

9. Bylae

9.1 Eksperimentele metodes

9.1.1 Ondersoek na effek van tipe reduceermiddel

Die vier reduceermiddels is elk in 3 verhoudings gemeng met magnetiet erts en bentoniet as bindmiddel.

Die bindmiddel was in elke geval 1% van die mengsel.

Die samestellings is bereken volgens die %vaste koolstof wat elk van die reduceermiddels bevat. Daar is bepaal wat die stoichiometriese hoeveelheid koolstof is wat nodig is om al die Fe_3O_4 na Fe te reduceer as aanvaar word dat al die C na CO geoksideer word. Dan is daar nog twee ander samestellings vir elke brandstof bereken. Een met 10% meer vaste koolstof as wat stoichiometries nodig is en een met 10% minder koolstof. Die persentasie yster in die erts is 70% volgens Tabel 9-2. Daar is 1% bentoniet as bindmiddelgebruik

Die samestellings is bereken met die volgende formule

$$\%Reduseermiddel \in mengsel = \frac{100 - \%Bindmiddel}{1 + 3.663 \frac{\%VC \text{ in reduceermiddel}}{\%Fe \text{ in erts}}}$$

Die samestellings wat gebruik is, is dus soos in Tabel 9-1

| Tabel 9-1 Samestellings wat getoets is (massa persent reduceermiddel) | | | |
|---|------------|-----------------|----------|
| Reduceermiddel | 10% minder | Stoichiometries | 10% meer |
| Leeuwan-steenwou | 23.9 | 25.9 | 27.7 |
| Kooks | 17.3 | 18.9 | 20.4 |
| Antrasiet | 17.0 | 18.5 | 20.0 |
| Grafiet | 14.9 | 16.3 | 17.6 |

Van die mengsel is korrels gemaak met diameter wat wissel tussen 13 en 18 mm.



Volgens die toets wat Midrex gedoen het, is 12 minute voldoende om die reaksie te voltooi.

'n Vertikale buisoond is gebruik om die toetse in te doen. 'n Muliët buis is gebruik met lengte van 70cm en 5cm binnediameter. Die toetse is gedoen in 'n oond waardeur N_2 gas gevoer is. 'n Gasvloei tempo van 10 l per uur is gebruik.

Die toets temperatuur is tussen $1275^\circ C$ en $1285^\circ C$. Die oond se beheermeganisme is ingestel op $1288^\circ C$. Daar is gemeet dat die temperatuur in die oond ongeveer $5^\circ C$ laer is in die senter as op die wand. Die temperatuur verspreiding in die oond is bepaal voor die toetse uitgevoer is. Die temperatuur in die middelste 10cm, waar die korrels geplaas word, het nie meer as $10^\circ C$ verskil nie.

Daar is drie verskillende tye waarvoor elke samestelling getoets is. Ten minste twee toetse is vir elke tyd gedoen. Die tye wat die korrels getoets is, is onderskeidelik 4 min, 8 min en 12 min.

Korrels is met die hand uitgesoek en geweeg sodat die grootte nie veel verskil van toets tot toets nie. In die geval van die antrasiet en kooks korrels is 'n gemiddelde massa per korrel van 7.1 gram gebruik. Omdat die ander brandstowwe ander samestellings vereis het, is ander gemiddelde massas van toepassing om 'n soortgelyke grootte te verkry.

Die massa van elke korrel is voor en na 'n toets gemeet sodat massaverlies bepaal kan word. Die massaverlies is direk nadat 2 toetse gedoen is bereken. As dit meer as 5% verskil het is nog 'n toets of twee gedoen.

Die toetsprosedure word in 'n opvolgende paragraaf uiteengesit

9.1.2 Eksperimentele metode vir bepaling van beeldanalises (volume fraksie metaal)

Metallografiese bereiding:

Die gedroogde korrel word gemonteer in koue set hars en deurgesny. Die deurgesnyde oppervlak word dan weer m.b.v vakuüm met hars geïmpregneer. Die doel is om alle fyn los deeltjies vas te bind sodat dit nie tydens polering verlore gaan en in o.a in die polleerdoek beland nie. Dit is belangrik dat die oppervlak 'n verteenwoordigende snit is.

Ondersoek en bepaling van fases:

Foto's word geneem op verskillende posisies op die snit. Die posisies moet noukeurig aangeteken word.

Elke foto word dan geskandeer om 'n beeld te lewer opgebou uit 256 skakerings van grys. M.b.v 'n beeldverwerkingsprogram word die beeld verwerk sodat daar net 4 kleure is:

- Swart: Pore
- Donkergrys: wüstiet
- Liggrys: magnetiet
- Wit : Ystermetaal

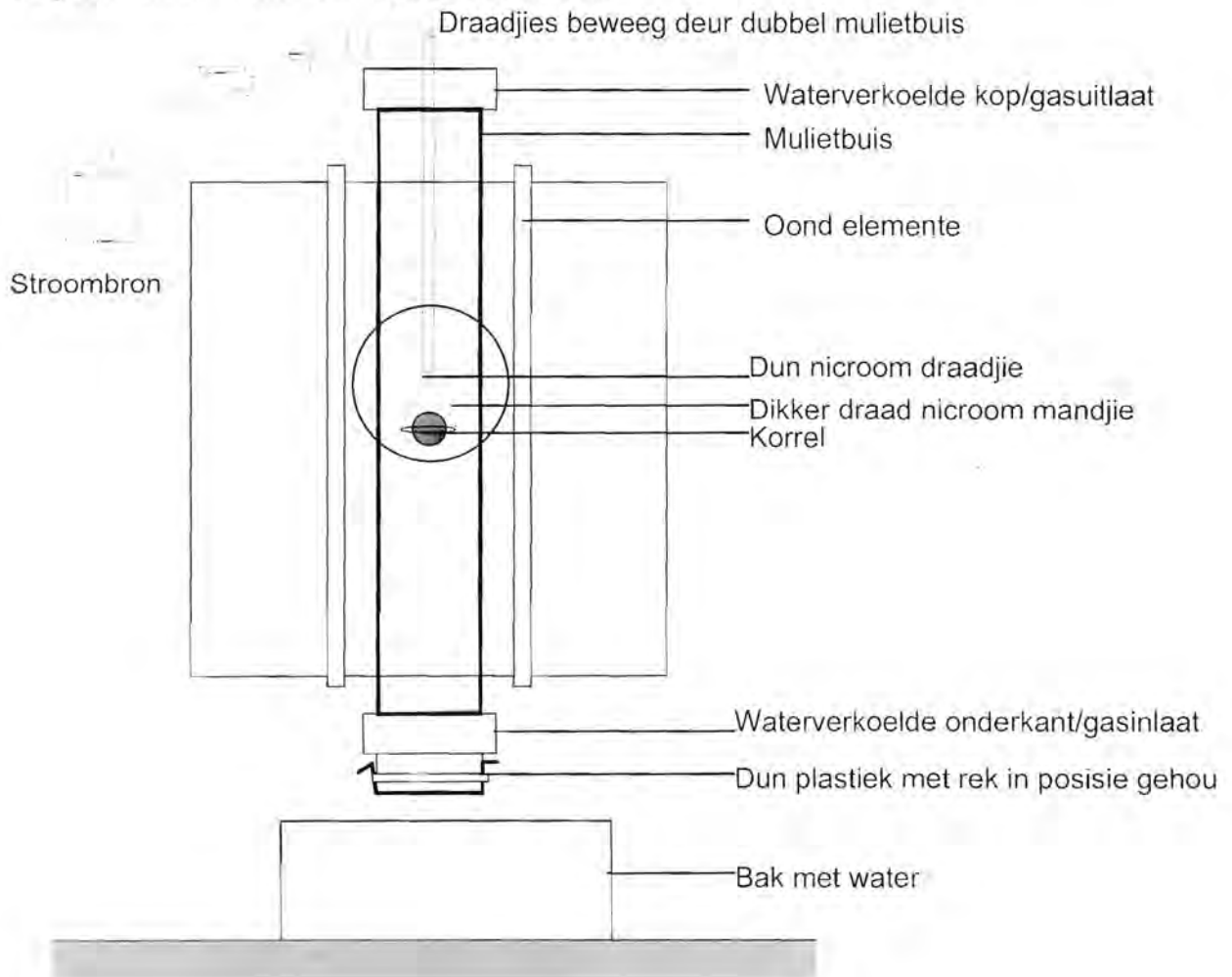
Tel van fases:

Die verwerkte beeld word gestoor in 'n lêer. M.b.v 'n ander program word die aantal piksels van elke kleur bepaal en omgesit in 'n mineralogiese analise. Deur die mineralogiese analises saam met die posisie in ag te neem word 'n resultaat verkry soos in Figuur 6-2 en Figuur 6-3.

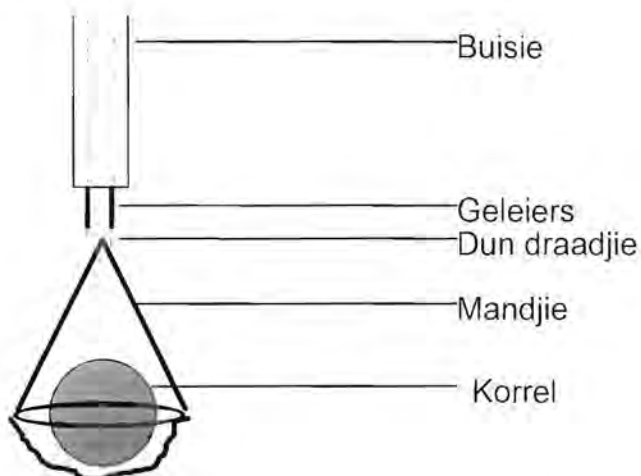
9.1.3 Eksperimentele opstelling vir enkelkorreltoetsing

Figuur 1 toon die hele opstelling saam met die oond. Die omringde gedeelte word verder vergroot en toegelig in figuur 2

Figuur 9-1 Oond en afblussisteem



Figuur 9-2 Korrel in mandjie

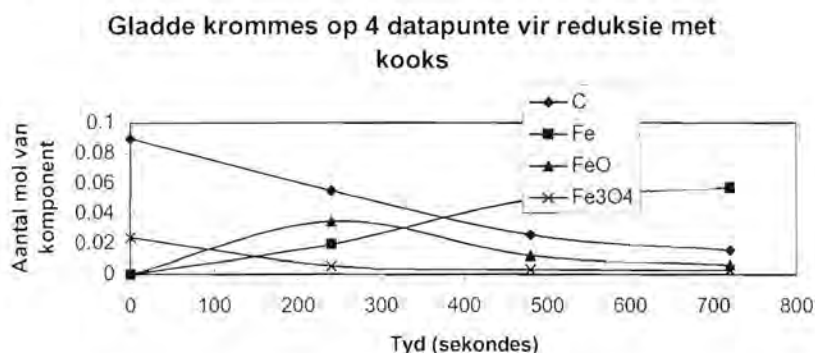


Aan die hand van bogenoemde twee figure word die eksperimentele opstelling wat gebruik is verduidelik. Die oond is vooraf verhit tot by die verlangde temperatuur terwyl die stikstof gas teen 2 cm/s in die buis opvloeit (by STD) Die boonste deksel kan verwyder word. Aan die deksel hang daar 'n muliet buisie waardeur daar twee nicroom draadjies gaan. Die onderpunte van die draade is verbind met 'n dun nicroom draadjie. Aan die dun draadjie hang 'n mandjie. Die mandjie is so gemaak dat maksimum straling die korrel wat daarin geplaas is kan bereik. Die lengte van die buisie is vooraf so verstel dat die korrel dadelik in die warmste deel van die buisoond geplaas word. Die tydelike deksel word nou verwyder en die samestelling word in die buis laat sak sodat die deksel op die bokant rus en die korrel dan in die oond hang. Die Tydsverloop vandat die oond oopgemaak is totdat die korrel op posisie is, is minder as 5 sekondes. Die boonste ente van die nicroomdrade word verbind aan 'n stroombron. Op die gegewe tyd wat die korrel verwyder moet word, word genoeg stroom deur die drade gestuur om die dun gedeelte waaraan die mandjie hang onmiddelik af te smelt. Die mandjie en korrel val dan deur die plastiek bodem van die oond. Die korrel word dadelik uit die water verwyder om heroksidasie te verhoed. Wanneer die korrel uit die water verwyder word is die korrel onmiddelik droog en amper nog te warm om vas te hou. Dit word egter verder met lug afgekoel. (Die korrel gloei niks meer as dit uit die water uit kom nie.

