CHAPTER IV: REFERENCES

Abraham, M.C., Gosh, A., 1979. Kinetics of reduction of iron by carbon. *Ironmaking and Steelmaking*, No. 1, pp 14-23.

Ajersch, F., 1987. Chemical and physical characteristics affecting the reduction kinetics of iron oxide pellets with solid carbon. *Canadian Metallurgical Quarterly*, Vol. 26, No. 2, pp 137-144.

Al-Kahtany, M.M., Rao, Y.K., 1980. Reduction of magnetite with hydrogen: Part 1 intrinsic kinetics. *Ironmaking and Steelmaking*, No. 2, pp 49-58.

Arendt, P., van Heek, K.-H., 1981. Comparative investigations of coal pyrolysis under inert gas and H_2 at low and high heating rates and pressures up to 10 MPa. *Fuel*, Vol. 60, September, pp 779-787.

Aukrust, A., 1992. Results of the AISI/DOE direct steelmaking program. *Proceedings of the Savard/Lee International Symposium on Bath Smelting*, The Mineral, Metal & Materials Society, pp 591-610.

Bandyopadhyay, D., Gosh, A., 1996. Validity of rate equation on Langmuir-Hinshelwood mechanism for gasification of carbon – a reappraisal. *Steel Research*, Vol. 67, No. 3, pp 79-86.

Blackwood, J.D., McGrory, F., 1958. The carbon-steam reaction at high pressure. *Australian Journal of Chemistry*, Vol. 11, pp 16-33.

Borlée, J., Steyls, D., Colin, R., Munnix, R., Economopoulos, M., 1999. COMET: a coal-based process for the production of high quality DRI from iron ore fines. *La Revue de Métallurgie-CIT*, March, pp 331-339.

Bornman, C.J., Ackerman, J.P., 1993. World's largest coal-based direct reduction plant-nine years later. *Steel Times International*, March, pp 18-22.

Chase, M.W., Jr., *NIST-JANAF Thermochemical Tables, Fourth Edition*, 1998. American Institute of Physics, Woodbury, New York.

Coats, A.W., Redfern, J.P., 1964. Kinetic Parameters from Thermogravimetric Data. *Nature* (London), Vol. 201, pp. 68-69.

Coetsee, T., Pistorius, P.C., de Villiers, E.E., 2002. Rate-determining steps for reduction in magnetite-coal pellets. *Minerals Engineering*, Vol. 15, pp. 919-929.

Contrucci, M. de A., 2000. Tecnored process industrial plant construction. Conference: *Commercializing New Hot Metal Processes Beyond the Blast Furnace.* Atlanta, Georgia, USA, June 5-7, 2000.

Cunningham, B.C., Stephenson, J.G., *Direct Reduced Iron – technology and economics of production and use, Chapter 6, Direct Reduction Processes.* 1980. The Iron & Steel Society of AIME, Warrendale, U.S.A., p. 67.

Cusack, B.L., Wingrove, G.S., Hardie, G.J., 1995. Initial operation of the Hismelt® research and development facility. *Iron and Steelmaker*, February, pp 13-20.

Desypris, J., Murdoch, P., Williams, A., 1982. Investigation of the flash pyrolysis of some coals. *Fuel*, Vol. 61, September, pp 807-816.

Devanathan, N., Saxena, S.C., 1987. Transport model for devolatilization of large nonplastic coal particles: The effect of secondary reactions. *Ind. Eng. Chem. Res.*, Vol. 26, pp 539-548.

Dey, S.K., Jana, B., Basumallick, A., 1993. Kinetics and reduction characteristics of hematite-noncoking coal mixed pellets under nitrogen gas atmosphere. *ISIJ International*, Vol. 33, No. 7, pp 735-739.

Dixit, S. K., Ray, H.S., 1982. Use of reciprocal temperature rise equation in analysis of non-isothermal kinetic data in general. *Thermochimica Acta*, Vol. 54, pp 245-250.

Dutta, S.K., Gosh, A., 1994. Study of nonisothermal reduction of iron ore-coal/char composite pellet. *Metallurgical Transactions B*, Vol. 25B, February, pp 15-26.

Dutta, S., Wen, C.Y., Belt, R.J., 1977. Reactivity of coal and char. 1.In carbon dioxide atmosphere. *Ind. Eng. Chem., Process Des. Dev.*, Vol. 16, No. 1, pp 20-30.

El-Geassy, A.A., Shehata, K.A., Ezz, S.Y., 1977. Mechanism of iron oxide reduction with hydrogen/carbon monoxide mixtures. *Transactions ISIJ*, Vol. 17, pp 629-635.

El-Rahaiby, S.K., Rao, Y.K., 1979. The kinetics of reduction of iron oxides at moderate temperatures. *Metallurgical Transactions B*, Vol. 10B, June, pp 257-269.

Ergun, S., 1956. Kinetics of the reaction of carbon dioxide with carbon. *Journal of Physical Chemistry*, Vol. 60, pp 480-485.

Flickenschild, A. J., Reufer, F., Eberle, A., Siuka, D., 1996. Combined Cores/DRI technology. *Iron and Steel Engineer*, August, pp 25-29.

Floyd, J.M., 2000. Research and development of Ausmelt technology. *The Brimacombe Memorial Symposium*, TMS, ISS, CIM, 1-4 October, pp 173-191.

Fortini, O.M., Fruehan, R.J., 2005. Rate of Reduction of Ore-Carbon Composites: Part II. Modeling of Reduction in Extended Composites. *Metallurgical Transactions B*, Vol. 36B, December, pp 709-717.

Fourie, L.J., 1995. U.S. Patent No. 5411570. *Steelmaking Process*. 2 May 1995.

Fourie, L.J., 2000. U.S. Patent No. 6146437. *Metal containing compound reduction and melting process*. 14 November 2000.

Fourie, L.J., DeVilliers, J.P., 2003. U.S. Patent No. 6537342. *Induction furnace for a metal reduction and melting process*. 25 March 2003.

Fruehan, R.J., 1977. The rate of reduction of iron oxides by carbon. *Metallurgical Transactions B*, Vol. 8B, June, pp 279-286.

Ghosh, P.C., Tiwari, S.N., 1970. Reduction of pellets of iron ore plus lignite coke. *Journal of The Iron and Steel Institute*, March, pp 255-257.

Gou, H., Lu, W.-K., 1998. Using the RHF/SRV or RHF/EAF to produce liquid iron at low coal rate. *Iron and Steelmaker*, March, pp. 81-86.

Goyal, A., Rehmat, A., 1993. Modeling of a fluidised-bed coal carbonizer. *Ind. Eng. Chem. Res.*, Vol. 32, pp 1396-1410.

Haque, R., Ray, H.S., Mukherjee, A., 1992a. Packed bed reduction of iron ore fines by coal fines: effect of operating variables. *Ironmaking and Steelmaking*, Vol. 19, No. 1, pp 31-35.

Haque, R., Ray, H.S., Mukherjee, A., 1992b. Carburisation of directly reduced iron during reduction of iron ore fines by coal fines. *Ironmaking and Steelmaking*, Vol. 19, No. 2, pp 127-130.

Haque, R., Ray, H.S., Mukherjee, A., 1993. Reduction of iron ore fines by coal fines in a packed bed and fluidized bed apparatus-a comparative study. *Metallurgical Transactions B*, Vol. 24B, June, pp 511-520.

Haworth, D.J., Doel, P.J., Hinrichsen, J.D., 1995. Davy DRC: Coal-based direct reduction in China. *Iron and Steel Engineer*, April, pp 76-80.

Hoffman, G.E., Harada, T., 1997. A status report on the FASTMET® process from the Kakogawa demonstration plant. *Iron and Steelmaker*, May, pp 51-53.

Holman, J.P., *Heat Transfer Seventh Edition in SI Units*, McGraw-Hill International (UK) Limited, Singapore, 1992.

Huang, N-H., Lu, W.-K., 1993. Kinetics and mechanisms of reactions in iron ore/coal composites. *ISIJ International*, Vol. 33, No. 10, pp 1055-1061.

Jones, J.F., Schmid, M.R., 1964. Fluidized bed pyrolysis of coal. *Chemical Engineering Progress*, Vol. 60, No. 6, 1964, pp 69-73.

Johnstone, H.F., Chen, C.Y., Scott, D.S., 1952. Kinetics of the steam-carbon reaction in porous graphite tubes. *Industrial and Engineering Chemistry*, Vol. 44, No. 7, pp 1564-1569.

Jüntgen, H., Van Heek, K.H., 1979. An update of German non-isothermal coal pyrolysis work. *Fuel Processing Technology*, Vol. 2, pp 261-293.

Kapteijn, F., Meijer, R., Moulijn, J.A., 1994. On why do different carbons show different gasification rates: A transient isotopic CO_2 gasification study. *Carbon*, Vol. 32, No. 7, pp 1223-1231.

Kayembe, N., Pulsifer, A.H., 1976. Kinetics and catalysis of the reaction of coal char and steam. *Fuel*, Vol. 55, pp 211-216.

Kubaschewski, O., Alcock, C.B., Spencer, P.J., *Materials Thermochemistry, Sixth Edition*, Pergamon Press Ltd., 1993.

Kühl, H., Kashani-Motlagh, M.M., Mühlen, H.-J., Van Heek, K.H., 1992. Controlled gasification of different carbon materials and development of pore structure. *Fuel*, Vol. 71, pp 879-882.

Lide, D.R. (Ed.), *CRC Handbook of Chemistry and Physics, 86th Edition*, 2005-2006. CRC Press., Boca Raton, Florida.

McKewan, W.M., 1960. Kinetics of Iron Oxide Reduction. *Trans. Met. Soc. AIME*, Vol. 218, pp 2-6.

McKewan, W.M., 1961. Reduction Kinetics of Magnetite in H_2-H_2O-N_2 Mixtures. *Trans. Met. Soc. AIME*, Vol. 221, pp 140-145.

McKewan, W.M., 1962a. Reduction Kinetics of Magnetite in Hydrogen at High Pressures. *Trans. Met. Soc. AIME*, Vol. 224, pp 2-5.

McKewan, W.M., 1962b. Reduction Kinetics of Magnetite in Hydrogen at High Pressures. *Trans. Met. Soc. AIME*, Vol. 224, pp 387-393.

Meraikib, M., Friedrichs, H.A., 1987. On the isothermal reduction of iron ore pellets with carbon monoxide, hydrogen, and their mixtures. *Steel Research*, Vol. 58, No. 10, pp.439-445.

Mookherjee, S., Ray, H.S., Mukherjee, A., 1985a. Thermogravimetric studies on the reduction of hematite ore fines by a surrounding layer of coal or char fines. Part 1. Isothermal kinetic studies. *Thermochimica Acta*, Vol. 95, pp 235-246.

Mookherjee, S., Ray, H.S., Mukherjee, A., 1985b. Thermogravimetric studies on the reduction of hematite ore fines by a surrounding layer of coal or char fines. Part 2. Non-isothermal kinetic studies. *Thermochimica Acta*, Vol. 95, pp 247-256.

Mookherjee, S., Ray, H.S., Mukherjee, A., 1986. Isothermal reduction of iron ore fines surrounded by coal or char fines. *Ironmaking and Steelmaking*, Vol.13, No. 5, pp 229-235.

Nabi, G., Lu, W-K., 1968. Reduction Kinetics of Hematite to Magnetite in Hydrogen-Water Vapor Mixtures. *Trans. Met. Soc. AIME*, Vol. 242, pp 2471-2477.

Nashan, G., Rohde, W., Wessiepe, K., 2000. Long term perspectives for the cokemaking technology from an individual country's view. *Cokemaking International*, No. 1, pp 44-47.

Nasr, M.I., Omar, A.A., Khadr, M.H., El-Geassy, A.A., 1994. Analysis of solid-state reduction of iron ore from a couple of experimental measurements. *Scandinavian Journal of Metallurgy*, Vol. 23, pp 119-125.

