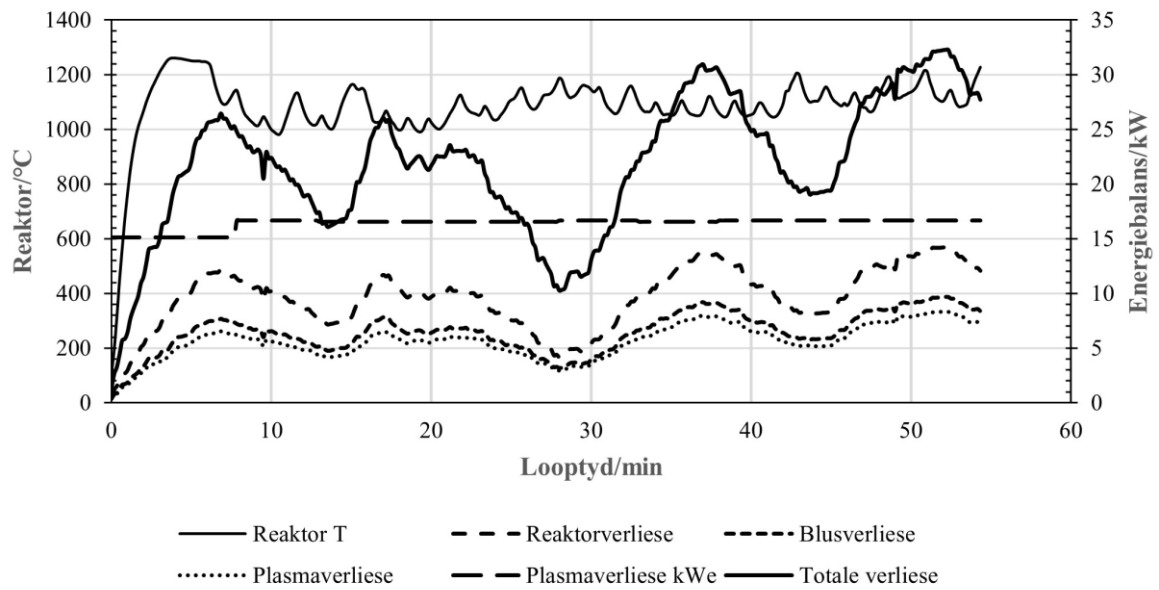


(c)

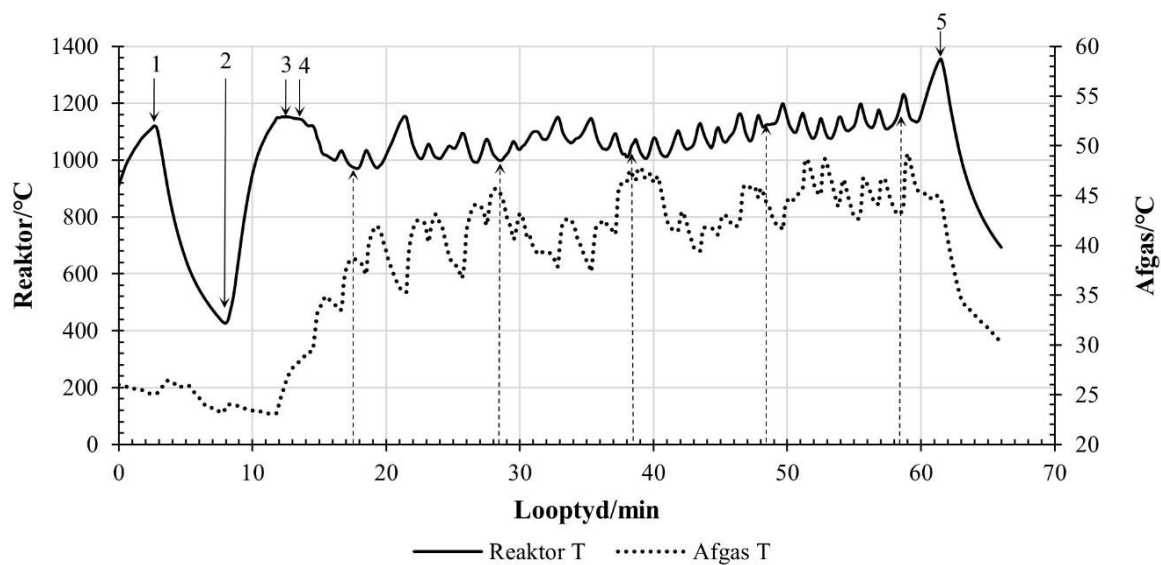
Figuur 7-32: Afgaskomponente, tru- Boudouardproses. (a), (b) Eksp. 221102_1; (c) Eksp. 221123_1.