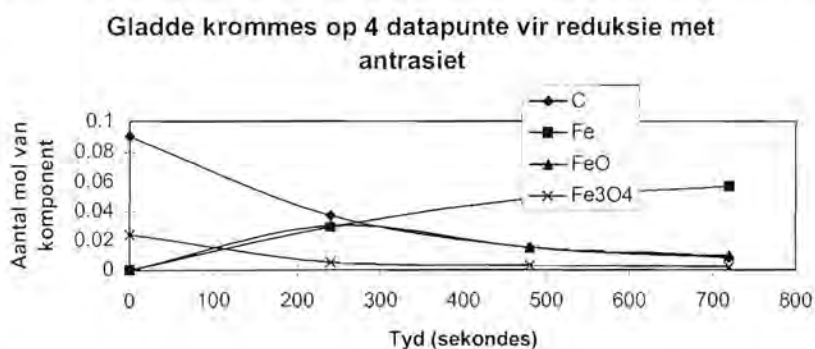
Oksidasie deur die water is as 'n moontlikheid beskou, maar mikroskopiese beskouing van die korrels het getoon dat daar geen waarneembare hoeveelhede hematiet of ysterhidroksied teenwoordig was nie

9.2 Verder verwerkte resultate van eerste reeks toetse

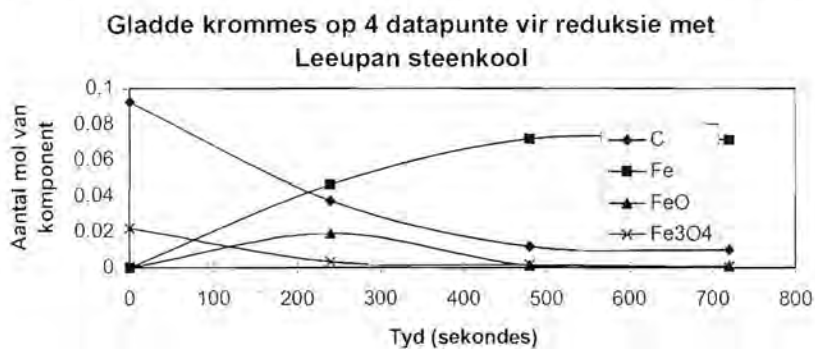
Figuur 9-3 Kinetika met kooks as reduseermiddel



Figuur 9-4 Kinetika met antrasiet as reduseermiddel

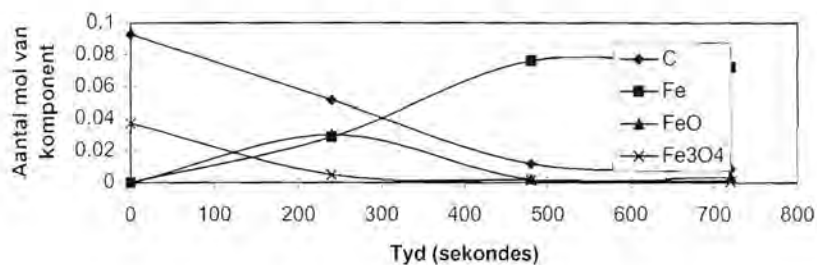


Figuur 9-5 Kinetika met Leeupan steenkool as reduseermiddel



Figuur 9-6 Kinetika met grafiet as reduseermiddel

Gladde krommes op 4 datapunte vir reduksie met grafiet



9.3 Eksperimentele data in onwerkte vorm

9.3.1 Eerste reeks toets

Tabel 9-2 Chemiese analyses van grondstowe wat gebruik is in die toetswerk

Hoeveelhede is in massa persentasie

| Komponent | Erts | Kooks | Antrasiet | Leeuwpan steenkool | Grafiet |
|--------------------------------|------|-------|-----------|--------------------|---------|
| Vlug | | 5.64 | 9.63 | 22.89 | 1.2 |
| As | | 13.36 | 7.37 | 16.11 | 1.8 |
| Vaste C | | 81 | 83 | 61 | 97 |
| Fe(totaal) | 70 | | | | |
| SiO ₂ | 1.35 | 7.77 | 4.09 | 8.9 | 0.92 |
| Al ₂ O ₃ | 0.19 | 3.84 | 2.03 | 5.46 | 0.78 |
| S | 0.08 | 0.77 | 0.74 | 1.00 | 0.01 |
| CaO | 0.11 | 0.8 | 0.42 | 0.42 | 0.063 |
| MgO | 0.18 | 0.18 | 0.09 | 0.33 | 0.028 |



Tabel 9-3 Rou chemiese data eerste toetsreeks

| Rou chemiese data van eerste reeks toetse | | | | | | | | | | | | | | | | |
|---|-------|-----|------------------|--------------------------------|------|------|---------|-------|-------|-------|---------|-----------------|-----------------|-----------------|--------|--|
| Reduseer | | | | | | | | | | | | | | | | |
| Middel | Dosis | Tyd | SiO ₂ | Al ₂ O ₃ | CaO | MgO | Fe(tot) | Swael | C | FeO | Fe(tot) | Fe ^o | Fe ² | Fe ³ | C | |
| K | - | 4" | 3.12 | 1.31 | 0.47 | 0.32 | 68.1 | 0.22 | 10.20 | 53.20 | 68.10 | 17.20 | 41.34 | 9.56 | 10.097 | |
| K | - | 8" | 3.39 | 1.33 | 0.46 | 0.29 | 79.0 | 0.24 | 5.06 | 25.60 | 79.00 | 50.70 | 19.89 | 8.41 | 5.897 | |
| K | - | 12" | 3.51 | 1.52 | 0.44 | 0.28 | 85.2 | 0.26 | 2.81 | 12.80 | 85.20 | 82.20 | 9.95 | -6.95 | 3.508 | |
| K | s | 4" | 3.5 | 1.05 | 0.57 | 0.27 | 67.6 | 0.25 | 10.50 | 46.50 | 67.60 | 22.10 | 36.13 | 9.37 | 10.290 | |
| K | s | 8" | 3.84 | 1.17 | 0.67 | 0.29 | 77.2 | 0.27 | 6.03 | 20.20 | 77.20 | 56.20 | 15.70 | 5.30 | 6.591 | |
| K | s | 12" | 3.8 | 1.44 | 0.44 | 0.28 | 85.9 | 0.29 | 3.67 | 10.50 | 85.90 | 72.60 | 8.16 | 5.14 | 3.238 | |
| K | + | 4" | 3.25 | 1.28 | 0.39 | 0.24 | 65.0 | 0.26 | 12.90 | 46.90 | 65.00 | 15.70 | 36.44 | 12.86 | 11.292 | |
| K | + | 8" | 3.23 | 1.24 | 0.39 | 0.26 | 78.5 | 0.29 | 7.26 | 19.60 | 78.50 | 55.50 | 15.23 | 7.77 | 6.090 | |
| K | + | 12" | 3.5 | 1.33 | 0.44 | 0.26 | 82.1 | 0.29 | 5.31 | 18.00 | 82.10 | 60.70 | 13.99 | 7.41 | 4.702 | |
| A | - | 4" | 2.24 | 0.72 | 0.29 | 0.23 | 72.4 | 0.18 | 5.30 | 57.00 | 72.40 | 16.80 | 44.29 | 11.31 | 8.440 | |
| A | - | 8" | 2.51 | 0.82 | 0.41 | 0.26 | 80.2 | 0.17 | 1.56 | 44.10 | 80.20 | 33.70 | 34.27 | 12.23 | 5.434 | |
| A | - | 12" | 2.56 | 0.85 | 0.39 | 0.27 | 83.6 | 0.18 | 0.29 | 35.10 | 83.60 | 46.80 | 27.27 | 9.53 | 4.124 | |
| A | s | 4" | 2.61 | 1.01 | 0.38 | 0.24 | 74.9 | 0.24 | 8.92 | 34.00 | 74.90 | 39.70 | 26.42 | 8.78 | 7.477 | |
| A | s | 8" | 2.75 | 1.03 | 0.36 | 0.25 | 80.6 | 0.27 | 5.41 | 15.90 | 80.60 | 64.10 | 12.35 | 4.15 | 5.280 | |
| A | s | 12" | 2.79 | 1.01 | 0.35 | 0.26 | 86.1 | 0.26 | 3.56 | 10.00 | 86.10 | 75.50 | 7.77 | 2.83 | 3.161 | |
| A | + | 4" | 2.47 | 0.88 | 0.39 | 0.24 | 71.7 | 0.22 | 9.11 | 41.80 | 71.70 | 28.90 | 32.48 | 10.32 | 8.710 | |
| A | + | 8" | 2.68 | 0.92 | 0.42 | 0.26 | 81.0 | 0.23 | 3.90 | 18.40 | 81.00 | 62.10 | 14.30 | 4.60 | 5.126 | |
| A | + | 12" | 2.83 | 0.95 | 0.42 | 0.27 | 86.9 | 0.24 | 2.40 | 8.16 | 86.90 | 77.30 | 6.34 | 3.26 | 2.853 | |
| L | - | 4" | 3.73 | 2.08 | 0.73 | 0.33 | 75.0 | 0.3 | 6.46 | 32.00 | 75.00 | 42.10 | 24.86 | 8.04 | 7.438 | |
| L | - | 8" | 3.72 | 2.06 | 0.74 | 0.32 | 84.8 | 0.34 | 1.97 | 7.55 | 84.80 | 75.20 | 5.87 | 3.73 | 3.662 | |
| L | - | 12" | 3.68 | 2.02 | 0.68 | 0.32 | 86.5 | 0.34 | 1.04 | 4.06 | 86.50 | 80.90 | 3.15 | 2.45 | 3.007 | |
| L | s | 4" | 3.84 | 2.34 | 0.77 | 0.32 | 74.0 | 0.34 | 7.98 | 30.00 | 74.00 | 44.90 | 23.31 | 5.79 | 7.824 | |
| L | s | 8" | 3.52 | 1.98 | 0.69 | 0.3 | 85.2 | 0.36 | 1.78 | 3.13 | 85.20 | 81.20 | 2.43 | 1.57 | 3.508 | |
| L | s | 12" | 4.31 | 2.43 | 0.8 | 0.36 | 85.0 | 0.4 | 2.44 | 1.08 | 85.00 | 84.20 | 0.84 | -0.04 | 3.585 | |
| L | + | 4" | 4.14 | 2.44 | 0.77 | 0.34 | 71.0 | 0.39 | 9.19 | 21.80 | 71.00 | 49.00 | 16.94 | 5.06 | 8.980 | |
| L | + | 8" | 4.57 | 3.35 | 0.84 | 0.36 | 87.1 | 0.4 | 4.56 | 1.69 | 87.10 | 80.20 | 1.31 | 5.59 | 2.775 | |
| L | + | 12" | 4.6 | 2.67 | 0.84 | 0.36 | 85.0 | 0.4 | 3.94 | 0.79 | 85.00 | 84.50 | 0.61 | -0.11 | 3.585 | |
| G | - | 4" | 1.85 | 0.44 | 0.41 | 0.25 | 72.7 | 0.066 | 8.39 | 44.60 | 72.70 | 29.30 | 34.65 | 8.75 | 8.325 | |
| G | - | 8" | 2.66 | 0.5 | 0.43 | 0.27 | 86.5 | 0.081 | 2.18 | 9.86 | 86.50 | 75.90 | 7.66 | 2.94 | 3.007 | |
| G | - | 12" | 2.05 | 0.59 | 0.53 | 0.32 | 88.0 | 0.084 | 0.64 | 7.03 | 88.00 | 82.90 | 5.46 | -0.36 | 2.429 | |
| G | s | 4" | 1.74 | 0.4 | 0.43 | 0.23 | 71.5 | 0.074 | 11.20 | 42.60 | 71.50 | 29.30 | 33.10 | 9.10 | 8.787 | |
| G | s | 8" | 1.64 | 0.4 | 0.47 | 0.25 | 93.3 | 0.082 | 3.11 | 3.72 | 93.30 | 86.80 | 2.89 | 3.61 | 0.386 | |
| G | s | 12" | 0.93 | 0.26 | 0.45 | 0.22 | 88.9 | 0.073 | 2.20 | 1.78 | 88.90 | 92.60 | 1.38 | -5.08 | 2.082 | |
| G | + | 4" | 1.68 | 0.39 | 0.41 | 0.23 | 72.0 | 0.073 | 12.90 | 45.20 | 72.00 | 25.20 | 35.12 | 11.68 | 8.594 | |
| G | + | 8" | 1.09 | 0.4 | 0.36 | 0.19 | 93.2 | 0.083 | 3.11 | 1.79 | 93.20 | 88.30 | 1.39 | 3.51 | 0.425 | |
| G | + | 12" | 1.15 | 0.46 | 0.47 | 0.21 | 95.1 | 0.091 | 3.66 | 11.00 | 95.10 | 76.80 | 8.55 | 9.75 | -0.307 | |