Otsuka, K-I., Kunii, D., 1969. Reduction of powdery ferric oxide mixed with graphite particles. *Journal of Chemical Engineering of Japan*, Vol. 2, No. 1, pp 46-50.

Patisson, F., Lebas, E, Hanrot, F., Ablitzer, D., Houzelot, J., 2000. Coal pyrolysis in a Rotary Kiln: Part I. Model of the pyrolysis of a single grain. *Metallurgical and Materials Transactions B*, Vol. 31B, April, pp 381-390.

Peters, W., Bertling, H., 1965. Kinetics of the rapid degasification of coals. *Fuel*, Vol. 44, 1965, pp 317-331.

Pilcher, J.M., Walker, P.L., Wright, C.C., 1955. Kinetic study of the steam-carbon reaction. *Industrial and Engineering Chemistry*. Vol. 47, No. 9, pp 1742-1749.

Pistorius, P.C., 2005. Kinetics of carbothermic reduction reactions under heat transfer control: modelling results. *Scandinavian Journal of Metallurgy*, Vol. 34, pp. 122-130.

Prakash, S., 1994. Non-isothermal kinetics of iron ore reduction. *Ironmaking and Steelmaking*, Vol. 21, No. 3, pp. 237-243.

Prakash, S., Goswami, M.C., Mahapatra, A.K.S., Ghosh, K.C., Das, S.K., Sinha, A.N., Mishra, K.K., 2000. Morphology and reduction kinetics of fluxed iron ore pellets. *Ironmaking and Steelmaking*, Vol. 27, No. 3, pp. 194-201.

Prakash, S., Ray, H. S., 1990. Prediction of reduction kinetics of iron ore under fluctuating temperature conditions. *ISIJ International*, Vol. 30, No. 3, pp 183-191.

Prakash, S., Ray, H. S., 1991. Moving-bed studies on reaction behaviour of ion ore and coal/char mixtures in gasifying agents. *Fuel*, Vol. 70, January, pp. 17-23.

Prakash, S., Ray, H.S., Gupta, K.N., 1986. Bench-scale experiment to simulate vertical retort process for production of direct reduced iron. *Ironmaking and Steelmaking*, vol. 13, No. 2, pp. 76-79.

Quets, J.M., Wadsworth, M.E., Lewis, J.R., 1960. Kinetics of Hydrogen Reduction of Magnetite. *Trans. Met. Soc. AIME*, Vol. 218, pp 545-550.

Rao, Y.K., 1971. The kinetics of reduction of hematite by carbon. *Metallurgical Transactions*, Vol. 2, May, pp 1439-1447.

Rao, Y.K., 1979. Mechanism and the intrinsic rates of reduction of metallic oxides. *Metallurgical Transactions B*, Vol. 10B, June, pp 243-255.

Rao, Y.K., Jalan, B.P., 1972. A study of the rates of carbon-carbon dioxide reaction in the temperature range 839° to 1050°C. *Metallurgical Transactions*, Vol. 3, September, pp 2465-2477.

Rao, Y.K., Moinpour, M., 1983. Kinetics of reduction of hematite with hydrogen gas at modest temperatures. *Metallurgical Transactions B*, Vol. 14B, December, pp 711-723.

Reddy, G.V., Sharma, T., Chakravorty, S., 1991. Kinetic rate equation for direct reduction of iron ore by non-coking coal. *Ironmaking and Steelmaking*, Vol. 18, No. 3, pp 211-213.

Reif, A.E., 1952. The mechanism of the Carbon Dioxide-Carbon reaction. *Journal of Physical Chemistry*, Vol. 56, pp 785-788.

Rierson, D.W., 1993. The ported kiln concept as applied to the grate-kiln system. *Skillings' Mining Review*, April 3, pp 4-10.

Rio Tinto News Realease, 9 November 2006, Hismelt® Homepage: http://www.hismelt.com.au

Roman-Moguel, G.J., Brimacombe, J.K., 1988. Kinetics of direct reduction of unagglomerated iron ore with coal char. *W.O. Philbrook Symposium Conference Proceedings*, pp 39-59.

Romenets, V., Valavin, V., Pokvisnev, Yu., Vandariev, S., 1999. Processing industrial wastes with the liquid-phase reduction Romelt process. *Journal of Metals*, August, pp 33-37.

Saito, K., 1992. Study on direct iron ore smelting reduction process (DIOS) and future program. *Proceedings of the Savard/Lee International Symposium on Bath Smelting*, The Mineral, Metal & Materials Society, pp 589-590.

Sampaio, R.S., Fruehan, R.J., Ozturk, B., 1992. Rate of coal devolatilization in iron and steelmaking processes. Part I – Experimental results. *Iron and Steelmaker*, August, pp 49-57.

Sarma, B, Fruehan, R.J., 1998. A review of coal-based direct ironmaking processes. *1998 ICSTI/Ironmaking Conference Proceedings*, pp 1537-1548.

Seaton, C.E., Foster, J.S., Velasco, J., 1983. Reduction kinetics of hematite and magnetite pellets containing coal char. *Transactions ISIJ*, Vol. 23, pp 490-496.

Shivaramakrishna, N., Sakar, S.B., Prasad, K.K., 1996. The role of internal coal in the reduction of composite pellets. *SEAISI Quarterly*, April, pp 82-95.

Sohn, I., Fruehan, R.J., 2006a. Reduction of Iron Oxides by Volatiles in a Rotary Hearth Furnace Process: Part II. The Reduction of Iron Oxide/Carbon Composites. *Metallurgical Transactions B*, Vol. 37B, April, pp 223-229.

Sohn, I., Fruehan, R.J., 2006b. Reduction of Iron Oxides by Volatiles in a Rotary Hearth Furnace Process: Part III. The Simulation of Volatile Reduction in a Multi-Layer Rotary Hearth Furnace Process. *Metallurgical Transactions B*, Vol. 37B, April, pp 231-238.

Srinivasan, N.S., Lahiri, A.K., 1977. Studies on the reduction pf hematite by carbon. *Metallurgical Transactions B*, Vol. 8B, March, pp 175-178.

Stubington, J.F., Sumaryono, 1984. Release of volatiles from large coal particles in a hot fluidised bed. *Fuel*, Vol. 63, July, pp 1013-1019.

Sun, S., Lu, W.-K., 1992. A Non-Isothermal Mathematical Model for Reduction of Iron Ore in Ore/Coal Composites. *10th PTD Conference Proceedings*, pp. 403-408.

Sun, S., Lu, W.-K., 1993. Mathematical Modelling of Reactions in Iron Ore/Coal Composites. *ISIJ International*, Vol 33, No 10, pp. 1062-1069.

Sun, S., Lu, W.-K., 1996. A study of kinetics and mechanisms of iron ore reduction in ore/coal composites. *1996 Steelmaking Conference Proceedings*, pp 641-647.

Sun, S., Lu, W.K., 1999a. Building of a mathematical model for the reduction of iron ore in ore/coal composites. *ISIJ International*, Vol. 39, No. 2, pp 130-138.

Sun, S., Lu, W.K., 1999b. A theoretical investigation of kinetics and mechanisms of iron ore reduction in an ore/coal composite. *ISIJ International*, Vol. 39, No. 2, pp 123-129.

Tomeczek, J., Kowol, J., 1991. Temperature field within a devolatilizing coal particle. *The Canadian Journal of Chemical Engineering*, Vol. 69, February, pp 286-293.

Tomeczek, J., Palugniok, H., 1996. Specific heat capacity and enthalpy of coal pyrolysis at elevated temperatures. *Fuel*, Vol. 75, No. 9, pp 1089-1093.

Towhidi, N., Szekely, J., 1981. Reduction kinetics of commercial low-silica hematite pellets with $CO-H_2$ mixtures over temperature range 600°-1234°C. *Ironmaking and Steelmaking*, No. 6, pp 237-249.

Towhidi, N., Szekely, J., 1983. The influence of carbon deposition on the reduction kinetics of commercial grade hematitie pellets with CO, H_2, and N_2. *Metallurgical Transactions B*, Vol. 14B, September, pp 359-367.

Trushenski, S.P., Li, K., Philbrook, W.O., 1974. Non-Topochemical Reduction of Iron Oxides. *Metallurgical Transactions*, Vol. 5, pp 1149-1158.

Tsay, Q.T., Ray, W.H., Szekely, J., 1976. The Modeling of Hematite Reduction with Hydrogen Plus Carbon Monoxide Mixtures: Part I The Bahvior of Single Pellets. *AIChe Journal*, Vol. 22, No. 6, pp 1064-1072.

Turkdogan, E.T., Koump, V., Vinters, J.V., Perzak, T.F., 1968. Rate of oxidation of graphite in carbon dioxide. *Carbon*, Vol. 6, pp 467-484.

Turkdogan, E.T., Vinters, J.V., 1969. Kinetics of oxidation of graphite and charcoal in carbon dioxide. *Carbon*, Vol. 7, pp 101-117.

Turkdogan, E.T., Vinters, J.V., 1972. Gaseous reduction of iron oxides: Part III. Reduction-oxidation of porous and dense iron oxides and iron. *Metallurgical Transactions*, Vol. 3, June, pp 1561-1574.

Turkdogan, E.T., Vinters, J.V., 1974. Catalytic effect of iron on decomposition of carbon monoxide: I. Carbon deposition in H_2-CO mixtures. *Metallurgical Transactions*, Vol. 5, January, pp 11-19.

Tyler, R.J., Smith, I.W., 1975. Reactivity of petroleum coke to carbon dioxide between 1030 and 1180K. *Fuel*, Vol. 54, pp 99-104.

Venkateswaran, V., Brimacombe, J.K., 1977. Mathermatical model of the SL/RN direct reduction process. *Metallurgical Transactions B*, Vol. 8B, September, pp 387-398.

Von Fredersdorff, C.G., Elliott, M.A., *Chemistry of Coal Utilization, Chapter 20, Coal Gasification.* 1963. John Wiley & Sons, Inc., U.S.A., p. 925-931.

Walker, P.L., Jr., Rusinko, F, Jr., Austin, L.G., *Advances in catalysis*, Vol. 11, pp 134-221, Academic Press, Inc., New York, 1959.

Wang, Q., Yang, Z., Tian, J., Li, W., Sun, J., 1997. Mechanisms of reduction in iron ore-coal composite pellet. *Ironmaking and Steelmaking*, Vol. 24, No. 6, pp 457-460.

Wang, Q., Yang, Z., Tian, J., Li, W., Sun, J., 1998. Reduction kinetics of iron ore-coal pellet during fast heating. *Ironmaking and Steelmaking*, Vol. 25, No. 6, pp 443-447.

Warner, N.A., 1964. Reduction kinetics of hematite and the influence of gaseous diffusion. *Transactions of the Metallurgical Society of AIME*, Vol. 230, February, pp 163-176.

Wiesinger, H., 2000. At the frontiers of technology. *Iron and Steelmaker*, January, pp 47-48.

Wong, H.Y., *Handbook of Essential Formulae and Data on Heat Transfer for Engineers*, Longman Group Limited, London, 1977.

Wright, J.K., Bowling, K., McG., Morrison, A.L., 1981. Reduction of hematite pellets with carbonised coal in a static bed. *Transactions ISIJ*, Vol. 2, pp 149-155.

Wu, P.C., Lower, W.E., Hottel, H.C., 1988. Reaction kinetics of carbon dioxide with electrode carbon particles. *Fuel*, Vol. 67, February, pp 205-214.