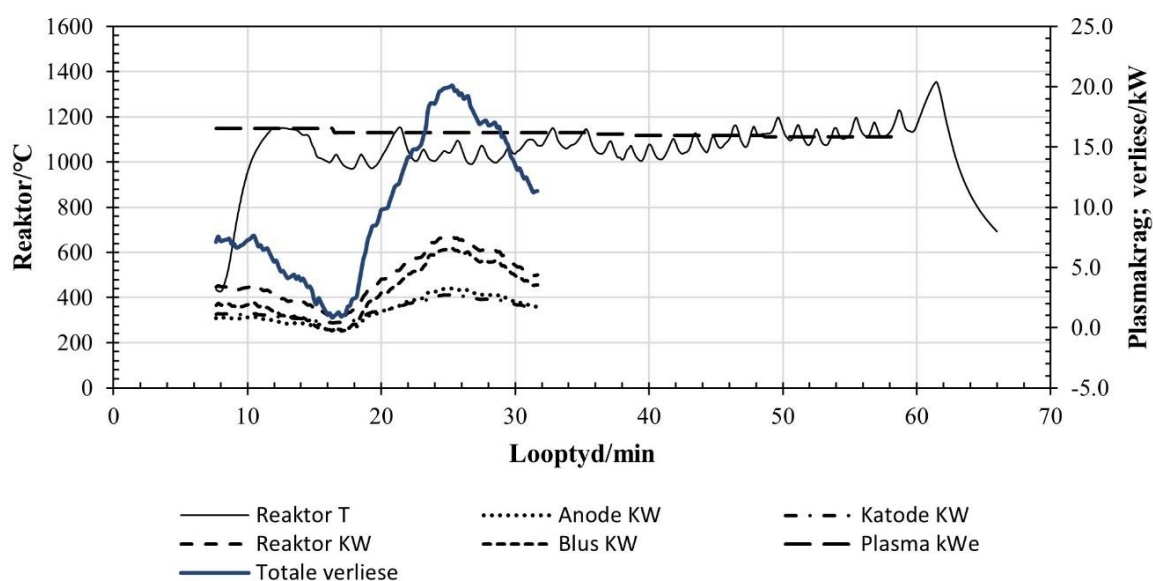
Figuur 7-33: Reaktor- en afgastemperatuur; monsternemingstye (Eksp. 221102_1)



Figuur 7-34: Energiebalans (Eksp. 221102_1)