Tabel 9-4 Grootteverspreiding van grondstowwe gebruik

| um | Gemid | Log(gemid) | Grootteverspreiding van grondstowwe | | | | | | | | | |
|-----|--------|------------|-------------------------------------|------|-------|------|-----------|------|---------|------|------------------|------|
| | | | Antrasiet | | Kooks | | Steenkool | | Grafiet | | Zandrivierspoort | |
| | | | Klas | Kum | Klas | Kum | Klas | Kum | Klas | Kum | Klas | Kum |
| 2.4 | 2.81 | 0.3802 | 1.7 | 1.7 | 3.2 | 3.2 | 1.6 | 1.6 | 0 | 0 | 0.2 | 0.2 |
| 3.3 | 3.94 | 0.5185 | 4.9 | 3.2 | 8 | 4.8 | 4.9 | 3.3 | 0 | 0 | 1.2 | 1 |
| 4.7 | 5.57 | 0.6721 | 9.8 | 4.9 | 14.6 | 6.6 | 9.9 | 5 | 0.9 | 0.9 | 3.4 | 2.2 |
| 6.6 | 7.88 | 0.8195 | 14.5 | 4.7 | 19.6 | 5 | 15.3 | 5.4 | 2.9 | 2 | 5.6 | 2.2 |
| 9.4 | 11.05 | 0.9731 | 23.2 | 8.7 | 27.7 | 8.1 | 23.4 | 8.1 | 7.9 | 5 | 12.5 | 6.9 |
| 13 | 15.72 | 1.1139 | 28 | 4.8 | 35.3 | 7.6 | 31.3 | 7.9 | 14 | 6.1 | 22.5 | 10 |
| 19 | 22.65 | 1.2788 | 35.9 | 7.9 | 44.1 | 8.8 | 40.6 | 9.3 | 21.7 | 7.7 | 34.9 | 12.4 |
| 27 | 32.03 | 1.4314 | 44.2 | 8.3 | 57.4 | 13.3 | 50.8 | 10.2 | 33.1 | 11.4 | 50.3 | 15.4 |
| 38 | 44.88 | 1.5798 | 54.2 | 10 | 70.7 | 13.3 | 61.3 | 10.5 | 45.9 | 12.8 | 65.8 | 15.5 |
| 53 | 63.05 | 1.7243 | 65.8 | 11.6 | 83.8 | 13.1 | 72.6 | 11.3 | 59.9 | 14 | 79.2 | 13.4 |
| 75 | 89.16 | 1.8751 | 79 | 13.2 | 92.6 | 8.8 | 84.7 | 12.1 | 76.8 | 16.9 | 91.8 | 12.6 |
| 106 | 126.10 | 2.0253 | 91.8 | 12.8 | 97.5 | 4.9 | 94.5 | 9.8 | 88.6 | 11.8 | 97.9 | 6.1 |
| 150 | 178.33 | 2.1761 | 97.9 | 6.1 | 99 | 1.5 | 98.5 | 4 | 96.5 | 7.9 | 99.5 | 1.6 |
| 212 | 252.19 | 2.3263 | 100 | 2.1 | 100 | 1 | 100 | 1.5 | 100 | 3.5 | 99.7 | 0.2 |
| 300 | | 2.4771 | 100 | 0 | 100 | 0 | 100 | 0 | 100 | 0 | 100 | 0.3 |
| | | | | 100 | | 100 | | 100 | | 100 | | 100 |

Tabel 9-5 Partikelgrootte

| Gemiddelde grootte van partikels, Dp [um] | |
|---|-------|
| Antrasiet | 18.9 |
| Kooks | 14.6 |
| Steenkool | 17.83 |
| Grafiet | 35.71 |
| Zandrivierspoort | 24.72 |

Tabel 9-6 Partikel deurlaatgrootte

| Deurlaat groottes in [um] | | | | | |
|---------------------------|-----------|-------|-----------|---------|------------------|
| Persentasie deur | Antrasiet | Kooks | Steenkool | Grafiet | Zandrivierspoort |
| %10 | 4.78 | 3.73 | 4.73 | 10.6 | 8.37 |
| %50 | 33.37 | 23 | 26.36 | 42.2 | 26.87 |
| %80 | 77.39 | 48.67 | 66.49 | 83.5 | 54.35 |



9.3.2 Tweede reeks toetse onverwerkte data

Tabel 9-7 Massadata in gram na verskikkelende tye van behandeling van met 15% kooks as reduseermiddel

| 1300°C | Voor | Na | |
|--------|------|------|------|
| | 2 | 5.65 | 5.55 |
| | 3 | 6.20 | 5.73 |
| | 3 | 5.68 | 5.08 |
| | 4 | 5.79 | 4.65 |
| | 4 | 6.08 | 4.96 |
| | 5 | 4.38 | 3.21 |
| | 5 | 4.72 | 3.51 |
| | 6 | 7.34 | 5.53 |
| | 6 | 5.40 | 3.84 |
| | 7 | 6.07 | 4.14 |
| | 7 | 5.59 | 3.81 |
| | 8 | 6.35 | 4.24 |
| | 8 | 4.19 | 2.70 |
| | 9 | 6.19 | 4.07 |
| | 10 | 7.39 | 4.96 |
| | 10 | 5.72 | 3.67 |
| | 12 | 5.00 | 3.17 |
| | 12 | 5.04 | 3.21 |
| | 16 | 5.91 | 3.74 |
| | 16 | 4.94 | 3.15 |
| | 19 | 5.64 | 3.65 |
| | 20 | 5.45 | 3.43 |

Tabel 9-8 Massa in gram van toets waar korrel van verskillende diameters almal 10 minute by 1300°C behandel is (samestelling selfde as vorige)

| Voor | Na |
|------|------|
| 7.39 | 4.96 |
| 5.72 | 3.67 |
| 5.55 | 3.58 |
| 6.75 | 4.44 |
| 5.00 | 3.18 |
| 5.66 | 3.71 |
| 6.15 | 3.97 |



Tabel 9-9 Massadata van korrels getoets by verskillende temperature, materiaal selfde as in vorige tabel

| 1280°C | Voor | Na | |
|---------------|------|------|------|
| | 6 | 4.83 | 3.73 |
| | 10 | 6.01 | 4.22 |
| | 16 | 5.96 | 3.85 |
| | 24 | 6.75 | 4.29 |
| 1260°C | | | |
| | 6 | 6.16 | 5.10 |
| | 12 | 6.01 | 4.21 |
| | 18 | 6.10 | 4.03 |
| | 24 | 6.00 | 3.86 |
| 1327°C | | | |
| | 3 | 6.18 | 5.31 |
| | 6 | 5.95 | 4.03 |
| | 9 | 4.23 | 2.71 |
| | 12 | 3.17 | 1.88 |
| 1350°C | | | |
| | 2 | 5.67 | 5.2 |
| | 4 | 5.35 | 3.85 |
| | 6 | 5.42 | 3.39 |
| | 8 | 5.08 | 3.19 |
| | 8 | 5.67 | 3.57 |

9.3.3 Resultate van eerste reeks toetse verwerkte waardes

| Redid | Tyd | Mass Gem | Swael Gem | C Gem | Fe(tot) Gem | Fe(tot)+vs gem | Fe(tot)-vs gem | Fe(tot)ber Gem | FeO Gem | Fe ¹ Gem | Fe ² Gem | Fe ³ Gem | SiO ₂ Gem | Al ₂ O ₃ Gem | CaO Gem | MgO Gem | |
|-----------|-----|-------------|--------------|----------|----------------|-------------------|-------------------|-------------------|------------|------------------------|------------------------|------------------------|-------------------------|---------------------------------------|------------|------------|------|
| K | 0 | 1.00 | 0.21 | 15.28 | 56.79 | 56.79 | 56.79 | 56.79 | 0.00 | 24.34 | 0.00 | 16.93 | 37.86 | 2.56 | 0.88 | 0.24 | 0.08 |
| K | 4 | 0.64 | 0.24 | 11.20 | 66.90 | 66.00 | 67.80 | 67.80 | -0.90 | 48.87 | 16.33 | 37.97 | 10.60 | 3.29 | 1.21 | 0.48 | 0.28 |
| K | 8 | 0.72 | 0.27 | 6.12 | 76.23 | 77.21 | 79.26 | 79.26 | -1.02 | 21.80 | 54.13 | 16.94 | 7.16 | 3.49 | 1.25 | 0.51 | 0.28 |
| Korrels | 12 | 0.67 | 0.28 | 2.93 | 84.40 | 84.46 | 84.34 | 84.34 | 0.00 | 13.77 | 67.17 | 10.70 | 6.54 | 3.60 | 1.43 | 0.44 | 0.27 |
| A | 0 | 1.00 | 0.20 | 15.36 | 57.05 | 57.05 | 57.05 | 57.05 | 0.00 | 24.45 | 0.00 | 19.01 | 38.04 | 1.86 | 0.51 | 0.17 | 0.07 |
| A | 4 | 0.81 | 0.21 | 7.78 | 73.00 | 75.35 | 70.65 | 70.65 | 2.35 | 44.27 | 28.47 | 34.40 | 10.14 | 2.44 | 0.87 | 0.35 | 0.24 |
| A | 8 | 0.72 | 0.22 | 3.62 | 80.60 | 81.64 | 79.56 | 79.56 | 1.04 | 26.13 | 53.30 | 20.31 | 6.99 | 2.65 | 0.92 | 0.40 | 0.26 |
| Antisiel | 12 | 0.68 | 0.23 | 2.08 | 85.53 | 86.65 | 84.41 | 84.41 | 1.12 | 17.75 | 66.53 | 13.79 | 5.21 | 2.73 | 0.94 | 0.39 | 0.27 |
| L | 0 | 1.00 | 0.32 | 15.78 | 51.92 | 51.92 | 51.92 | 51.92 | 0.00 | 22.25 | 0.00 | 17.30 | 34.61 | 3.30 | 1.55 | 0.19 | 0.14 |
| L | 4 | 0.71 | 0.34 | 7.88 | 73.33 | 73.75 | 72.92 | 72.92 | 0.41 | 27.93 | 45.33 | 21.79 | 6.30 | 3.90 | 2.29 | 0.76 | 0.33 |
| L | 8 | 0.63 | 0.37 | 2.77 | 85.70 | 88.38 | 83.02 | 83.02 | 2.66 | 4.12 | 78.87 | 3.20 | 3.63 | 3.94 | 2.46 | 0.76 | 0.33 |
| van steel | 12 | 0.60 | 0.38 | 2.47 | 85.50 | 84.64 | 86.36 | 86.36 | -0.86 | 1.98 | 83.20 | 1.54 | 0.76 | 4.20 | 2.37 | 0.77 | 0.35 |
| G | 0 | 1.00 | 0.07 | 15.78 | 58.61 | 58.61 | 58.61 | 58.61 | 0.00 | 25.12 | 0.00 | 19.53 | 39.06 | 1.28 | 0.20 | 0.10 | 0.06 |
| G | 4 | 0.80 | 0.07 | 10.83 | 72.07 | 70.91 | 73.22 | 73.22 | -1.16 | 44.13 | 27.03 | 34.29 | 9.84 | 1.76 | 0.41 | 0.42 | 0.34 |
| G | 8 | 0.62 | 0.06 | 2.80 | 91.00 | 88.04 | 83.96 | 83.96 | -2.96 | 5.12 | 83.57 | 3.98 | 3.35 | 1.80 | 0.43 | 0.42 | 0.24 |
| Gruel | 12 | 0.59 | 0.06 | 2.17 | 90.73 | 82.32 | 89.15 | 89.15 | -6.42 | 6.60 | 84.10 | 5.13 | 1.50 | 1.38 | 0.44 | 0.48 | 0.25 |