CHAPTER V: APPENDICES

Appendix I

Gas retention times for samples & Product gas calculations

Time multiple data for graphite and pre-reduced Sishen ore sample mixtures

Sample Reference No.	Sample lowered time [seconds]	Re-zero time - %H2 [seconds]	Re-zero time - %CO2 [seconds]	Re-zero time - %CO [seconds]	Re-zero time - %H2O [seconds]	Re-zero time - %CH4 [seconds]	Sample removal time [seconds]	Gas retention time in furnace tube volume [seconds]	Re-zero time/gas retention time - %H2 [seconds]	Re-zero time/gas retention time - %CO2 [seconds]	Re-zero time/gas retention time - %CO [seconds]	Re-zero time/gas retention time - %H2O [seconds]
1300A	1503	1359	1558	1682	1161	n.p.	3347	159	-1	0	1	-2
1300B	1498	154	1559	2271	499	n.p.	3417	159	-8	0	5	-6
1400C	897	n.p.	952	999	508	n.p.	2701	159	n.p.	0	1	-2
1400D	897	350	954	1145	315	n.p.	2821	159	-3	0	2	-4
1500E	260	355	344	332	482	n.p.	1388	159	1	1	0	1
1500F	268	337	337	360	325	n.p.	1503	159	0	0	1	0

n.p. = component not present in product gas

Time multiple data for coal-ore sample mixtures

Furnace Temperature (°C)	Coal/Char	Coal/Char Size*	Ore Size*	Reaction Time [min.]	Sample Layer Thickness [mm]	Sample lowered time [seconds]	Re-zero time - %H2 [seconds]	Re-zero time - %CO2 [seconds]	Re-zero time - %CO [seconds]	Re-zero time - %H2O [seconds]	Re-zero time - %CH4 [seconds]	Sample removal time [seconds]	Gas retention time in furnace tube volume [seconds]	Re-zero time/gas retention time - %H2 [seconds]	Re-zero time/gas retention time - %CO2 [seconds]	Re-zero time/gas retention time - %CO [seconds]	Re-zero time/gas retention time - %H2O [seconds]
1300	Coal	2	2	3	40	177	342	246	no	1045	n.a.	2179	159	1	0	no	5
1300	Coal	2	2	6	40	360	631	442	no	934	n.a.	2037	159	2	1	no	4
1300	Coal	2	2	9	40	537	789	606	595	1395	n.a.	1806	159	2	0	0	5
1300	Coal	2	2	15	40	898	1207	965	1388	1553	n.a.	2698	159	2	0	3	4
1300	Coal	2	2	12	40	720	1173	789	1244	1563	n.a.	2224	159	3	0	3	5
1400	Coal	2	2	3	40	179	514	261	293	928	n.a.	1424	159	2	1	1	5
1400	Coal	2	2	6	40	359	769	455	444	1111	n.a.	1556	159	3	1	1	5
1400	Coal	2	2	9	40	540	1020	626	595	1350	n.a.	1917	159	3	1	0	5
1400	Coal	2	2	12	40	718	1164	779	885	1117	n.a.	2226	159	3	0	1	3
1400	Coal	2	2	15	40	900	1273	977	1398	1540	n.a.	2768	159	2	0	3	4
1500	Coal	2	2	3	40	180	526	311	257	1482	n.a.	2108	159	2	1	0	8
1500	Coal	2	2	6	40	357	966	487	444	1105	n.a.	1790	159	4	1	1	5
1500	Coal	2	2	9	40	536	1061	669	648	1309	n.a.	2183	159	3	1	1	5
1500	Coal	2	2	12	40	718	1155	881	1255	1491	n.a.	2530	159	3	1	3	5
1500	Coal	2	2	15	40	897	1184	1033	1434	1345	n.a.	2708	159	2	1	3	3
1400	Coal	2	2	3	16	177	292	280	280	915	n.a.	1317	159	1	1	1	5
1400	Coal	2	2	6	16	355	487	441	415	786	n.a.	1537	159	1	1	0	3
1400	Coal	2	2	9	16	537	612	612	929	682	n.a.	2162	159	0	0	2	1
1400	Coal	2	2	12	16	717	783	795	1074	947	n.a.	2035	159	0	0	2	1
1400	Coal	2	2	15	16	899	863	933	1772	702	n.a.	4299	159	0	0	5	-1
1400	Coal	2	1	9	40	538	1188	700	603	1530	n.a.	1980	159	4	1	0	6
1400	Coal	1	2	9	40	538	1111	621	627	1218	n.a.	2147	159	4	1	1	4
1400	Coal	3	2	9	40	537	1220	625	1043	1114	n.a.	2011	159	4	1	3	4
1400	Coal	2	3	9	40	537	1215	625	1297	990	n.a.	2083	159	4	1	5	3
1400	Char	2	2	3	40	190	293	293	225	1184	n.a.	1877	159	1	1	0	6
1400	Char	2	2	6	40	358	441	452	429	623	n.a.	1758	159	1	1	0	2
1400	Char	2	2	9	40	539	627	627	603	828	n.a.	2241	159	1	1	0	2
1400	Char	2	2	12	40	717	791	885	756	953	n.a.	2479	159	0	1	0	1
1400	Char	2	2	15	40	897	947	1075	994	947	n.a.	2868	159	0	1	1	0

n.p. = component not present in product gas
no = component concentration did not return to initial level
* 1 = -2000 +1400 µm; 2 = -850 +425 µm; 3 = -425 +300 µm

Product gas composition calculation

Data for the pressure of water vapour over water, in mm Hg, for temperatures of -16 to 30 was taken from CRC Handbook of Chemistry and Physics, 86th Edition, 2005-2006. An equation fit for the data was made and this equation used to calculate the $\%H_2O$ in the product gas.

$$P_{H_2O} = 2.896 \cdot 10^{-6} \cdot T_{dp}^4 + 1.986 \cdot 10^{-4} \cdot T_{dp}^3 + 1.058 \cdot 10^{-2} \cdot T_{dp}^2 + 3.332 \cdot 10^{-1} \cdot T_{dp} + 4.587$$

$$\%H_2O = P_{H_2O} / 760 \cdot P_{atm.}$$

P_{H_2O} = Water vapour pressure (mm Hg)
$P_{atm.}$ = atmospheric pressure (Bar)

T_{dp} = water dewpoint (°C)

$$\%g_n = \frac{\%g_a}{\sum_0^i \%g_a + \%H_2O} \cdot 100$$

$$Q_g = Q_{Ar} \frac{\%g_n}{\%Ar_n} \cdot \frac{t_p}{60}$$

$n_g = Q_g / 22400$

$\%g_n$ = % of component g in gas

$\%g_a$ = % of component analysed by mass spectrometer

$\sum_0^i \%g_a$ = sum of % of components 0 to *i* analysed by mass spectrometer

Q_{Ar} = Ar flow rate into experiment [Ncm^3/min.]

Q_g = flow rate of gas *g* in product gas [Ncm^3/min.]

t_p = time interval [seconds]

n_g = mol gas *g* in product gas for time interval t_p

Appendix II

View factor calculations for radiation network

The view factors were calculated as follows.

From parallel disk geometry (Wong, 1977):

$$F_{24} = \frac{1}{2B^2}(X - \sqrt{X^2 - 4B^2C^2})$$

$$B = \frac{r_2}{h}$$

$$C = \frac{r_4}{h}$$

$$X = (1 + B^2 + C^2)$$

F_{ij} = view factor from area *i* to *j*

r_i = radius of disk [m]

h = separation distance between disks [m]

A_i = area of surface *i* [m^2]

Similarly the following view factors were calculated: F_{27}, $F_{2(3+4)}$, F_{28}, $F_{(3+4)7}$, F_{47}, F_{48}, $F_{(3+4)8}$, F_{87}.