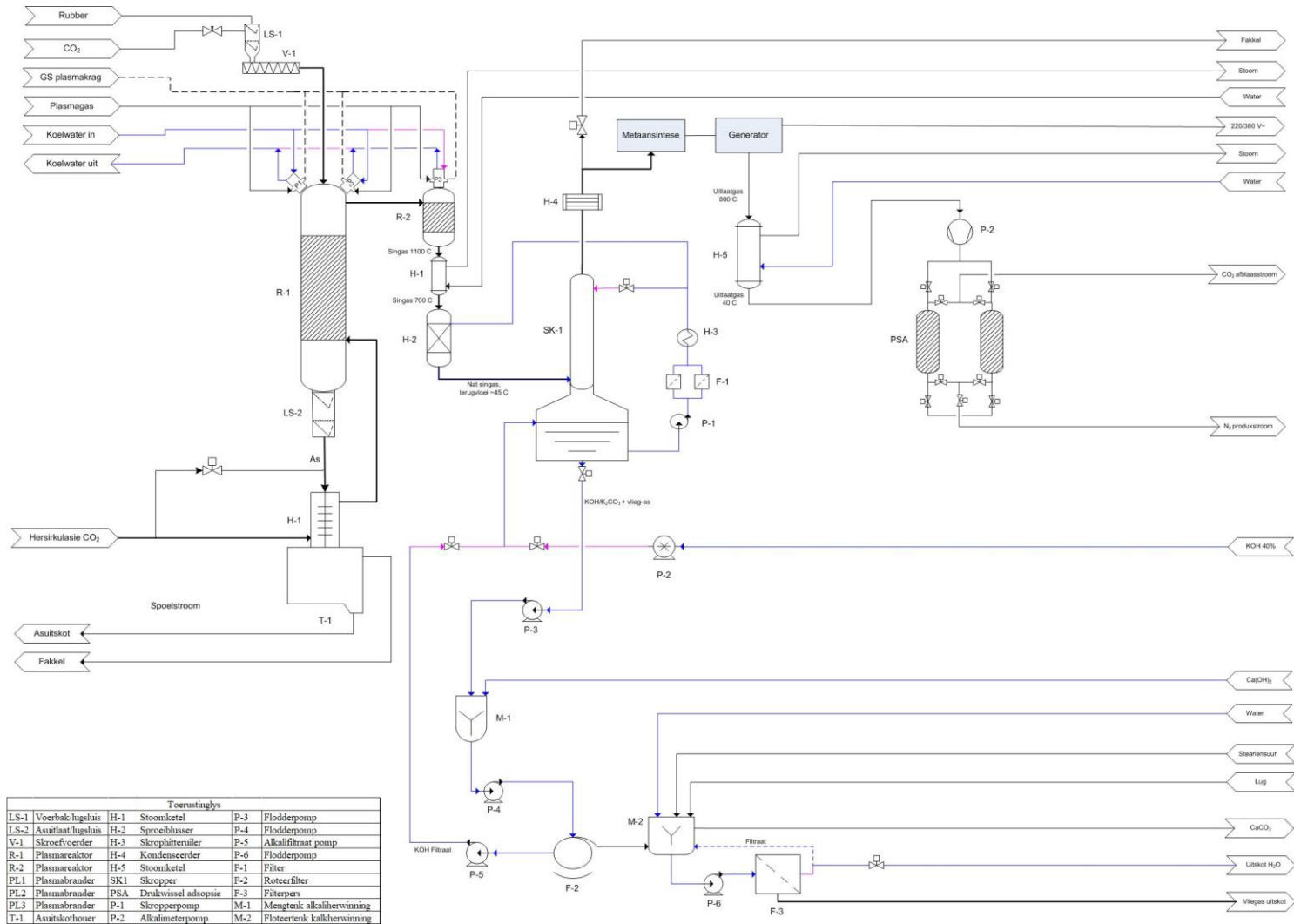
Figuur 7-35: Reaktor, afgastemperatuur en monsterpunte (Eksp. 221123_1). (1) Kragbron val uit; (2) Kragbron aan; (3) CO₂ voer begin; (4) rubbervoer begin; (5) plasma afgeskakel.



Figuur 7-36: Energiebalans (Eksp. 221123_1)

Hoofstuk 8.