9.3.4 Mikroskopiese foto's van snitte deur korrels

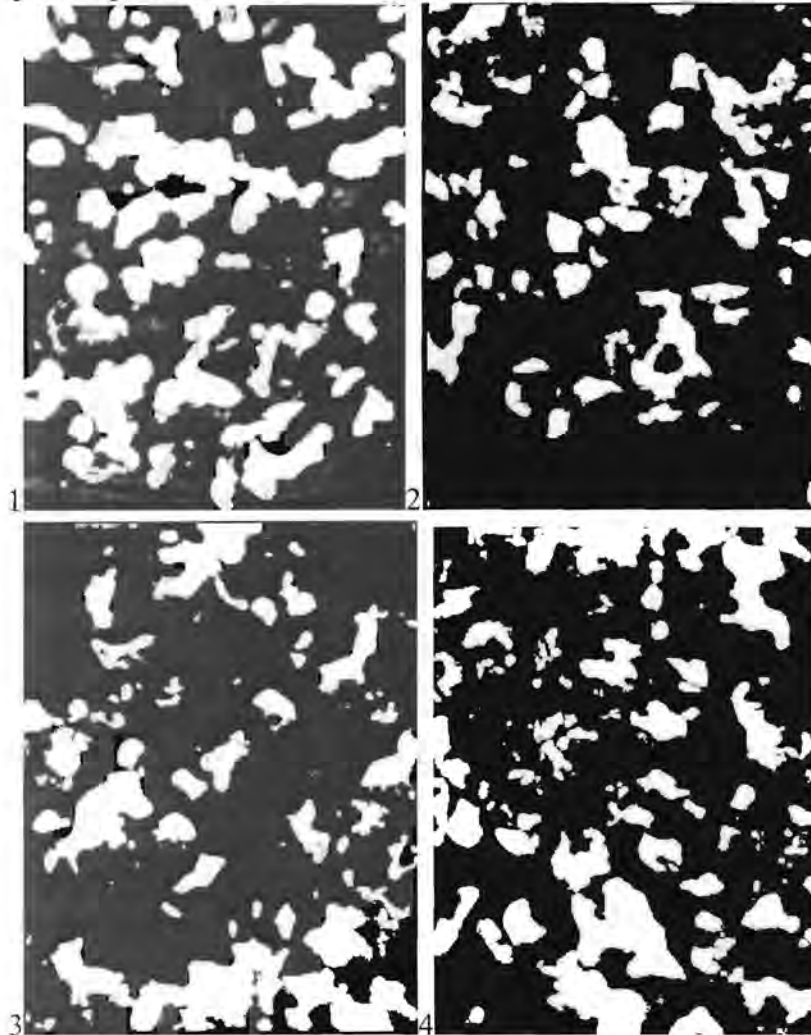
Die donkergrys is magnetiet. Die liggrys is wüstiet, Die wit is yster, 'n Donkergrys fase met 'n grower tekstuur is oorblyfsels van die kooks. Die swart is pore.

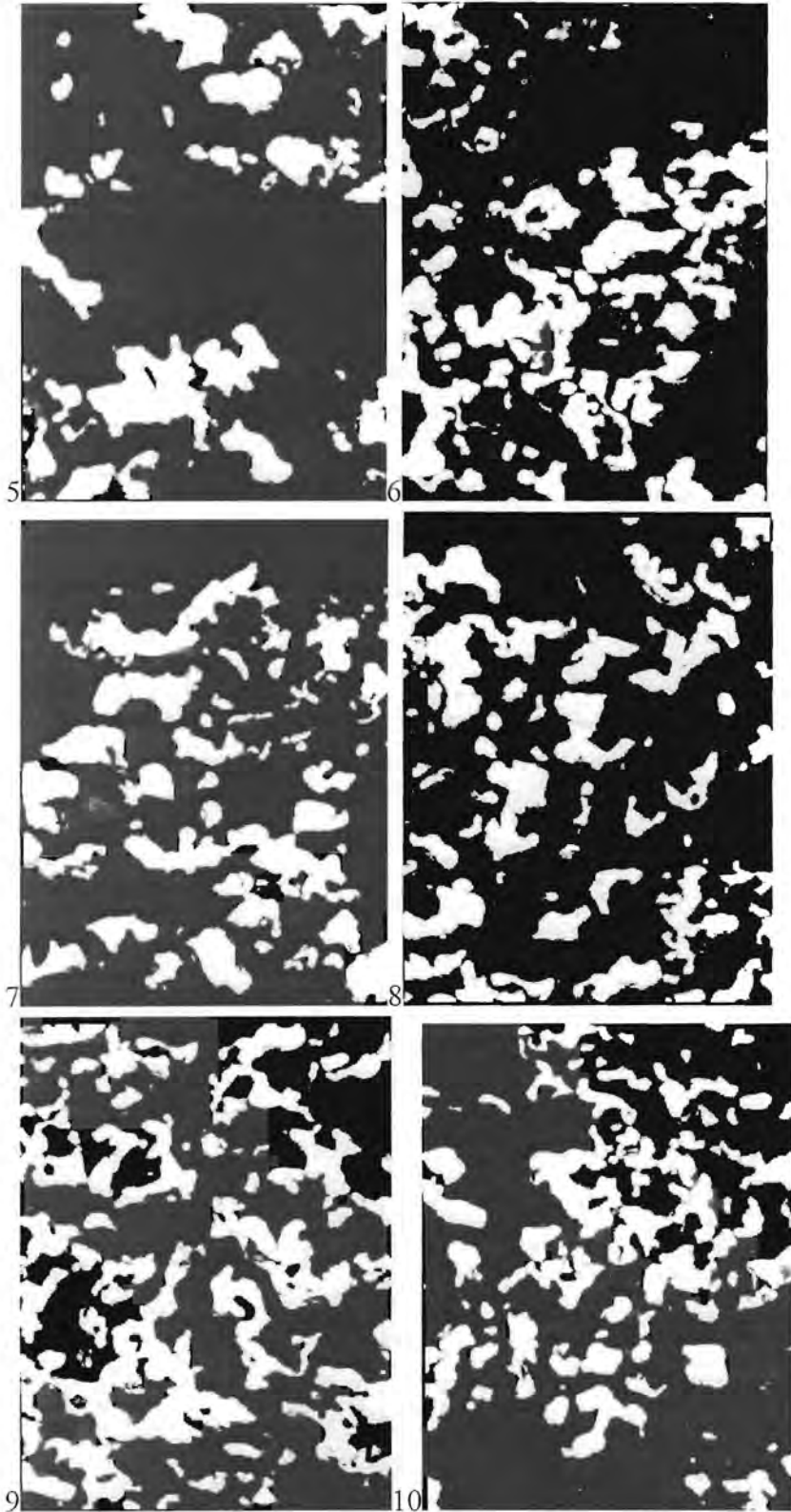
Die fotos is van 'n monsters wat by 1300°C behandel is vir 12 minute.

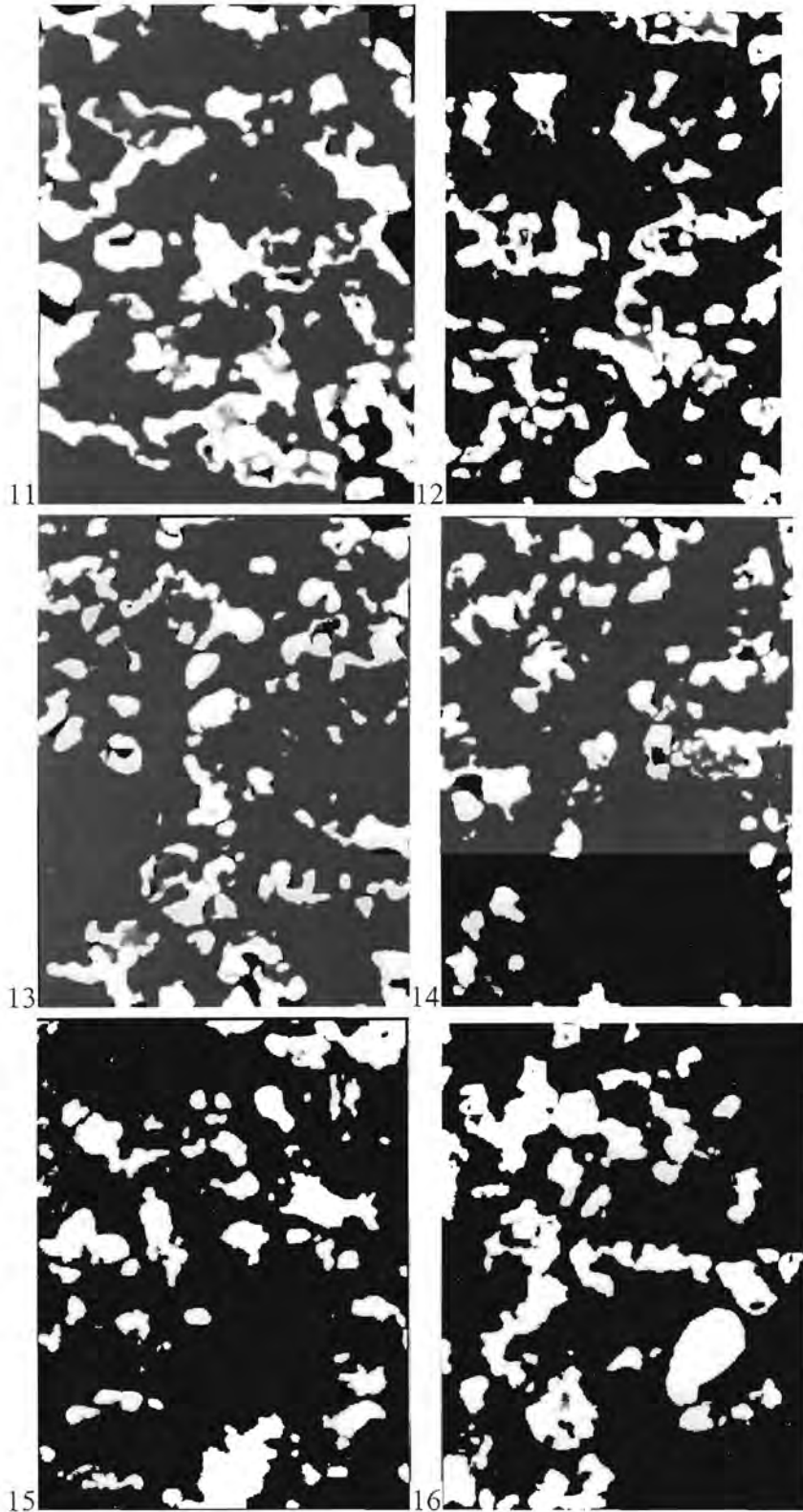
Eerste monster (Antrasiet as reduseermiddel):