$$F_{21} = 1 - F_{27}$$

$$F_{22} = 0$$

$$F_{23} = F_{2(3+4)} - F_{24}$$

$$F_{25} = F_{27} - F_{28}$$

$$F_{26} = F_{28} - F_{2(3+4)}$$

$$F_{11} = 1 - 2F_{12}; \ F_{12} = F_{17}$$

$$F_{12} = F_{21}\frac{A_2}{A_1}$$

$$F_{(3+4)1} = F_{(3+4)7} - F_{(3+4)2}$$

$$F_{(3+4)2} = F_{2(3+4)}\frac{A_2}{A_{(3+4)}}$$

$$F_{1(3+4)} = F_{(3+4)1}\frac{A_{(3+4)}}{A_1}$$

$$F_{13} = F_{1(3+4)} - F_{14}$$

$$F_{14} = F_{41} \frac{A_4}{A_1}$$

$$F_{41} = F_{47} - F_{42}$$

$$F_{15} = F_{51} \frac{A_5}{A_1}$$

$$F_{16} = 1 - (F_{11} + F_{12} + F_{13} + F_{14} + F_{15})$$

$$F_{41} = F_{47} - F_{42}$$

$$F_{43} = 0 ;\ F_{44} = 0$$

$$F_{45} = F_{48} - F_{47}$$

$$F_{46} = 1 - (F_{41} + F_{42} + F_{45})$$

$$F_{51} = F_{57} - F_{52}$$

$$F_{57} = F_{58}$$

$$F_{85} = 1 - F_{87}$$

$$F_{58} = F_{85} \frac{A_8}{A_5}$$

$$F_{52} = F_{25} \frac{A_2}{A_5}$$

$$F_{53} = F_{5(3+4)} - F_{54}$$

$$F_{5(3+4)} = F_{(3+4)5} \frac{A_3 + A_4}{A_5}$$

$$F_{(3+4)5} = F_{(3+4)8} - F_{(3+4)7}$$

$$F_{54} = F_{45} \frac{A_4}{A_5}$$

$$F_{55} = 1 - 2F_{58}$$

$$F_{56} = 1 - (F_{51} + F_{52} + F_{53} + F_{54} + F_{55})$$

$$F_{31} = F_{13} \frac{A_1}{A_3}$$

$$F_{32} = F_{23} \frac{A_2}{A_3}$$

$$F_{34} = 0\,;\; F_{33} = 0$$

$$F_{35} = F_{53} \frac{A_5}{A_3}$$

$$F_{36} = F_{63} \frac{A_6}{A_3}$$

$$F_{61} = F_{16} \frac{A_1}{A_6}$$

$$F_{62} = F_{26} \frac{A_2}{A_6}$$

$$F_{63} = F_{6(3+4)} - F_{64}$$

$$F_{6(3+4)} = F_{68}\,;\; F_{(3+4)6} = 1 - F_{(3+4)8}$$

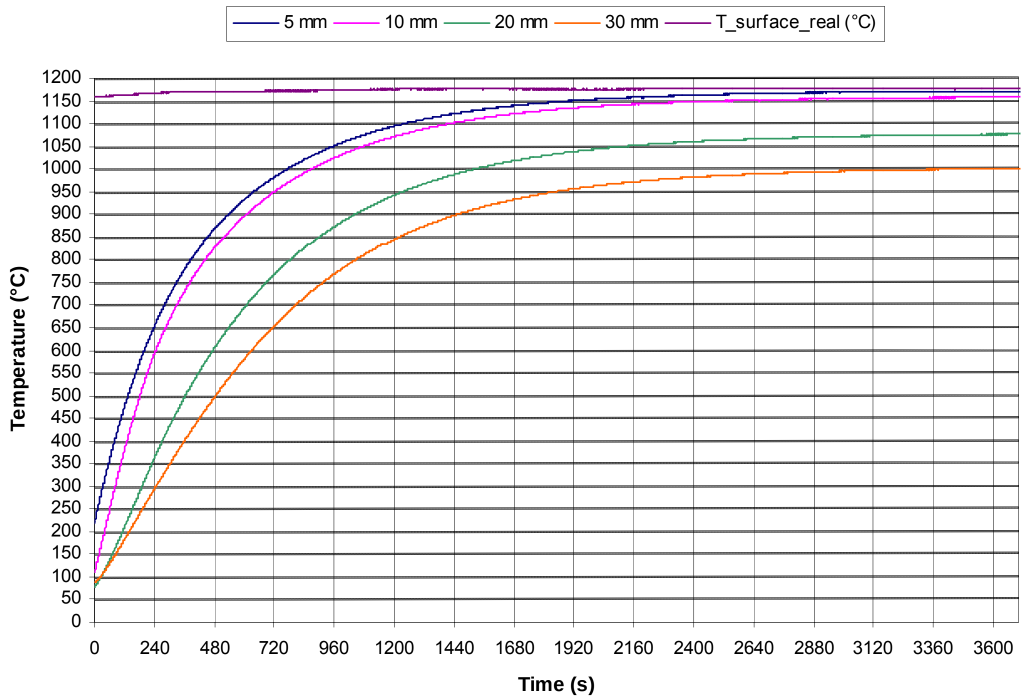
$$F_{64} = F_{46} \frac{A_4}{A_6}$$

$$F_{66} = 1 - 2F_{68}\,;\; F_{68} = F_{6(3+4)}$$

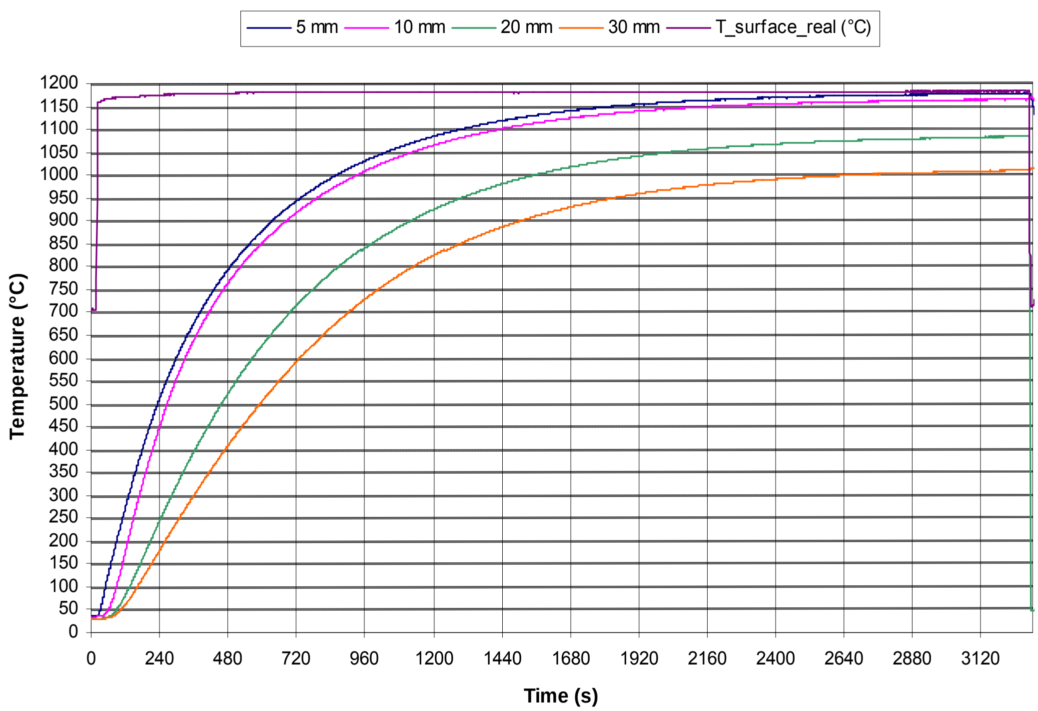
$$F_{65} = 1 - (F_{61} + F_{62} + F_{63} + F_{64} + F_{66})$$

Appendix III

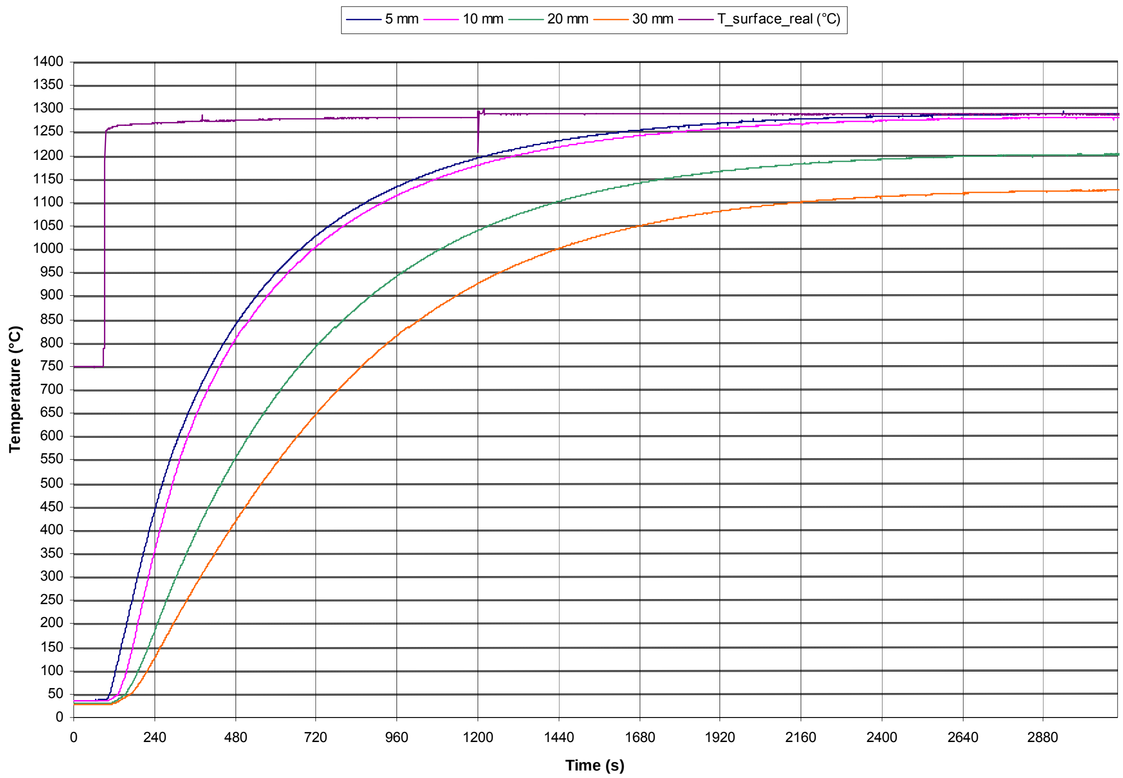
Surface temperature measurement for alumina sample (1300°C a)



Surface temperature measurement for alumina sample (1300°C b)

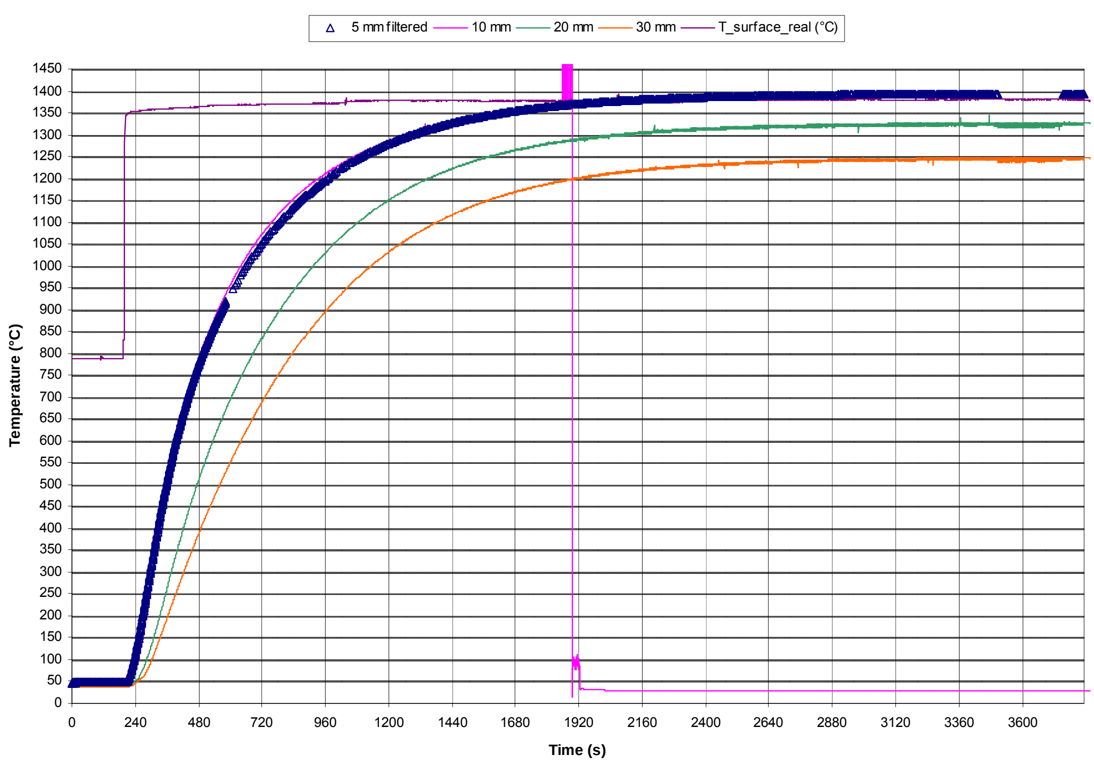


Surface temperature measurement for alumina sample (1400°C)



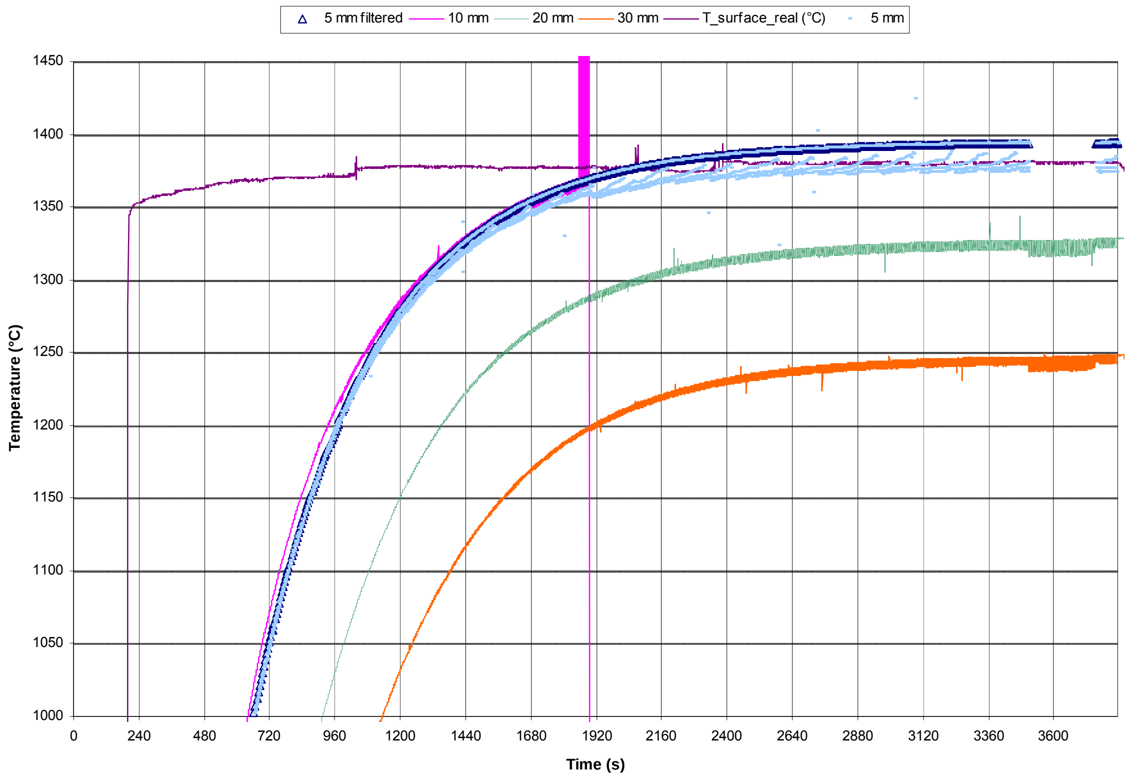
Surface temperature measurement for alumina sample (1500°C)

(Filtered data for thermocouple placed 5 mm from sample surface shown)



Surface temperature measurement for alumina sample (1500°C)

(Both filtered and original data for thermocouple placed 5 mm from sample surface shown)