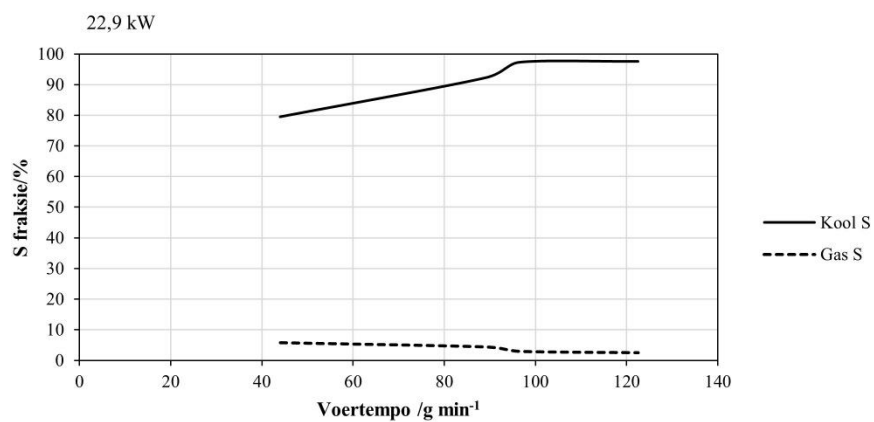
1



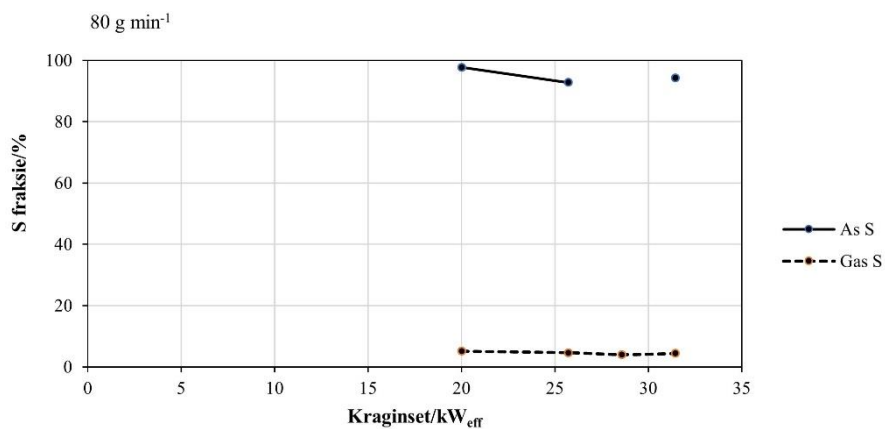
2

3

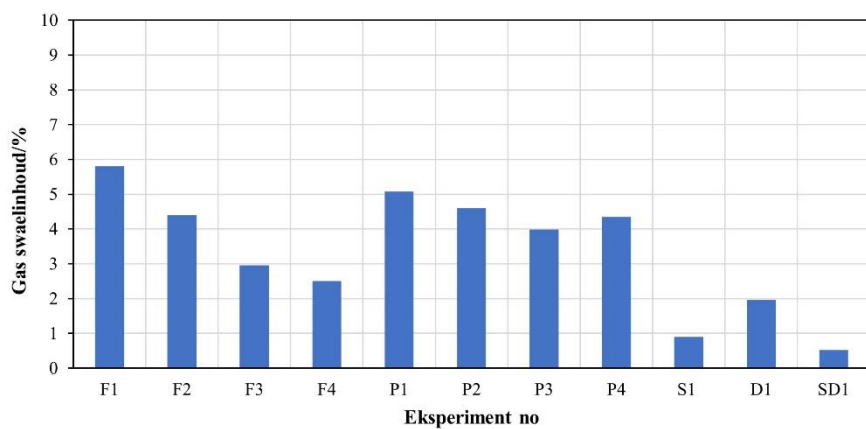
Figuur 8-1: Voorgestelde vereenvoudigde prosesvloei-diagram vir tru-Boudouardvergassing met CO₂.



(a)



(b)



(c)

Figuur 8-2: Effect van kraginset (a) en voertempo (b) op S verdeling. (c) Opsomming, afgas swaelinhoud.