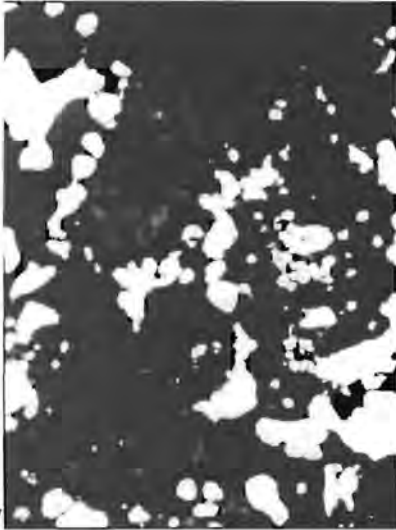
L.W die foto's is in volgorde van binne na buite geneem Die vergroting is so dat elke foto ongeveer 'n halwe milimeter wyd is. Die eerste stel foto's is genummer van 1 tot 17 die linkerkant van elke foto sluit direk aan by die regterkant van die volgende een. Die linkerkant is die naaste aan die middel van die korrel.

Figuur 9-7 Mikroskopiese beelde van 'n snit deur 'n gereageerde korrel (Antrasiet as reduseermiddel)









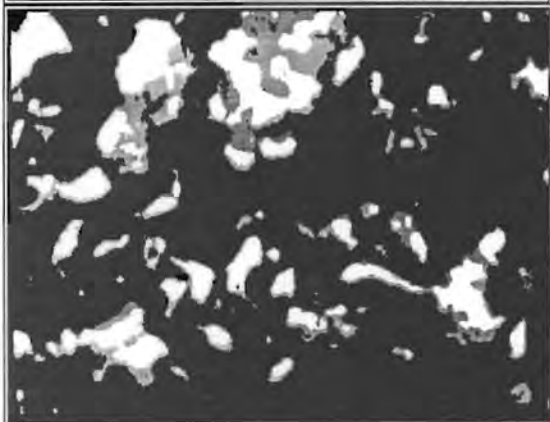
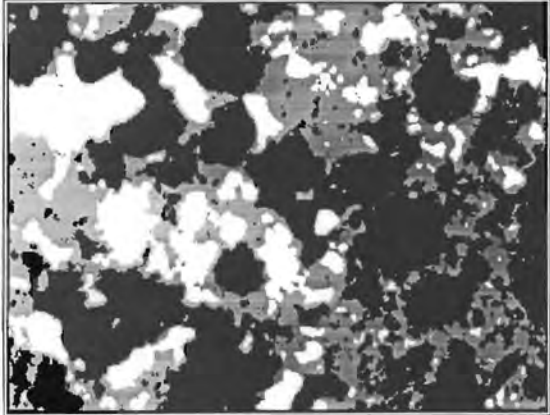
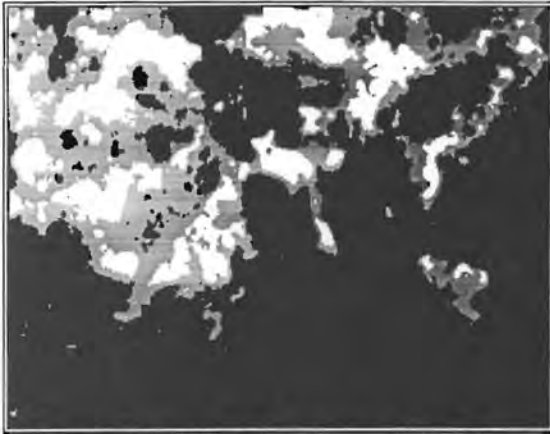
17

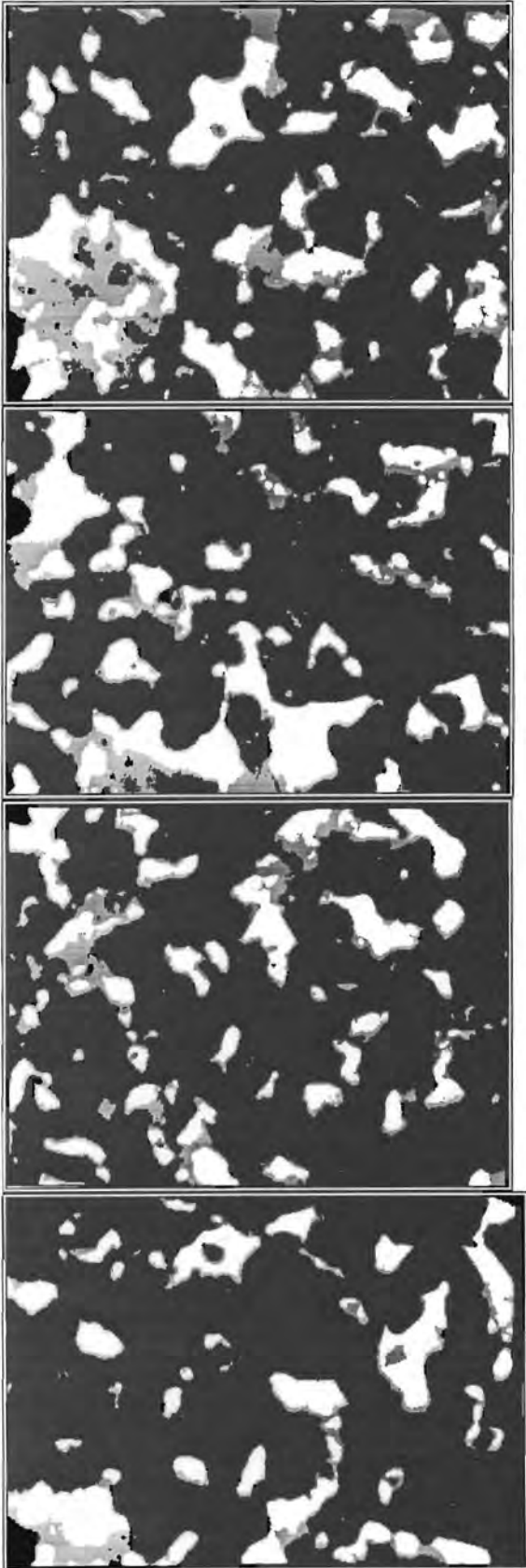
Tweede monster: (Grafiet as reduseermiddel)

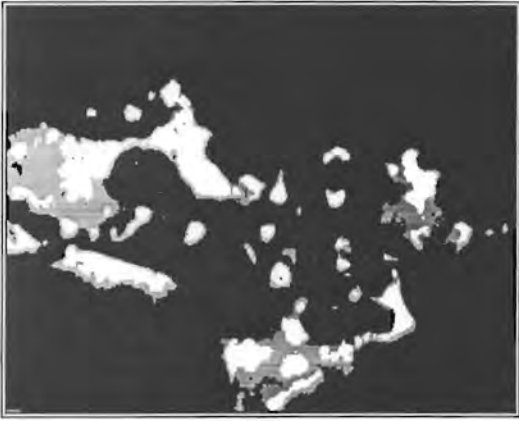
Die Foto's is anders gerangskik as in lg geval. Hier sluit die onderkant kant van elke by die bokant van volgende foto aan. Die foto's is oor die volle deursnit van 'n korrel bepaal. M.a. w die middelste foto's is in die senter van die korrel. Die vergroting is so dat elke foto is omtrent 1 mm hoog.

Figuur 9-8 Mikroskopiese beelde van snit deur gereageerde korrel na 12 minute, Grafiet as reduseermiddel











9.4 Rekenaarprogram

Program Korrelmodel;

Uses graph, Inset, Crt, Grafies, Ewewig1, N, Rho, gelei, Hitte, grinset, Crou;

```
const tol=1E-1;
```

```
    {komponent=(CO,CO2,C,Fe,FeO,Fe3O4,Fe2O3,Inert,H,Swael,gas);}
```

```
Var
```

```
    i:integer;
```

```
    NN,      {aantal stappe}
```

```
    j:longint; {tydindeks}
```

```
    tel:integer;
```

```
    komp:kpnt;
```

```
    tf:real;  {maksimum tyd (sekondes)}
```

```
    tt:real;  {tyd (sekodes)}
```

```
    dFH:real;
```

```
    RandIn:real;
```

```
    fout:real;
```

```
    Rrr:real;
```

```
    lr:text;
```

```
    netnou:real;
```

```
    mErts:real; {massa erts}
```

```
    mKool:real; {massa steenkool}
```

```
    FetC:real; {aanvanklike massa-verhouding van Erts tot steenkool}
```

```
    Ri:array[0..MMM,0..3] of real; {skikking vir gebruik in gelyktydige  
                                     oplossing van energievergelykings}
```

```
    dataN:word;
```

```
    data:array[1..2,1..30] of real; {eksperimentele data word hierin geplaas}
```

```
Var
```

```
    ai,br,r1,r2,r3,r5,
```

```
    k11,k12,k13,
```

```
    k21,k22,k31,k32,
```

```
    k5,
```

```
    E11,E12,E13,
```

```
    E21,E22,E31,E32,
```

```
    E5,
```

```
    ent:real;
```

```
Var
```

```
    Metallisasie:real;
```

```
    Metallisasietyd:real;
```

```
    Metaal,Ooor:real; {hoeveel mol O oor in korrel}
```

```
{Prosedure wat die tempos van die verskillende reaksies bereken}
```

```
PROCEDURE TEMPOVGS(C:smst;Var X:real,Pt,Tp,w,wco:real);
```

```
{ Toevoer: C, Pt, Tp, w, wco}
```

```
{Resultaat: X, r1, r2, r3, r5}
```

```

var
  X1,X2,X3 : real; {ewewigsdrukke van FeO/Fe2O3 en FeO/Fe}
  Ewewigsposisie : byte; {1 = bo, 2= middel, 3= onder}
  Bb,Dd : real;
  nn,kwad : real;
A,A1,A2,B,B1,D,D1,E : real;

const
  maksfout=1E-18;

function Verskil(x:real):real;

begin
  ar:=A*(2*(X1-X)/(A1*X+A2) + wco - ((X1-X)/(A1*X+A2)+w));

  if X>X3 then Bb:=B else Bb:=B1;
  if X>X2 then Dd:=D else Dd:=D1;
  br:=(Bb+Dd+E)*X - Bb*X3 -Dd*X2;

  Verskil:=br-ar;

end;

Begin

if tp>1000 then begin
  write;
end;
if Tp<538+273 then begin
  D:=0; D1:=0;
  B:=0; B1:=0;
end else begin
  D :=k21*C[Fe3O4] * exp( -E21/R/Tp)/Pt; { Fe3O4 > FeO }
  D1 :=k22*C[FeO] * exp( -E22/R/Tp)/Pt; { FeO > Fe3O4}
  B :=k31*C[FeO] * exp( -E31/R/Tp)/Pt; { FeO > Fe }
  B1 :=k32*C[Fe] * exp( -E32/R/Tp)/Pt; { Fe > FeO }
end;

A := k11*C[CC] *exp( -E11/R/Tp)/Pt; { C+CO2 > CO }
A1 := k12 *exp( -E12/R/Tp)/Pt; { C+CO2 > CO }
A2 := k13 *exp( -E13/R/Tp)/Pt; { C+CO2 > CO }
E := k5 *C[Fe2O3] *exp( -E5 /R/Tp)/Pt; { Fe2O3 > Fe3O4}

X1 := Cew(Tp)/pt;
X2 := Fe3O4ew(Tp);
X3 := FeOew(Tp);

X:=1;
nn:=1;

if Tp>538+273 then begin {impliseer dat geen reaksie onder 538 C}
  repeat