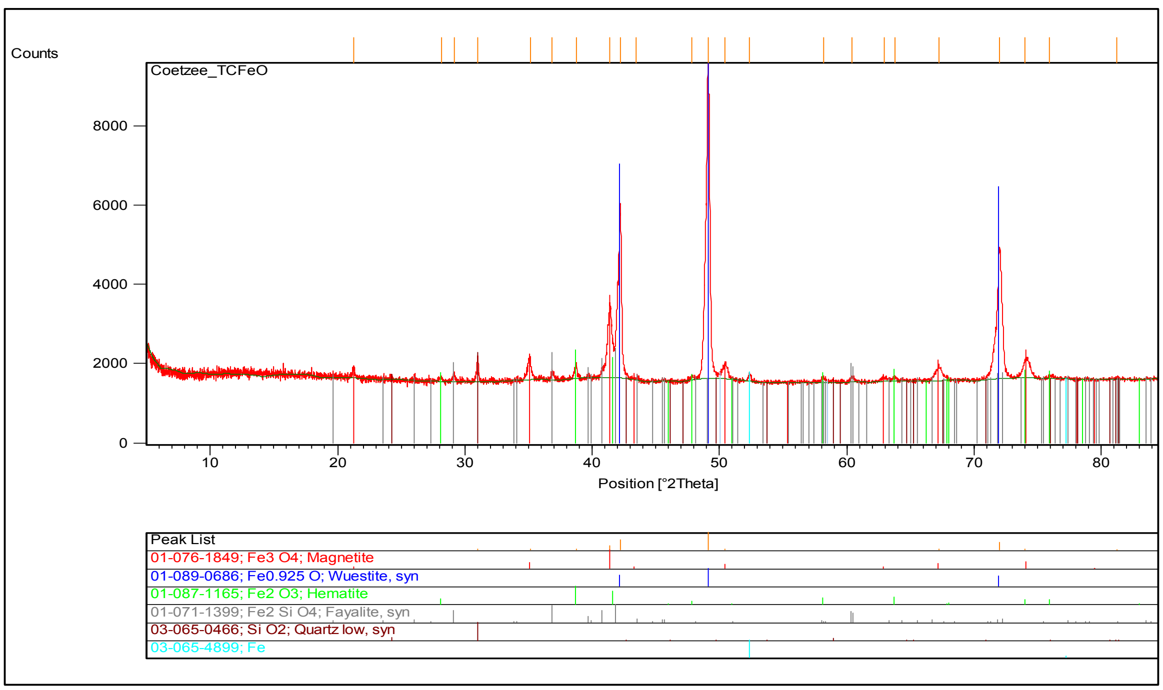
Appendix IV

Chemical Analyses of Input Materials

Ore Analyses

	Sishen Fines: -425 +300 µm	Sishen Fines: -850 +425 µm	Sishen Fines: -2000 +1400 µm	Pre-Reduced Sishen Fines
Al_2O_3	1.35	1.64	1.35	1.81
CaO	0.25	0.19	0.25	0.10
Cr	<0.05	<0.05	<0.05	n.d.
Fe(total)	63.5	63.0	63.5	71.1
Fe^0	n.d.	n.d.	n.d.	0.64
FeO	n.d.	n.d.	n.d.	68.1
Fe_2O_3	n.d.	n.d.	n.d.	25.0
K_2O	0.20	0.23	0.20	0.23
MgO	0.08	0.05	0.08	0.04
MnO	0.03	0.04	0.03	0.04
Ni	<0.05	<0.05	<0.05	n.d.
P	0.05	0.05	0.05	0.05
SiO_2	3.43	3.95	3.43	3.84
C	0.03	0.01	0.03	n.d.
S	0.01	0.02	0.01	n.d.
Ba	<0.05	0.49	<0.05	n.d.
TiO_2	0.06	0.10	0.06	0.08
Moisture	0.02	0.01	0.02	n.d.

XRD analysis of pre-reduced Sishen fines



Hand milled, top loading onto zero-background holder due to small sample size
Analysed using a PANalytical X'Pert Pro powder diffractometer with X'Celerator detector and variable divergence- and roeceiving slits with Fe filtered Co-Kα radiation
Phases identified using X'Pert Highscore plus software

Coal, Char and Electrode Graphite Analyses

Ultimate Analyses (Dry basis)

%	Eikeboom Coal: -425 +300 µm	Eikeboom Coal: -850 +425 µm	Eikeboom Coal: -2000 +1400 µm	Eikeboom Char: -850 +425 µm	Electrode Graphite
C	76.0	75.9	76.0	78.9	98.7
H	3.60	3.53	3.60	0.26	0.01
N	1.80	1.81	1.80	0.60	<0.01
O	5.72	6.03	5.72	2.64	---

Proximate Analyses

%	Eikeboom Coal: -425 +300 µm	Eikeboom Coal: -850 +425 µm	Eikeboom Coal: -2000 +1400 µm	Eikeboom Char: -850 +425 µm
Moisture content (air dried)	3.2	3.3	3.2	4.0
Ash content (air dried)	12.0	12.0	12.0	17.3
Volatile matter content (air dried)	22.8	22.5	22.8	1.9
Fixed Carbon (air dried)	62.0	62.2	62.0	77.5
Total Sulphur	0.36	0.36	0.36	0.31

Ash Composition

%	Eikeboom Coal: -425 +300 µm	Eikeboom Coal: -850 +425 µm	Eikeboom Coal: -2000 +1400 µm	Eikeboom Char: -850 +425 µm
Al_2O_3	39.37	38.72	39.37	32.75
CaO	2.81	2.42	2.81	0.96
Cr_2O_3	0.04	0.05	0.04	0.17
Fe_2O_3	1.32	1.65	1.32	5.42
K_2O	0.50	0.50	0.50	0.66
MgO	0.68	0.67	0.68	0.51
MnO	0.02	0.02	0.02	0.67
Na_2O	0.27	0.30	0.27	0.02
P_2O_5	1.25	1.17	1.25	0.14
SiO_2	49.10	50.62	49.10	55.90
TiO_2	2.11	2.13	2.11	1.86
V_2O_5	0.04	0.05	0.04	0.05
ZrO_2	0.14	0.12	0.14	0.08
Ba	0.25	0.24	0.25	0.10
Sr	0.20	0.18	0.20	0.05
SO_3	1.26	0.81	1.26	0.55
Total	98.77	99.68	98.77	99.89

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Appendix V

Mass measurements of sand samples divided in Sample Cutter-Splitter

Crucible Number	Fibre Board Crucible Mass In (g.)	Sand Mass In (g.)	g. Sand - Top Node	g. Sand - Middle Node	g. Sand - Bottom Node	g. Fibre Board - Top Node	g. Fibre Board - Middle Node	g. Fibre Board - Bottom Node	Mass Sand out (g.)	Mass Fibre board out (g.)	**Mass%Top Node**	**Mass% Middle Node**	**Mass% Bottom Node**	Mass%Top Node	Mass% Middle Node	Mass% Bottom Node	Mass Sand In - Mass Sand Out (g.)	Mass Fibre Board In - Mass Fibre Board Out (g.)	Sum of Sand and FB Mass Differences (g)
1	21.05	36.52	17.3	12.4	7.9	6.6	4.3	8.6	37.65	19.48	**46**	**33**	**21**	34	22	44	1.13	-1.57	-0.44
2	20.93	36.52	18.3	12.4	7.0	6.7	4.2	8.4	37.70	19.39	**48**	**33**	**19**	35	22	44	1.18	-1.55	-0.37
3	21.56	36.53	18.1	12.3	7.4	6.7	4.4	8.9	37.83	19.98	**48**	**33**	**20**	34	22	45	1.30	-1.58	-0.28
4	20.45	36.52	18.2	12.7	6.8	6.6	4.2	8.3	37.63	19.10	**48**	**34**	**18**	35	22	43	1.11	-1.34	-0.23
5	20.23	36.52	16.9	12.8	8.1	5.9	4.3	8.3	37.84	18.58	**45**	**34**	**21**	32	23	45	1.31	-1.66	-0.34
6	20.24	36.52	16.4	12.9	8.1	5.5	4.1	8.4	37.41	17.96	**44**	**34**	**22**	31	23	47	0.88	-2.28	-1.40
7	21.02	36.52	17.8	12.7	7.4	6.5	4.3	8.5	37.94	19.34	**47**	**33**	**20**	34	22	44	1.42	-1.68	-0.26
8	19.90	36.52	17.2	12.7	8.0	6.0	4.2	8.2	37.86	18.34	**45**	**34**	**21**	33	23	45	1.34	-1.57	-0.22
9	21.10	36.52	16.9	12.8	8.4	5.4	4.4	9.5	38.03	19.34	**44**	**34**	**22**	28	23	49	1.51	-1.76	-0.25
10	21.16	36.53	16.8	12.6	8.5	6.6	4.5	8.4	37.93	19.47	**44**	**33**	**22**	34	23	43	1.41	-1.69	-0.28
Average	20.76	36.52	17.4	12.6	7.8	6.3	4.3	8.6	37.8	19.1	46	33	21	33	22	45			
Population Standard Deviation			0.6	0.2	0.5	0.5	0.1	0.4			1.7	0.5	1.4	2.0	0.5	1.7			
95% Confidence Limit			0.4	0.1	0.3	0.3	0.1	0.2			1.0	0.3	0.9	1.2	0.3	1.0			

Appendix VI

Calibration sample masses and analyses

			Sample Mix Out			Fibreboard			Thermocouples			Totals Out			In			
Sample Name	Sample Reference No.	Reaction Time (minutes)	g. sample mix - top	g. sample mix - middle	g. sample mix - bottom	g. Fibreboard - top	g. Fibreboard -middle	g. Fibreboard -bottom	g. thermocouple - top	g. thermocouple - middle	g. thermocouple -bottom	Total g. sample mix out	Total g. Fibreboeard out	Total g. Thermocouples out	g. Fibreboard in	g. Mix in	mass% "FeO" in	mass% Graphite in
19_09_2006_1300_A_25	1300A	25	15.981	16.182	11.261	13.906	3.371	12.299	0.16	0.098	0.328	43.424	29.576	0.586	31.854	43.787	85.4	14.6
19_09_2006_1300_B_25	1300B	25	18.615	15.453	8.847	10.798	6.092	12.643	0	0	0	42.915	29.533	0	31.264	43.218	85.4	14.6
20_09_2006_1400_C_15	1400C	15	16.283	16.030	9.815	11.435	6.303	13.048	0.234	0.217	0.193	42.128	30.786	0.644	32.365	44.023	85.4	14.6
20_09_2006_1400_D_15	1400D	15	15.534	15.739	10.043	11.572	5.972	12.867	0.346	0.337	0.534	41.316	30.411	1.217	32.096	43.017	85.4	14.6
21_09_2006_1500_E_4.5	1500E	4.3	18.954	16.168	9.610	11.560	6.162	13.160	0	0	0	44.732	30.882	0	32.395	44.519	85.4	14.6
21_09_2006_1500_F_4.5	1500F	4.5	11.482	15.372	18.011	5.814	6.784	16.174	0	0	0	44.865	28.772	0	30.868	43.968	85.4	14.6

	Sample out Fe analyses												Sample out Fe analyses - Corrected*																		
Sample Reference No.	% Fe(met) - Top	% Fe(met) - Middle	% Fe(met) - Bottom	% FeO - Top	% FeO - Middle	% FeO - Bottom	% Fe2O3 -Top	% Fe2O3 - Middle	% Fe2O3 - Bottom	% Fe(total) - Top	% Fe(total) - Middle	% Fe(total) - Bottom	% Fe(met) - Top (Corrected)*	% Fe(met) - Middle (Corrected)*	% Fe(met) - Bottom (Corrected)*	% FeO - Top (Corrected)*	% FeO - Middle (Corrected)*	% FeO - Bottom (Corrected)*	% Fe2O3 - Top (Corrected)*	% Fe2O3 - Middle (Corrected)*	% Fe2O3 - Bottom (Corrected)*	% Fe(+2) - Top (Corrected)*	% Fe(+2) - Middle (Corrected*)	% Fe(+2) - Bottom (Corrected)*	% Fe(+3) - Top (Corrected*)	% Fe(+3) - Middle (Corrected*)	% Fe(+3) - Bottom (Corrected*)	% Fe(total) - Top (Corrected)*	% Fe(total) - Middle (Corrected)*	% Fe(total) - Bottom (Corrected)*	g. Fe in/ g. Fe out
1300A	15.6	0.2	0.2	51.5	57.2	52.6	11.6	20.5	24.0	63.8	59.1	57.9	16.2	0.3	0.2	53.6	60.3	55.5	12.06	21.61	25.34	41.6	46.8	43.1	8.4	15.1	17.7	66.3	62.2	61.1	1.01
1300B	11.4	0.1	0.1	52.5	57.7	52.7	17.6	20.9	21.6	64.5	59.5	56.2	11.6	0.1	0.1	53.6	61.0	54.1	17.98	22.08	22.19	41.6	47.3	42.1	12.6	15.4	15.5	65.9	62.9	57.7	1.00
1400C	17.3	0.1	0.2	53.4	57.5	53.1	11.5	19.7	21.3	66.9	58.6	56.4	17.6	0.1	0.2	54.4	61.2	55.1	11.72	20.96	22.12	42.3	47.5	42.8	8.2	14.7	15.5	68.1	62.3	58.5	1.04
1400D	23.0	0.1	0.1	47.5	59.8	55.8	6.5	18.8	20.7	64.5	59.8	58.0	23.7	0.1	0.1	49.0	63.8	57.8	6.71	20.05	21.45	38.1	49.5	44.9	4.7	14.0	15.0	66.5	63.7	60.1	1.04
1500E	4.3	0.4	0.4	56.4	46.9	51.2	17.2	31.9	26.2	60.2	59.2	58.5	4.4	0.4	0.4	57.1	49.3	53.9	17.41	33.53	27.57	44.3	38.3	41.8	12.2	23.5	19.3	60.9	62.1	61.5	1.02
1500F	7.1	0.2	0.4	58.0	50.2	50.8	12.1	26.2	27.3	60.7	57.6	58.9	7.1	0.2	0.4	58.1	53.2	54.0	12.13	27.77	29.04	45.2	41.3	42.0	8.5	19.4	20.3	60.7	61.0	62.7	1.01

	Product gas analysed					%C calculated vs. Analysed							Mass C in and out											g. Mass loss		g. O to gas		
Sample Reference No.	Total g. CO_2 in Product Gas	Total g. CH_4 in Product Gas	Total g. CO in Product Gas	Total g. H_2 in Product Gas	Total g. H_2O in Product Gas	%C out analysed - top (Corrected)*	%C out calculated from incremental Mass & Energy Balance - Top	%C out analysed - middle (Corrected)*	%C out calculated from incremental Mass & Energy Balance - Middle	%C out analysed - bottom (Corrected)*	%C out calculated from incremental Mass & Energy Balance - Bottom	%Fixed Carbon in start mixture	Total g. C in	g. C in - top	g. C in - middle	g. C in - bottom	Total g. C remaining in sample	Total g. C consumption according to %C chemical ana	g. C to gas - Product gas analysis	g. C to gas according to incremental Mass & Energy Balance	g. C to gas according to chemical ANALYSIS - top	g. C to gas according to chemical ANALYSIS - middle	g. C to gas according to chemical ANALYSIS - bottom	Massa Loss according to Product gas [Total Time]	Mass loss calculated in incremental mass & energy balance	g. O in CO & CO_2 Product gas [Total Time]	g. O From Reduction to gas according to incremental Mass & Energy Balance	g. O From Reduction to gas according to incremental Mass & Energy Balance
1300A	0.92	0.00	2.34	0.03	0.75	12.9	14.5	13.2	13.5	15.1	12.7	14.4	6.4	2.9	2.1	1.3	5.6	0.77	1.25	0.58	0.96	0.09	-0.27	4.0	2.2	2.0	0.9	0.9
1300B	0.56	0.00	1.71	0.01	0.21	12.4	12.9	12.7	13.7	18.7	15.6	14.4	6.3	2.9	2.1	1.3	5.7	0.59	0.89	0.45	0.65	0.23	-0.29	2.5	1.3	1.4	0.7	0.7
1400C	0.99	0.03	1.30	0.01	0.30	10.5	14.1	13.5	13.7	18.0	14.5	14.4	6.4	3.0	2.1	1.3	5.4	1.01	0.83	0.54	1.28	0.08	-0.35	2.6	1.8	1.5	1.0	1.0
1400D	0.63	0.00	2.96	0.01	0.14	12.2	13.4	11.1	13.5	16.2	13.7	14.4	6.3	2.9	2.1	1.3	5.0	1.24	1.44	0.83	1.05	0.43	-0.25	3.7	2.2	2.2	1.3	1.3
1500E	0.72	0.02	0.41	0.01	0.29	16.8	15.1	12.2	12.2	13.9	14.4	14.4	6.5	3.0	2.1	1.4	6.3	0.21	0.37	0.13	-0.16	0.27	0.10	1.5	0.7	0.8	0.3	0.3
1500F	0.33	0.01	0.47	0.01	0.12	14.6	21.6	14.3	12.7	13.6	7.5	14.4	6.4	3.0	2.1	1.3	6.1	0.36	0.29	0.17	1.28	0.04	-0.96	0.9	0.6	0.5	0.3	0.3

*Corrected for Fibreboard carry over

							g. Al2O3 pick-up			g. SiO2 pick-up			%Al2O3 - Out			%SiO2 - Out			Corrected masses out			Correced Fibreboard masses		
Sample Reference No.	g. Al2O3 In	g. Al2O3 out	g. SiO2 In	g. SiO2 out	Total g. Al2O3 pick-up	Total g. SiO2 pick-up	g. Al2O3 pick-up - top	g. Al2O3 pick-up - middle	g. Al2O3 pick-up - bottom	g. SiO2 pick-up - top	g. SiO2 pick-up - middle	g. SiO2 pick-up - bottom	%Al2O3 Analysed -Top	%Al2O3 Analysed -Middle	%Al2O3 Analysed -Bottom	%SiO2 Analysed -Top	%SiO2 Analysed -Middle	%SiO2 Analysed -Bottom	g. sample mix out - Top (Corrected)*	g. sample mix out - Middle (Corrected)*	g. sample mix out - Bottom (Corrected)*	g. Fibreboard out - Top (Corrected)*	g. Fibreboard out - Middle (Corrected)*	g. Fibreboard out - Bottom (Corrected)*
1300A	0.68	1.91	1.44	2.24	1.24	0.81	0.42	0.51	0.31	0.19	0.32	0.29	4.59	4.52	3.99	5.35	4.92	5.26	15.4	15.4	10.7	14.5	4.2	12.9
1300B	0.67	1.54	1.42	2.00	0.87	0.58	0.23	0.50	0.14	0.16	0.32	0.10	2.88	4.68	3.15	4.37	5.12	4.47	18.2	14.6	8.6	11.2	6.9	12.9
1400C	0.68	1.71	1.45	2.05	1.03	0.61	0.20	0.61	0.21	0.11	0.35	0.15	3.17	5.22	3.64	4.74	5.18	4.61	16.0	15.1	9.5	11.7	7.3	13.4
1400D	0.67	1.74	1.41	2.15	1.08	0.74	0.31	0.59	0.18	0.18	0.39	0.17	3.95	5.15	3.17	5.31	5.43	4.69	15.1	14.8	9.7	12.1	7.0	13.2
1500E	0.69	1.65	1.46	1.99	0.96	0.53	0.17	0.50	0.29	0.05	0.29	0.19	2.58	4.48	4.52	3.82	4.77	5.15	18.7	15.4	9.1	11.8	6.9	13.6
1500F	0.68	1.89	1.44	2.21	1.21	0.77	0.15	0.54	0.52	-0.12	0.33	0.56	3.99	4.97	3.69	4.77	5.24	4.78	11.5	14.5	16.9	5.8	7.7	17.3

*Corrected for Fibreboard carry over

Incremental Heat-mass balance calculation sheets for sample 1400C

Top Node mass balance

Top Node Mass IN								Mass in (g.)																
Time (s)	Top Node %	T (°C)	%Reduction	%Fe(total)	%Fe(met)	%Fe(+2)	%Fe(+3)	g. Fe (total)	g. Fe (met)	g. FeO	g. Fe2O3	g. Al2O3	g. CaO	g. K2O	g. MgO	g. MnO	g. P2O5	g. SiO2	g. TiO2	g. C	g. Mullite	g. H2O	g. Ar	Total g. in
0	46	25	25.7	71.1	0.6	52.9	17.5	10.9	0.1	10.4	3.8	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.91	12.1	0.300	0.0	30.7
120		25	25.7	71.1	0.6	52.9	17.5	10.9	0.1	10.4	3.8	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.91	12.1	0.300	5.1	35.8
240		175	28.5	68.1	0.0	58.2	9.9	10.9	0.0	12.0	2.3	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.87	12.1	0.150	5.1	35.5
360		497	31.3	68.1	2.0	57.9	8.2	10.9	0.3	11.9	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.81	12.1	0.011	5.1	35.2
480		755	34.1	68.1	4.9	55.0	8.2	10.9	0.8	11.3	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.74	12.1	0.000	5.1	34.9
600		920	36.9	68.1	7.7	52.2	8.2	10.9	1.2	10.7	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.67	12.1	0.000	5.1	34.7
720		1021	39.7	68.1	10.6	49.3	8.2	10.9	1.7	10.1	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.59	12.1	0.000	5.1	34.5
840		1059	42.5	68.1	13.5	46.4	8.2	10.9	2.2	9.5	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.50	12.1	0.000	5.1	34.3
897		1055	45.3	68.1	16.3	43.6	8.2	10.9	2.6	9.0	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.42	12.1	0.000	2.4	31.4

Top Node Mass OUT		Mass Out:	16.0	g. Fe out:	10.9			Mass out (g.)																				
Time (s)	T (°C)	%Reduction Aim	%Reduction	%Fe(total)	%Fe(met)	%Fe(+2)	%Fe(+3)	g. Fe (total)	g. Fe (met)	g. FeO	g. Fe2O3	g. Al2O3	g. CaO	g. K2O	g. MgO	g. MnO	g. P2O5	g. SiO2	g. TiO2	g. C	g. Mullite	g. H2O (g)	g. Ar	g. CO	g. CO2	Total g. Out	%CO/(%CO+%CO2)	Aim %CO/(%CO+%CO2)
0	25.0	25.7	25.7	68.1	0.00	52.5	15.59	10.9	0.0	10.8	3.6	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.92	12.1	0.000	0.0	0.00	0.00	30.7	100	#DIV/0!
120	175	28.5	28.5	68.1	0.00	58.2	9.87	10.9	0.0	12.0	2.3	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.87	12.1	0.150	5.1	0.00	0.18	35.8	0	0
240	497	31.3	31.3	68.1	2.02	57.9	8.20	10.9	0.3	11.9	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.81	12.1	0.075	5.1	0.03	0.15	35.5	25	25
360	755	34.1	34.1	68.1	4.88	55.0	8.20	10.9	0.8	11.3	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.74	12.1	0.038	5.1	0.08	0.12	35.2	50	50
480	920	36.9	36.9	68.1	7.74	52.2	8.20	10.9	1.2	10.7	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.67	12.1	0.038	5.1	0.13	0.08	34.9	71	71
600	1021	39.7	39.7	68.1	10.60	49.3	8.20	10.9	1.7	10.1	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.59	12.1	0.000	5.1	0.14	0.07	34.7	75	75
720	1059	42.5	42.5	68.1	13.46	46.4	8.20	10.9	2.2	9.5	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.50	12.1	0.000	5.1	0.17	0.04	34.5	86	86
840	1055	45.3	45.3	68.1	16.32	43.6	8.20	10.9	2.6	9.0	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.42	12.1	0.000	5.1	0.18	0.04	34.3	88	88
897	1054	46.6	46.5	68.1	17.60	42.3	8.20	10.9	2.8	8.7	1.9	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	2.38	12.1	0.000	2.4	0.08	0.02	31.4	88	88