```



```
nn:=nn*2;  
kwad:=verskil(X);  
if kwad<0 then x:=x+1/nn else x:=x-1/nn;  
until (abs(kwad)<maksfout) or (nn>1E10);  
end else begin  
X:=X1;  
Bb:=0;  
Dd:=0;  
end;
```

```
r1 := A*(X1-X)/(A1*X+A2);  
r5 := E*X;  
r2 := Dd*(X-X2);  
r3 := Bb*(X-X3);
```

End;

{SI Rapport}

{ Die volgende twee funksies is daar om sekere vektor operasies uit te voer;
function Z(A,B:smst):real; {bereken die puntproduk van A en B}

```
var v:kpnt;  
zz:real;
```

Begin

```
zz:=0;  
for v:=CO to Al2O3 do begin  
zz:=zz+A[v]*B[v];  
end;
```

Z:=zz;

End;

```
procedure ZZ(Var A,B:smst;aa:real); {A = aa*B}
```

```
var v:kpnt;
```

Begin

```
for v:=CO to Al2O3 do begin  
A[v]:=B[v]*aa;
```

```
end;
```

End;

```
Procedure Trans(X:skik:Var T:skik);
```

Type

```
ary=record  
a:real;  
xx:skik;  
end;
```

Var

```
XXX:ary absolute X;
```

Begin

```
T:=XXX.XX;
```

End;

{Die volgende drie prosedures bereken volumes en areas
vir verskillende Geometrie}



Procedure BepaalSfeerVolumeEnAreaDoppe;

Begin

If M=0 then begin

rr[0]:= dr;

AA[0]:= pi*4*rr[0]*rr[0];{buite oppvlak van dop i}

V[0]:= pi*4/3*dr*dr*dr;

End else begin

For i:=0 to M do begin

rr[i]:= i*dr;

if i=0 then begin

V[i]:= pi*4/3*dr*dr*dr/8;

AA[i]:= pi*dr*dr;{buite oppvlak van dop i}

end else begin

if i=M then begin

V[i]:= pi*4/3*((rr[i])*(rr[i])*(rr[i])
-(rr[i]-dr/2)*(rr[i]-dr/2)*(rr[i]-dr/2));

AA[i]:= pi*4*rr[i]*rr[i];{buite oppvlak van dop i}

end else begin

V[i]:= pi*4/3*((rr[i]+dr/2)*(rr[i]+dr/2)*(rr[i]+dr/2)
-(rr[i]-dr/2)*(rr[i]-dr/2)*(rr[i]-dr/2));

AA[i]:= pi*4*(rr[i]+dr/2)*(rr[i]+dr/2);{buite oppvlak van dop i}

end;

end;

End;

End;

End;

Procedure BepaalSilinderVolumeEnAreaDoppe;

Begin

If M=0 then begin

rr[0]:= dr;

AA[0]:= 2*pi*dr*rk;{buite oppvlak van dop i}

V[0]:= pi*dr*dr*rk;

End else begin

rr[0]:=0;

V[0]:= pi*rk*dr*dr/4;

AA[0]:= pi*rk*dr;{buite oppvlak van dop i}

For i:=1 to M-1 do begin

rr[i]:= i*dr;

V[i]:= pi*rk*((rr[i]+dr/2)*(rr[i]+dr/2)-(rr[i]-dr/2)*(rr[i]-dr/2));

AA[i]:=2*pi*(rr[i]+dr/2)*rk;{buite oppvlak van dop i}

end;

rr[m]:= rk;

V[m]:= pi*rk*((rk*rk)-(rk-dr/2)*(rk-dr/2));

AA[m]:= 2*pi*rk*rk;{buite oppvlak van dop i}

End;

End;



```
Procedure BepaalKasVolumeEnArea;
```

```
Begin
```

```
  For i:=0 to M do begin
```

```
    rr[i]:= i*dr;
```

```
    AA[i]:= 0.00001;
```

```
    V[i]:= dr*0.00001;
```

```
  End;
```

```
  V[0]:= dr/2*0.00001;
```

```
  V[M]:= dr/2*0.00001;
```

```
End;
```

```
Procedure BepaalCn(i:integer); {Bereken konsentrasie in mol/m3}
```

```
var
```

```
  ele:kpnt;
```

```
Begin
```

```
  For ele:=CO to gas do Cn[i][ele]:=S[i][ele]/V[i];
```

```
End;
```

```
var dtmin:real;
```

```
  dims:byte;
```

```
  tyd:word; {tyd in minute}
```

```
  reel:string;
```

```
  lr1:text;
```

```
  lr2:text;
```

```
  fak:real;
```

```
  kmpt:kpnt;
```

```
  endmet:real;
```

```
  Ttyd:real;
```

```
const   raport = true;
```

```
        raport2 = false;
```

```
        Nieoordraginkorrel = 0;
```

```
        Geenoordrag = 0;
```

```
Begin
```

```
  assign(lr1,'enkel63.pas');
```

```
  reset(lr1);
```

```
  repeat readln(lr1,reel) until reel='Begin{*}';
```

```
  assign(lr,'11-0.txt'); {skryf die gekose parameters oor in 'n ander leer}
```

```
  rewrite(lr);
```

```
  writeln(lr,'Multi model.');
```

```
  for i:=1 to 35 do begin
```

```
    readln(lr1,reel);
```

```
    writeln(lr,reel);
```

```
  end;
```

```
  close(lr1);
```



Begin{*}

```
em := 0.8; {emisiwiteit}
Rk := 0.0075; {korrelradius}
endmet := 0.90; {eindelijke metalisasievlak}
tyd := 20; {tyd in oond}
NN := tyd*30; {aantal berekeningstappe}
tf := tyd*60; {totale tydsverloop in sekondes}
dt := tf/NN; {tydstapgrootte}
M := 5; {aantal doppe-1}
dims := 2; {geometrie 0=plaat 1= silinder 2=sfeer}
FetC := 5.2; {17% Verhouding van Yster tot koolstof in die korrel}
Ept := 0.202; {Beginporositeit van korrel}
Tomg := 1300+273; {oondtemperatuur}
T00 := 300; {bbegintemperatuur}
fak := 1; {faktor wat geleiding uit is}

k11 := 150 ; {primere Boudouard tempokonstante}
k21 := 10000000;
k31 := 10000000;
k31 := 10000000;
E11 := 90000 ;
E21 := 190000 ;
E31 := 200000 ;
```




```
Erts := NULsmst;
Skool := NULsmst;
Erts[Fe3O4] := 0.98; {fraksie van komponent}
Erts[FeO] := 0;
Erts[Fe] := 0;
Erts[SiO2] := 0.02;
Skool[CC] := 0.95; {fraksie van komponent}
Skool[SiO2] := 0.03;
Skool[Al2O3] := 0.02;

{minder belangrike tempokostantes}
k12:= 0;
k13:= 2;
k22:= 300;
k32:= 500;
k5:= 1300;
E32:= 200000; E5:= 61000;
E22:= 100000;

assign(lr1,'data.pas');reset(lr1);{lees eksperimentele data}
repeat readln(lr1,data[1,1]) until (data[1,1]=Tomg-273) or eof(lr1);
if eof(lr1) then begin
  dataN:=2;
  data[1,1]:=0;data[1,2]:=0;
  data[2,1]:=0;data[2,2]:=0;
end else begin
  readln(lr1,dataN);
  for j:=1 to dataN do begin
    read(lr1,data[1,j],data[2,j]);
  end;
  j:=0;
  close(lr1);
end;

{Beginvolume}
case dims of
  0: Vt := Rk*0.00001;
  1: Vt := pi*Rk*Rk*Rk;
  2: Vt := 4/3*pi*Rk*Rk*Rk;
end;

{bereken massas steenkool en erts in korrel op grond van
gegewe volume porositeit en verhouding}

mkool:= (1-Ept)*Vt/(FetC*Z(Erts,Ohr)+Z(Skool,Ohr));
mErts:= FetC*mkool;

{chemiese samestelling bereken
met geewe verhouding porositeit en volume}

For komp:=CO to gas do begin
  S0[komp]:= (mErts*Erts[komp]+mkool*Skool[komp])/Mgetal[komp];
End;
```



```
M1:=M+1;
if M = 0 then dr:=Rk else dr := Rk/M;
rr[0]:=0;

case dims of
2:BepaalSfeervolumeenAreadoppe;
1:BepaalSilindervolumeenAreadoppe;
0:BepaalKasVolumeEnArea;
end;

For i:=0 to M do begin
  ZZ(S[i]{=},S0{*},V[i]/Vt); {bereken die hoeveelheid van elke komponent in dop i}
  T[i]:= T00;           {alle doppe by begintemperatuur}
  Ep[i]:= Ept;         {ale doppe by beginporisiteit}
  k[i]:= kk(i);        {alle doppe met selfde geleidingsvermoe}
  Pco[i]:= Fe3O4ew(T[i]-273); {pco bereken as in alle doppe in ewewig met Fe3O4}
  Pc2[i]:= Ptot-Pco[i]; {Pco2 vanaf Pco bereken}
  Pt [i]:= Ptot;       {Totale druk oorals dieselfde in begin}
  X [i]:= Pco[i]/Pt[i]; {Bereken begin fraksie CO}

  BepaalCn(i);         {Bepaal konsentrasie van elke komponent in elke dop}
End;

Pt[M]:=1.0;

if raport then Opskrifte(Cn[M],Pco[M],Pc2[M],T[M],Ep[M],Cn[0],Pco[0],Pc2[0],T[0],Ep[0]);

So0:=S;

j:=0;

if geenoordrag=1 then begin
  read(lr2,ttyd);
  readln(lr2,Tomg);
end;

Repeat

{konstnate temperatuur model}
If geenoordrag=1 then if j*dt>=Ttyd then begin
  read(lr2,Ttyd);
  readln(lr2,Tomg);
  for i:=0 to M do T[i]:=Tomg*1300+273;
end;

T0:=T;
So:=S;
```



```

{*****}
{Bereking van Tempo's en oplos van massabalans vir tydstep j}
{*****}

For i:=0 to M do begin

  BepaalCn(i);

  Tempovgs(Cn[i],X[i],Pt[i],T[i],w[i],wco[i]);

  Pco [i]:=Pt[i]*X[i];
  Pc2 [i]:=Pt[i]*(1-X[i]);

  S[i][CC ]:= S[i][CC ]+( - r1)*V[i]*dt;
  S[i][Fe2O3]:= S[i][Fe2O3]+( -3*r5)*V[i]*dt;
  S[i][Fe3O4]:= S[i][Fe3O4]+( 2*r5 - r2)*V[i]*dt;
  S[i][FeO ]:= S[i][FeO ]+( 3*r2 - r3)*V[i]*dt;
  S[i][Fe ]:= S[i][Fe ]+( r3 )*V[i]*dt;
  S[i][CO ]:= S[i][CO ]+( 2*r1 - r2 - r3 - r5)*V[i]*dt;
  S[i][CO2 ]:= S[i][CO2 ]+( -r1 + r2 + r3 + r5)*V[i]*dt;

  Ep[i] := Poros(S[i],V[i]);{porisiteit berekening}

  O[i] := 150*(1-Ep[i])*(1-Ep[i])/Ep[i]/Ep[i]/Ep[i]
        *mu(i)*lamda*lamda*dr/dp/dp/101300/101300;{weerstand
        teen gasvloei}
  k[i] := kk(i)*fak; {geleidingsvermoe}

  {bereken netto gasgenerasie}

  gco[i] := 2*r1 - r2 - r3 - 4*r4 - r5;
  gc2[i] := -r1 + r2 + r3 + 4*r4 + r5;

  w[i+1] :={0;} (gco[i]+gc2[i])*V[i]+w[i];
  wco[i+1] :={0;} gco[i]*V[i]+wco[i];
  wc2[i+1] :={0;} w[i+1]-wco[i+1];

End;{For i=0 to M} {massabalans}

{*****}
{Bepaling van druk in korrel}
{*****}

For i:=M-1 downto 0 do begin
  Pt[i]:=0.5*(Pt[i+1]+sqrt(Pt[i+1]*Pt[i+1]+4*(R*T[i]*O[i]*w[i+1]/Aa[j])));
End;

```



```

{*****}
{ENERGIEBALANS}
{*****}

For i:=0 to M do begin
  Eo[i] := E(So[i],T0[i]); {Joule} {Energiee in vorige stap}
End;

BepaalSAenSB;
BepaalSA0enSB0;

If Geenoordrag=1 then begin {konstante temperatuur model}
end else
If Nieoordraginkorrele=1 then begin {homogene temperatuur model}

  T[M]:=((wco[M+1])*B[co]+(wc2[M+1])*B[co2]-SB[M]/dt+SB0[M]/dt
    +( hwaarde(T0[M]) *Aa[M ] ))*Tomg
    +SA0[M]/dt*T0[M]
  )/(
    +hwaarde(T0[M]) *Aa[M ]
    +SA[M]/dt
    +wco[M+1]*A[co]+wc2[M+1]*A[co2]
  );
  for i:=M-1 downto 0 do T[i]:=T[i+1];

end else begin

Ri[1,3]:=-SB[0]/dt - Eo[0]/dt + wco[1]*B[co]+wc2[1]*B[co2];
Ri[1,0]:= 0;
Ri[1,1]:=-SA[0]/dt -k[1]*Aa[0]/dr - wco[1]*A[co]+wc2[1]*A[co2];
Ri[1,2]:= k[1]*Aa[0]/dr;

For i:=1 to M-1 do begin
  Ri[i+1,3]:=+SB[i]/dt -Eo[i]/dt - wco[i]*B[co]+wc2[i]*B[co2]
    + wco[i+1]*B[co]+wc2[i+1]*B[co2];
  Ri[i+1,0]:= k[i]*Aa[i-1]/dr + wco[i]*A[co]+wc2[i]*A[co2];
  Ri[i+1,1]: -SA[i]/dt -k[i]*Aa[i-1]/dr - k[i]*Aa[i]/dr
    - wco[i+1]*A[co]+wc2[i+1]*A[co2];
  Ri[i+1,2]:= k[i]*Aa[i]/dr;
End;
Ri[M+1,3]:=+SB[M]/dt - Eo[M]/dt - wco[M]*B[co]+wc2[M]*B[co2]
  + wco[M+1]*B[co]+wc2[M+1]*B[co2]
  -Hwaarde(T0[M])*AA[M]*Tomg;
Ri[M+1,0]:= k[M]*Aa[M-1]/dr + wco[M]*A[co] + wc2[M]*A[co2];
Ri[M+1,1]:=-SA[M]/dt-k[M]*Aa[M-1]/dr - Hwaarde(T0[M])*AA[M]
  - wco[M+1]*A[co]+wc2[M+1]*A[co2];
Ri[M+1,2]:=0;

  Crout(M1,Ri,T);
  Trans(T,T);
end;
{*****}

```



```
{*****}
{Bereken metallisasie}
{*****}

Se:=NULSmst;
Ooor:=0;
For i:=0 to M do begin
  Oori[i]:=S[i][FeO]+4*S[i][Fe3O4]+3*S[i][Fe2O3];
  Metali[i]:=1-Oori[i]/(So0[i][FeO]+4*So0[i][Fe3O4]+3*So0[i][Fe2O3]);
  VSi[i]:=S[i][Fe]/(S[i][FeO]*PFeO+S[i][Fe3O4]*PFe3O4+S[i][Fe]*PFe)*PFE;
  Ooor:=Ooor+Oori[i];
  for kmpt:=CO to Al2O3 do Se[kmpt]:=Se[kmpt]+S[i][kmpt];
End;
Metallisasie:=1-Ooor/(S0[FeO]+4*S0[Fe3O4]+3*S0[Fe2O3]);

{*****}

{raporteer resultate op skerm}
if raport then
Raporteer(Cn[M],Pco[M],Pc2[M],T[M],Ep[M],Cn[0],Pco[0],Pc2[0],T[0],Ep[0],metallisasie);
if (j mod 25)=0 then begin
gotoXY(1,j mod 24+1); clreol;
write(Cn[0][Fe]/1000:3:0,' ');
write(Cn[M][Fe]/1000:3:0,' ');
write( k[0]:3:3,' ');
write( k[M]:3:3,' ');
write(Pt[0]:3:3,' ');
write(Pt[M]:3:3,' ');
write(' ',metallisasie:3:3);
end;

{***** Einde van Lus as tyd nognie verby keer weer terug na berkening
van tempovergelykngs}
Inc(j);Until (Metallisasie>0.99) or (j>NN) or keypressed;

Metallisasietyd:=dt*j;

{Voer parameters vir grafiekprosedude en teken grafiek}

if raport then begin
Wag(1,whereY+1);
Xgrens(0,round(metallisasietyd/200)*200);
Asse(round(gr.u2/100),5,10,5);
Ygrens(0,50000);
Ygrens2(0,1);
Grafiek;
closegraph;
end;
```



{Voer parameters vir grafiekprosedude en teken grafiek}

```
if raport2 then begin
  Nuwelyn(0,1,15,'+', 'Eksperimentele Data');
  for i:=1 to dataN do begin
    nuwepunt(data[1,i],data[2,i]);
  end;
  Nuwelyn(1,1,9," 'Model Voorspelling');
  for i:=0 to M do begin
    nuwepunt(rr[i]*1000,vSi[i]-0.05);
  end;
end;
Ygrens(0.5,1);
Xgrens(0,8);
Grafiek;

End;

close(lr);

End.
```



Eenhede

```
Unit N; {Konstantes en veranderlikes gebruik in die model}
interface
const MMM=90;
Type
{ real=extended;}
kpnt=(CO,CO2,CC,Fe,FeO,Fe3O4,Fe2O3,SiO2,Al2O3,H,Swael,gas);
skik=array[0..MMM] of real;
Smst=array[kpnt] of real;
Maat=array[0..MMM] of smst;
Kelvin=real;
const
NULSmst:smst=(0,0,0,0,0,0,0,0,0,0,0,0);
faseS:array[kpnt] of string[5]= ('CO ','CO2 ','C ','
                               'Fe ','FeO ','Fe3O4','Fe2O3',
                               'SiO2','Al2O3','H ','Swael','Gas ');

Dp:real = 0.000020; {gemiddelde partikel diameter} {LW is funksie van samestelling}
  {Dp Kooks:15um Antrasiet:19um Steenkool:18um Grafiet:36um Magnetiet:25um}
lamda:real = 1.1; {vormfaktor van partikels}
R      = 8.314;
Pr: real= 0.72;    {prandtl getal gemiddeld vir gasmengsel en alle temp}
Mgetal : Smst=(28,44,12,55,85,71,85,231,55,159,7,60,101,96,2,32,18);
```

Const

{Gekose begintoestande}

```
Rk: real=0.0075; {m}    {radius van korrel}
T00: kelvin=300{1573}; {aanvanklike temperatuur}
Ptot: real=1; {atm}    {Aanvanklike gasdruk}
Ept: real=0.202;
```

{Gekose berekeningskonstantes}

```
M: integer=0; {aantal doppe}
M1: word=1; {aantal doppe+1}
dt: real=0.1; {s} {tydstapgrootte}
dr: real=0.00075; {m} {dikte van dop} {word bereken vanaf Rk en M}
```

Var

```
T0:skik;{K}    {temperatuur in vorige interval}
T:skik;{K}    {temperatuur in huidige interval}
S:Maat;{mol}   {aantal mol van al die komponente in kontrole volumes}
So:Maat;{mol}  {selfde as S maar vir vorige berekeningstydstep}
So0:Maat;{mol} {372 0357}
```

```
Ep:skik;{}    {porositeit}
k:skik;{W/m/C} {geleidingsvermoe}
```

```
Cn:Maat;{mol/m3} {aantal mol van al die komponent in kontrole volumes}
```



X:skik;{Fraksie} {CO in gas}
gc2:skik;{mol/s/m3} {netto gasgenerasietempo van co2}
gco:skik;{mol/s/m3} {netto gasgenerasietempo van co}

wCO:skik;{mol/s} {CO gasvloeiempo in element i in}
w:skik;{mol/s} {gasvloeiempo in element i in}

O:skik;{Pa s/m} {weerstand teen gasvloei}
u:skik;{m/s} {gasvloeisnelheid}
Pt:skik;{Pascal}
Pco:skik;{Pascal}

Pc2:skik;{Pascal}
wc2:skik;{mol/s} {CO2 gasvloeiempo in element i in}

Ee:skik;{J} {entalpieinhoud van element}
Eo:skik;{J} {entalpieinhoud van element vorige tydsinkrem}
SA:skik;{J/K}
SB:skik;{J}
SA0:skik;{J/K}
SB0:skik;{J}
Oori:skik;
Metali:skik;
Vsi:skik;{volumefraksie yster}

{Slegs van toepassing in begin van bereking}

Erts:smst;{fraksie} {samestelling van erts}
Skool:smst;{fraksie} {samestelling van steenkool}
S0:smst;{mol} {aanvanklike chemiese samestelling van korrel}
{totale aantal molle van elk in die hele korrel}
Se:smst;