Top Node heat balance

Top Node kJ IN																
Time (s)	Fe (met)	FeO	Fe2O3	Al2O3	CaO	K2O	MgO	MnO	P2O5	SiO2	TiO2	C	Mullite	H2O	Ar	kJ IN
0	0.0	-38.2	-19.7	-5.1	-0.2	-0.2	-0.1	0.0	-0.2	-10.0	-0.2	0.0	-192.9	-4.8	0.0	-271.6
120	0.0	-38.2	-19.7	-5.1	-0.2	-0.2	-0.1	0.0	-0.2	-10.0	-0.2	0.0	-192.9	-4.8	0.8	-270.8
240	0.0	-42.6	-11.4	-5.1	-0.2	-0.1	-0.1	0.0	-0.2	-10.0	-0.2	0.4	-191.3	-2.0	0.8	-261.9
360	0.1	-39.5	-8.9	-5.0	-0.2	-0.1	-0.1	0.0	-0.2	-9.7	-0.2	1.7	-187.1	-0.1	0.8	-248.7
480	0.4	-35.2	-8.4	-4.9	-0.2	-0.1	-0.1	0.0	-0.2	-9.5	-0.2	2.8	-183.5	0.0	0.8	-238.3
600	0.8	-32.0	-8.2	-4.8	-0.2	-0.1	-0.1	0.0	-0.2	-9.4	-0.2	3.6	-181.0	0.0	0.8	-231.0
720	1.2	-29.4	-8.0	-4.8	-0.2	-0.1	-0.1	0.0	-0.2	-9.3	-0.2	4.0	-179.5	0.0	0.8	-225.8
840	1.5	-27.4	-7.9	-4.8	-0.2	-0.1	-0.1	0.0	-0.2	-9.3	-0.2	4.0	-178.9	0.0	0.8	-222.7
897	1.9	-25.7	-7.9	-4.8	-0.2	-0.1	-0.1	0.0	-0.2	-9.3	-0.2	3.9	-179.0	0.0	0.4	-221.4

Top Node kJ OUT																			
Time (s)	Fe (met)	FeO	Fe2O3	Al2O3	CaO	K2O	MgO	MnO	P2O5	SiO2	TiO2	C	Mullite	H2O	Ar	CO	CO2	kJ OUT	(kJ OUT) - (kJ IN)
0	0.0	-39.5	-18.4	-5.1	-0.2	-0.2	-0.1	0.0	-0.2	-10.0	-0.2	0.0	-192.9	0.0	0.0	0.0	0.0	-266.8	5
120	0.0	-42.6	-11.4	-5.1	-0.2	-0.1	-0.1	0.0	-0.2	-10.0	-0.2	0.4	-191.3	-2.0	3.5	0.0	-1.6	-260.8	10
240	0.1	-39.5	-8.9	-5.0	-0.2	-0.1	-0.1	0.0	-0.2	-9.7	-0.2	1.7	-187.1	-0.9	3.5	-0.1	-1.3	-248.1	14
360	0.4	-35.2	-8.4	-4.9	-0.2	-0.1	-0.1	0.0	-0.2	-9.5	-0.2	2.8	-183.5	-0.4	3.5	-0.2	-1.0	-237.3	11
480	0.8	-32.0	-8.2	-4.8	-0.2	-0.1	-0.1	0.0	-0.2	-9.4	-0.2	3.6	-181.0	-0.4	3.5	-0.4	-0.6	-229.7	9
600	1.2	-29.4	-8.0	-4.8	-0.2	-0.1	-0.1	0.0	-0.2	-9.3	-0.2	4.0	-179.5	0.0	3.5	-0.4	-0.6	-224.0	7
720	1.5	-27.4	-7.9	-4.8	-0.2	-0.1	-0.1	0.0	-0.2	-9.3	-0.2	4.0	-178.9	0.0	3.5	-0.5	-0.3	-220.8	5
840	1.9	-25.7	-7.9	-4.8	-0.2	-0.1	-0.1	0.0	-0.2	-9.3	-0.2	3.9	-179.0	0.0	3.5	-0.5	-0.3	-219.0	4
897	2.0	-25.0	-7.9	-4.8	-0.2	-0.1	-0.1	0.0	-0.2	-9.3	-0.2	3.8	-179.0	0.0	1.7	-0.2	-0.1	-219.6	2

Middle Node mass balance

Middle Node Mass IN								**Mass in (g.)**																
Time (s)	**Middle Node %**	T (°C)	%Reduction	%Fe(total)	%Fe(met)	%Fe(+2)	%Fe(+3)	g. Fe (total)	g. Fe (met)	g. FeO	g. Fe_2O_3	g. Al_2O_3	g. CaO	g. K_2O	g. MgO	g. MnO	g. P_2O_5	g. SiO_2	g. TiO_2	g. C	g. Mullite	g. H_2O	g. Ar	Total g. in
0	33	25	25.6	62.3	0.10	47.5	14.70	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	22.2
120		25	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	22.2
240		50	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	22.2
360		182	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	22.2
480		404	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	22.2
600		652	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	22.2
720		826	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	22.2
840		958	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	22.2
960		1038	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	22.2

Middle Node Mass OUT		**Mass Out:**	15.1	**g. Fe out:**	9.4		**Mass out (g.)**																		
Time (s)	**T (°C)**	%Reduction	%Fe(total)	%Fe(met)	%Fe(+2)	%Fe(+3)	g. Fe (total)	g. Fe (met)	g. FeO	g. Fe_2O_3	g. Al_2O_3	g. CaO	g. K_2O	g. MgO	g. MnO	g. P_2O_5	g. SiO_2	g. TiO_2	g. C	g. Mullite	g. H_2O	g. Ar	g. CO	g. CO_2	Total g. Out
0	25.0	25.6	62.3	0.10	47.5	14.70	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	0	0	22.2
120	50	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	0	0	22.2
240	182	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	0	0	22.2
360	404	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	0	0	22.2
480	652	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	0	0	22.2
600	826	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	0	0	22.2
720	958	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	0	0	22.2
840	1038	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	0	0	22.2
960	1071	25.6	62.3	0.1	47.5	14.7	9.4	0.0	9.2	3.2	0.2	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.1	7.0	0.0	0.0	0	0	22.2

Middle Node heat balance

Middle Node kJ IN															
Time (s)	Fe (met)	FeO	Fe2O3	Al2O3	CaO	K2O	MgO	MnO	P2O5	SiO2	TiO2	C	Mullite	H2O	Ar	Total kJ IN
0	0.0	-33.7	-16.3	-3.7	-0.1	-0.1	-0.1	0.0	-0.2	-7.2	-0.1	0.0	-111.3	0.0	0.0	-172.8
120	0.0	-33.7	-16.3	-3.7	-0.1	-0.1	-0.1	0.0	-0.2	-7.2	-0.1	0.0	-111.3	0.0	0.0	-172.8
240	0.0	-33.5	-16.3	-3.7	-0.1	-0.1	-0.1	0.0	-0.1	-7.2	-0.1	0.0	-111.1	0.0	0.0	-172.4
360	0.0	-32.7	-16.0	-3.7	-0.1	-0.1	-0.1	0.0	-0.1	-7.1	-0.1	0.3	-110.3	0.0	0.0	-170.1
480	0.0	-31.2	-15.4	-3.6	-0.1	-0.1	-0.1	0.0	-0.1	-7.0	-0.1	0.9	-108.7	0.0	0.0	-165.5
600	0.0	-29.4	-14.6	-3.5	-0.1	-0.1	-0.1	0.0	-0.1	-6.9	-0.1	1.8	-106.7	0.0	0.0	-159.9
720	0.0	-28.2	-14.1	-3.5	-0.1	-0.1	-0.1	0.0	-0.1	-6.8	-0.1	2.4	-105.2	0.0	0.0	-155.9
840	0.0	-27.2	-13.7	-3.5	-0.1	-0.1	-0.1	0.0	-0.1	-6.7	-0.1	3.0	-104.1	0.0	0.0	-152.7
960	0.0	-26.6	-13.5	-3.4	-0.1	-0.1	-0.1	0.0	-0.1	-6.7	-0.1	3.3	-103.4	0.0	0.0	-150.8

Middle Node kJ OUT																		
Time (s)	Fe (met)	FeO	Fe2O3	Al2O3	CaO	K2O	MgO	MnO	P2O5	SiO2	TiO2	C	Mullite	H2O	Ar	CO	CO2	Total kJ OUT	(kJ OUT) - (kJ IN)
0	0.0	-33.7	-16.3	-3.7	-0.1	-0.1	-0.1	0.0	-0.2	-7.2	-0.1	0.0	-111.3	0.0	0.0	0.0	0.0	-172.8	0.0
120	0.0	-33.5	-16.3	-3.7	-0.1	-0.1	-0.1	0.0	-0.1	-7.2	-0.1	0.0	-111.1	0.0	0.0	0.0	0.0	-172.4	0.4
240	0.0	-32.7	-16.0	-3.7	-0.1	-0.1	-0.1	0.0	-0.1	-7.1	-0.1	0.3	-110.3	0.0	0.0	0.0	0.0	-170.1	2.3
360	0.0	-31.2	-15.4	-3.6	-0.1	-0.1	-0.1	0.0	-0.1	-7.0	-0.1	0.9	-108.7	0.0	0.0	0.0	0.0	-165.5	4.5
480	0.0	-29.4	-14.6	-3.5	-0.1	-0.1	-0.1	0.0	-0.1	-6.9	-0.1	1.8	-106.7	0.0	0.0	0.0	0.0	-159.9	5.6
600	0.0	-28.2	-14.1	-3.5	-0.1	-0.1	-0.1	0.0	-0.1	-6.8	-0.1	2.4	-105.2	0.0	0.0	0.0	0.0	-155.9	4.1
720	0.0	-27.2	-13.7	-3.5	-0.1	-0.1	-0.1	0.0	-0.1	-6.7	-0.1	3.0	-104.1	0.0	0.0	0.0	0.0	-152.7	3.1
840	0.0	-26.6	-13.5	-3.4	-0.1	-0.1	-0.1	0.0	-0.1	-6.7	-0.1	3.3	-103.4	0.0	0.0	0.0	0.0	-150.8	1.9
960	0.0	-26.3	-13.4	-3.4	-0.1	-0.1	-0.1	0.0	-0.1	-6.7	-0.1	3.4	-103.1	0.0	0.0	0.0	0.0	-150.0	0.8

Bottom Node mass balance

Bottom Node Mass IN								Mass in (g.)																
Time (s)	Bottom Node %	T (°C)	%Reduction	%Fe(total)	%Fe(met)	%Fe(+2)	%Fe(+3)	g. Fe (total)	g. Fe (met)	g. FeO	g. Fe2O3	g. Al2O3	g. CaO	g. K2O	g. MgO	g. MnO	g. P2O5	g. SiO2	g. TiO2	g. C	g. Mullite	g. H2O	g. Ar	Total g. in
0	21	25	24.7	58.5	0.20	42.8	15.50	5.5	0.0	5.2	2.1	0.1	0.01	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	22.4
57		25	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	22.4
146		56	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	22.4
241		150	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	22.4
340		265	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	22.4
448		386	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	22.4
522		546	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	22.4
616		711	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	22.4
713		822	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	22.4