{Wordbepaal in begin en bly dan konstant regdeur berekening}

rr:skik;{m} {buiterradius van dop}
AA:skik;{m2} {arrea van dop met radius rr}
V:skik;{m3} {volume van dopelement}
Vt:real;{m3} {Totale volume van korrel}

komp:kpnt;

r1,r2,r3,r4:real;

const Atm=101000;

implementation

begin
end.



```
Unit Rho; {Digthede van verskillende spesies en mengsel}
interface
Uses N;
{m.a.w waardes i.t.v m3/mol}
const
  PC:real=6.316E-6;      {SG:1.9 koolstof steenkool=1.4}  {12}
  PFe:real=7.16E-6;     {SG:7.8}  {55.85}  {formule **** M/1E6/p *****}
  PFeO:real=12E-6; {m3/mol} {SG:5.6 g/cm3} {Fe 0.95 O} {MFexO = 69.6}
  PFe3O4:real=41.35E-6; {SG:5.6 g/cm3} {231.55}
  PFe2O3:real=32E-6;   {SG:5} {159.7}
  {P:smst=(0.0224,0.0224,8.6E-6,7.2E-6,12E-6,45E-6,32E-6,22.2E-6,0.0224,0.0224,0.0224);}
  {Ohr:smst=(0,0.534.7E-9,128.2E-9,166.6E-9,178.6E-9,200E-9,370.3E-9,312.5E-9,0,0,0);}
  { kpnt=(CO,CO2,CC,Fe,FeO,Fe3O4,Fe2O3,SiO2,Al2O3,H,Swael,gas);}

Function VolS(S:smst):real;
Function Poros(S:smst;V:real):real;
Function Mu(i:integer):real;

implementation

Function VolS(S:smst):real;
Begin
  VolS:=PC*S[CC]+PFe*S[Fe]+PFeO*S[FeO]+PFe3O4*S[Fe3O4];
End;

Function Poros(S:smst;V:real):real;
Begin
  Poros:=(V-VolS(S))/V;
End;

Function Mu(i:integer):real; {viskositeitsfunksie}
Begin {hierdie is vir CO2}
  Mu:=1E-5*(-1.1188E-06*T[i]*T[i] + 5.0256E-03*T[i] + 9.3761E-02);
End;
End.
```



```
Unit Ewig1; {Ewigfunksies }
interface
Uses Inset, Grafies, N;

Const Ptew:real=1;

type celsius=real;

Function Cew (T:celsius):real; {parsiele druk van CO by ewewig met C}
Function FeOew (T:celsius):real; {parsiele druk van CO by ewewig met FeO}
Function Fe3O4ew (T:celsius):real; {parsiele druk van CO by ewewig met Fe3O4}

implementation
Function Cew (T:celsius):real; {parsiele druk van CO by ewewig met C}
var z,P,Q:real;

Begin
  If T<=200 then P:=0 else begin
    Q:=exp(19940/T-20.5); {exp(A/R/T+B/R);}
    P:=(sqrt(4*Q*Ptew/atm+1)-1)/2/Q;
  End;
  Cew:=-P*atm;
End;

Function FeOew (T:celsius):real; {parsiele druk van CO by ewewig met FeO}
Begin
  FeOew:=(6.339E-11*T*T*T-6.299E-7*T*T+0.00133*T-0.0426)*Ptew;
End;

Function Fe3O4ew (T:celsius):real; {parsiele druk van CO by ewewig met Fe3O4}
Begin
  If T<538 then begin
    Fe3O4ew:=(-4.89E-7*T*T+0.0008933*T+0.1609)*Ptew;
  end else begin
    Fe3O4ew:=(-5.484E-10*T*T*T+2.100E-6*T*T-0.00294*T+1.560)*Ptew;
  end;
End;

End.
```



Unit Hitte; {Berken entalpiewaardes van komponente in korrel}

interface

Uses Grafies, Inset, N;

const

A:smst=(32.6,52.3,20.8,40.4,66.7,207,146.1,68.9,122.9,0,0,0);

B:smst=(-121000,-411400,-8037.2,-14475,-297030,-1183400,-872650,
-931430,-1717600,0,0,0);

Function HFe(T:kelvin):real;

Function HFeO(T:kelvin):real;

Function HFe3O4(T:kelvin):real;

Function HFe2O3(T:kelvin):real;

Function HC(T:kelvin):real;

Function HCO(T:kelvin):real;

Function HCO2(T:kelvin):real;

Function HSiO2(T:kelvin):real;

Function HAl2O3(T:kelvin):real;

Procedure BepaalSAenSB;

Procedure BepaalSA0enSB0;

Function E(var S:smst;T:kelvin):real; {mol en Kelvin}

implementation

Function HFe(T:real):real;

Begin

HFe:=A[Fe]*T+B[Fe];

End;

Function HFeO(T:real):real;

Begin

HFeO:=A[FeO]*T+B[FeO];

End;

Function HFe3O4(T:real):real;

Begin

HFe3O4:=A[Fe3O4]*T+B[Fe3O4];

End;

Function HFe2O3(T:real):real;

Begin

HFe2O3:=A[Fe2O3]*T+B[Fe2O3];

End;

Function HC(T:real):real;

Begin

HC:=A[CC]*T+B[CC];

End;

Function HCO(T:real):real;

Begin

HCO:=A[CO]*T+B[CO];

End;



```
Function HCO2(T:real):real;  
Begin  
  HCO2:=A[CO2]*T+B[CO2];  
End;
```

```
Function HSiO2(T:real):real;  
Begin  
  HSiO2:=A[SiO2]*T+B[SiO2];  
End;
```

```
Function HAl2O3(T:real):real;  
Begin  
  HAl2O3:=A[Al2O3]*T+B[Al2O3];  
End;
```

```
Procedure BepaalSAenSB;  
var i:word;  
Begin  
  for i:=0 to M do begin  
    SB[i]:=(S[i][Fe]*B[Fe]+S[i][CC]*B[CC]+S[i][FeO]*B[FeO]+S[i][Fe3O4]*B[Fe3O4]+  
      +S[i][Fe2O3]*B[Fe2O3]+S[i][SiO2]*B[SiO2]+S[i][Al2O3]*B[Al2O3]  
      +S[i][CO]*B[CO]+S[i][co2]*B[Co2]);  
    SA[i]:=S[i][Fe]*A[Fe]+S[i][CC]*A[CC]+S[i][FeO]*A[FeO]+S[i][Fe3O4]*A[Fe3O4]+  
      +S[i][Fe2O3]*A[Fe2O3]+S[i][SiO2]*A[SiO2]+S[i][Al2O3]*A[Al2O3]  
      +S[i][CO]*A[CO]+S[i][co2]*A[Co2];  
  end;  
End;
```

```
Procedure BepaalSA0enSB0;  
var i:word;  
Begin  
  for i:=0 to M do begin  
    SB0[i]:=(So[i][Fe]*B[Fe]+So[i][CC]*B[CC]+So[i][FeO]*B[FeO]+So[i][Fe3O4]*B[Fe3O4]+  
      +So[i][Fe2O3]*B[Fe2O3]+So[i][SiO2]*B[SiO2]+So[i][Al2O3]*B[Al2O3]  
      +So[i][CO]*B[CO]+So[i][co2]*B[Co2]);  
    SA0[i]:=So[i][Fe]*A[Fe]+So[i][CC]*A[CC]+So[i][FeO]*A[FeO]+So[i][Fe3O4]*A[Fe3O4]+  
      +So[i][Fe2O3]*A[Fe2O3]+So[i][SiO2]*A[SiO2]+So[i][Al2O3]*A[Al2O3]  
      +So[i][CO]*A[CO]+So[i][co2]*A[Co2];  
  end;  
End;
```

```
Function E(var S:smst;T:kelvin):real; {mol en Kelvin}  
Begin  
  E:=S[Fe]*HFe(T)+S[CC]*HC(T)+S[FeO]*HFeO(T)-S[Fe3O4]*HFe3O4(T)+  
    +S[Fe2O3]*HFe2O3(T)+S[SiO2]*HSiO2(T)+S[Al2O3]*HAl2O3(T)  
    +S[CO]*HCO(T)+S[CO2]*HCO2(T);  
End;  
  
End.
```



```
Unit Gelei;{Berken geleidingsvermoe in korrel}  
interface  
Uses N, Rho, grafies;  
Const sigma=5.670E-8;{W/m2/K4}  
Em:real=0.8; {emisiwiteit van vastestof}  
Tomg:kelvin=1573;
```

```
Function kk(i:word):real;  
Function Hwaarde(T:kelvin):real;
```

Implementation

```
Function kN2 (T:kelvin):real;  
Begin  
kN2:= -2.35E-8*T*T+8.82E-5*T+2.50E-7 ;  
End;
```

```
Function km(Komp:kpnt;T:kelvin):real;  
begin  
case komp of  
CC:km:=0.444+2.9E-3*(T-273);  
CO:km:=-6.702E-9*T*T +3.61E-6*T+2.72E-5;  
CO2:km:=-6.702E-9*T*T +3.61E-6*T+2.72E-5;  
Fe:km:=2.54E-5*T*T - 0.0553*T + 65.3;  
FeO:if T<825 then km:=1/(2.335E-4*T+0.1136) else km:=1/(-9.739E-5*T+0.3795);  
Fe3O4:if T<906 then km:=1/(1.693E-4*T) else km:=1/(2.967E-6*T+0.1508);  
Fe2O3:if T<912 then km:=1/(1.887E-4*T) else km:=1/(8.319E-5*T+0.09243);  
SiO2:km:=806*exp(-0.803*ln(T));  
Al2O3:km:=30241*exp(-1.1832*ln(T));  
end;  
end;
```

```
Function KK(i:word):real;  
var  
Kmp:kpnt;  
ks,kg:real;  
Stot:real; {totale vastestof mol}  
Begin  
Stot:=S[i][CC];  
ks:=S[i][CC]*ln(km(CC,T[i]));  
for Kmp:=Fe to Al2O3 do begin  
Stot:=Stot+S[i][Kmp];  
ks:=ks +S[i][Kmp]*ln(km(Kmp,T[i]));  
end;  
Ks:=exp(ks/Stot);  
kg:=km(CO,T[i]);  
Kk:=ks*(2*ks+kg-2*ep[i]*(ks-kg))/(2*ks+kg+ep[i]*(ks-kg)); {laat straling buite rekening in die bepaling  
van k}  
End;
```

```
Function Hwaarde(T:kelvin):real;  
var hs:real; hk:real;  
BuiteArea:real;  
Begin  
hs:=Em*Sigma*(Tomg+T)*(Tomg*Tomg-T*T);
```



```
hk:=6;  
Hwaarde:=(hs+hk)  
End;  
End.
```

```
{Numeriese prosedure vir oplos van tridiagonale stelsel}
```

```
{r1 r2 0 0 = r3}  
{r0 r1 r2 0 = r3}  
{0 r0 r1 r2 = r3}  
{0 0 r0 r1 = r3}  
{LW R[i,1] is die diagonaal element in ry i}  
{ R[i,3] is die regterkant in elke vergelyking}  
{ R[1,0] en R[N,2] word dus glad nie gebruik nie}  
{ Na faktorisering bevat R[i,1] en R[i,0] die L matriks se elemente}  
{ R[i,2] bevat die Diagonaal in die U matriks}
```

```
Unit Crou;
```

```
Interface
```

```
Procedure Crout(Var N:word;Var Ri;Var Xi);
```

```
Type
```

```
Rye=array[0..1500,0..3] of real;
```

```
Ry=array[0..1500] of real;
```

```
Implementation
```

```
Procedure Crout(Var N:word;Var Ri;Var Xi);
```

```
Var
```

```
R:Rye absolute Ri;
```

```
X:Ry absolute Xi;
```

```
i:word;
```

```
Begin
```

```
R[1,2]:=R[1,2]/R[1,1];
```

```
For i:=2 to n-1 do begin
```

```
  R[i,1]:=R[i,1] - R[i,0]*R[i-1,2];
```

```
  If R[i,1]=0 then begin N:=0;Exit;end;
```

```
  R[i,2]:=R[i,2]/R[i,1];
```

```
End;
```

```
R[n,1]:=R[n,1] - R[n,0]*R[n-1,2];
```

```
If R[n,1]=0 then begin N:=0;Exit;end;
```

```
R[1,3]:=R[1,3]/R[1,1];
```

```
For i:=2 to n do R[i,3]:=(R[i,3] - R[i,0]*R[i-1,3])/R[i,1];
```

```
X[n]:=R[n,3];
```

```
For i:=n-1 downto 1 do X[i]:=R[i,3]-R[i,2]*X[i+1];
```

```
End;
```

```
End,
```