Bottom Node Mass OUT		Mass Out:	9.5	g. Fe out:	5.5		Mass out (g.)																		
Time (s)	T (°C)	%Reduction	%Fe(total)	%Fe(met)	%Fe(+2)	%Fe(+3)	g. Fe (total)	g. Fe (met)	g. FeO	g. Fe2O3	g. Al2O3	g. CaO	g. K2O	g. MgO	g. MnO	g. P2O5	g. SiO2	g. TiO2	g. C	g. Mullite	g. H2O	g. Ar	g. CO	g. CO2	Total g. Out
0	25.0	24.7	58.5	0.20	42.8	15.50	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	0	0	22.4
57	56	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	0	0	22.4
146	150	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	0	0	22.4
241	265	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	0	0	22.4
340	386	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	0	0	22.4
448	546	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	0	0	22.4
522	711	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	0	0	22.4
616	822	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	0	0	22.4
713	874	24.7	58.5	0.2	42.8	15.5	5.5	0.0	5.2	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0	1.3	13.2	0.0	0.0	0	0	22.4

Bottom Node heat balance

Bottom Node kJ IN															
Time (s)	Fe (met)	FeO	Fe2O3	Al2O3	CaO	K2O	MgO	MnO	P2O5	SiO2	TiO2	C	Mullite	H2O	Ar	kJ IN
0	0.0	-19.1	-10.8	-2.4	-0.1	-0.1	0.0	0.0	-0.1	-4.6	-0.1	0.0	-211.6	0.0	0.0	-248.8
57	0.0	-19.1	-10.8	-2.4	-0.1	-0.1	0.0	0.0	-0.1	-4.6	-0.1	0.0	-211.6	0.0	0.0	-248.8
146	0.0	-18.9	-10.8	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.6	-0.1	0.0	-211.3	0.0	0.0	-248.3
241	0.0	-18.6	-10.6	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.6	-0.1	0.1	-210.2	0.0	0.0	-246.5
340	0.0	-18.2	-10.4	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.5	-0.1	0.3	-208.7	0.0	0.0	-244.2
448	0.0	-17.7	-10.2	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.5	-0.1	0.6	-207.0	0.0	0.0	-241.5
522	0.0	-17.1	-9.9	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.4	-0.1	0.9	-204.5	0.0	0.0	-237.7
616	0.0	-16.4	-9.5	-2.2	-0.1	-0.1	0.0	0.0	-0.1	-4.4	-0.1	1.3	-202.0	0.0	0.0	-233.6
713	0.0	-15.9	-9.3	-2.2	-0.1	-0.1	0.0	0.0	-0.1	-4.3	-0.1	1.5	-200.2	0.0	0.0	-230.8

Bottom Node kJ OUT																			
Time (s)	Fe (met)	FeO	Fe2O3	Al2O3	CaO	K2O	MgO	MnO	P2O5	SiO2	TiO2	C	Mullite	H2O	Ar	CO	CO2	kJ OUT	(kJ OUT) - (kJ IN)
0	0.0	-19.1	-10.8	-2.4	-0.1	-0.1	0.0	0.0	-0.1	-4.6	-0.1	0.0	-211.6	0.0	0.0	0.0	0.0	-248.8	0.0
57	0.0	-18.9	-10.8	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.6	-0.1	0.0	-211.3	0.0	0.0	0.0	0.0	-248.3	0.5
146	0.0	-18.6	-10.6	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.6	-0.1	0.1	-210.2	0.0	0.0	0.0	0.0	-246.5	1.7
241	0.0	-18.2	-10.4	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.5	-0.1	0.3	-208.7	0.0	0.0	0.0	0.0	-244.2	2.4
340	0.0	-17.7	-10.2	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.5	-0.1	0.6	-207.0	0.0	0.0	0.0	0.0	-241.5	2.7
448	0.0	-17.1	-9.9	-2.3	-0.1	-0.1	0.0	0.0	-0.1	-4.4	-0.1	0.9	-204.5	0.0	0.0	0.0	0.0	-237.7	3.8
522	0.0	-16.4	-9.5	-2.2	-0.1	-0.1	0.0	0.0	-0.1	-4.4	-0.1	1.3	-202.0	0.0	0.0	0.0	0.0	-233.6	4.1
616	0.0	-15.9	-9.3	-2.2	-0.1	-0.1	0.0	0.0	-0.1	-4.3	-0.1	1.5	-200.2	0.0	0.0	0.0	0.0	-230.8	2.8
713	0.0	-15.7	-9.2	-2.2	-0.1	-0.1	0.0	0.0	-0.1	-4.3	-0.1	1.7	-199.3	0.0	0.0	0.0	0.0	-229.5	1.3

Time (s)	kJ Out - kJ In Top	kJ Out - kJ In Middle	kJ Out - kJ In Bottom	Incremental kJ
120	10	0	1	11
240	14	2	2	18
360	11	5	2	18
480	9	6	3	17
600	7	4	4	15
720	5	3	4	12
840	4	2	3	8
897	2	1	1	4
Total Incremental kJ:				103
Weighted Average kW/m^2:				163

Appendix VII
Mass and Heat Balance equations

(a) Mass balance equations

$m_j^{i\_in}$ = mass of component *j* in node *i* of unreacted sample

$m_j^{i\_out}$ = mass of component *j* in node *i* of reacted sample

$m_{j\_corr}^{i\_out}$ = corrected mass of component *j* in node *i* of reacted sample

m_{total}^{in} = total g. unreacted sample mix in crucible

$\%Y^{i\_in}$ = mass% of component *Y* in node *i* of unreacted sample

$\%Y^{i\_out}$ = mass% of component *Y* in node *i* of reacted sample

$\%Y_{corr}^{i\_out}$ = corrected mass% of component *Y* in node *i* of reacted sample

mm_k = molar mass of component *k*

X_i = mass fraction of sample material mix in node *i*, *i* = top, mid, bot for top, middle or bottom node

i = top, mid, bot for top, middle or bottom node

$n_{j\_phase}^{i\_out}$ = mol of component *j* in node *i* of reacted sample in a phase

Correction of reacted mass out for fibreboard carry over to top node reacted sample mix:

$$m_{total}^{top\_in} = m_{total}^{in} \cdot X_{top}$$

$$m_{Al_2O_3}^{carry-over} = m_{total}^{top\_out} \cdot \frac{\%Al_2O_3^{top\_out}}{100} - m_{total}^{top\_in} \cdot \frac{\%Al_2O_3^{top\_in}}{100}$$

$$m_{SiO_2}^{carry-over} = m_{total}^{top\_out} \cdot \frac{\%SiO_2^{top\_out}}{100} - m_{total}^{top\_in} \cdot \frac{\%SiO_2^{top\_in}}{100}$$

$$m_{Al_2O_3\_corr}^{top\_out} = m_{total}^{top\_in} - m_{Al_2O_3}^{carry-over} - m_{SiO_2}^{carry-over}$$

$m_{Al_2O_3}^{carry-over}$ = g. Al_2O_3 carry-over from fibreboard to reacted sample mix in top node

$m_{SiO_2}^{carry-over}$ = g. SiO_2 carry-over from fibreboard to reacted sample mix in top node

m_{total}^{in} = total g. unreacted sample mix in crucible

The fibreboard carry-over calculations for the middle and bottom node are done in the same manner.

Correction of fibreboard crucible mass, in top node section, for fibreboard carry-over to top node reacted sample mix:

$$m_{FB\_corr}^{top\_out} = m_{FB}^{top\_out} + m_{Al_2O_3}^{carry-over} + m_{SiO_2}^{carry-over}$$

$m_{Al_2O_3}^{carry-over}$ = g. Al_2O_3 carry-over from fibreboard to reacted sample mix in top node

$m_{SiO_2}^{carry-over}$ = g. SiO_2 carry-over from fibreboard to reacted sample mix in top node

The fibreboard mass correction calculations for the middle and bottom node are done in the same manner.

Correction of FeO analyses for top node for fibreboard carry-over to top node reacted sample mix:

$$m_{FeO}^{top\_out} = m_{total}^{top\_out} \cdot \frac{\%FeO^{top\_out}}{100}$$

$$\%FeO_{corr}^{top\_out} = \frac{m_{FeO}^{top\_out}}{m_{total\_corr}^{top\_out}} \cdot 100$$

$$\%Fe(+2)_{corr}^{top\_out} = \frac{m_{FeO}^{top\_out}}{m_{total\_corr}^{top\_out}} \cdot 100 / mm_{FeO} \cdot mm_{Fe}$$

Similarly the corrected mass% of C, Fe_2O_3, Fe metal, Fe(total) can be calculated. The calculations are done for the top, middle and bottom nodes.

Calculation of mass FeO into top node material mix

$$m_{FeO}^{top\_in} = m_{total\_corr}^{top\_out} \cdot \frac{\%Fe(+2)^{top\_in}}{Fe(total)^{top\_in}} \cdot \frac{\%Fe(total)_{corr}^{top\_out}}{100} / mm_{Fe} \cdot mm_{FeO}$$

$$m_{FeO}^{top\_out} = m_{total\_corr}^{top\_out} \cdot \frac{\%Fe(+2)_{corr}^{top\_out}}{100} / mm_{Fe} \cdot mm_{FeO}$$

Calculation of CaO into top node material mix

$$m_{CaO}^{top\_out} = m_{CaO}^{top\_in} = m_{total}^{top\_in} \cdot \frac{\%CaO^{top\_in}}{100}$$

$$m_{total}^{top\_in} = m_{total}^{in} \cdot X_{top}$$

Fe balance calculation to check Fe mass accounting

$$m_{Fe}^{total\_in} = m_{total}^{in} \cdot \frac{\%"FeO"^{total\_in}}{100} \cdot \frac{\%Fe(total)^{total\_in}}{100}$$

$\%"FeO"$ = mass% pre-reduced ore in sample mix

$$m_{Fe}^{total\_out} = m_{corr}^{top\_out} \cdot \frac{\%Fe(total)_{corr}^{top\_out}}{100} + m_{corr}^{mid\_out} \cdot \frac{\%Fe(total)_{corr}^{mid\_out}}{100} + m_{corr}^{bot\_out} \cdot \frac{\%Fe(total)_{corr}^{bot\_out}}{100}$$

$$\frac{m_{Fe}^{total\_in}}{m_{Fe}^{total\_out}} \approx 1$$

C balance

$$m_{C}^{top\_in} = m_{total}^{top\_in} \cdot \frac{\%Graphite^{total\_in}}{100} \cdot \frac{\%C^{total\_in}}{100}$$

$$m_{total}^{top\_in} = m_{total}^{in} \cdot X_{top}$$

$$m_{C}^{top\_out} = m_{C}^{top\_in} - (n_{CO\_gas}^{top\_out} + n_{CO_2\_gas}^{top\_out}) \cdot mm_C$$

$\%Graphite^{total\_in}$ = mass% graphite in sample mix

$\%C^{total\_in}$ = %C in graphite

O balance

$$n_{O\_gas}^{top\_out} = m_{FeO}^{top\_in} / mm_{FeO} + m_{Fe_2O_3}^{top\_in} / mm_{Fe_2O_3} \cdot 3 - m_{FeO}^{top\_out} / mm_{FeO} - m_{Fe_2O_3}^{top\_out} / mm_{Fe_2O_3} \cdot 3$$

$$\frac{n_{CO\_gas}^{top\_out}}{n_{CO\_gas}^{top\_out} + n_{CO_2\_gas}^{top\_out}} = r / 100$$

$$n_{CO\_gas}^{top\_out} + 2 \cdot n_{CO_2\_gas}^{top\_out} = n_{O\_gas}^{top\_out}$$

$$n_{CO_2\_gas}^{top\_out} = n_{O\_gas}^{top\_out} \cdot (1-r)/(2-r)$$

$r = \frac{\%CO}{\%CO + \%CO_2}$ in product gas analysis

(b) Heat balance equations

$C_p(T) = A + BT + C/T^2 + DT^2$ [J/mol K]

$$\Delta H = \int_{T_1}^{T_2} C_p dT + \Delta H_{T_1} = A \cdot (T_2 - T_1) + B/2 \cdot (T_2^2 - T_1^2) - C/(T_2 - T_1) + D/3 \cdot (T_2^3 - T_1^3)$$

The $C_p(T)$ equations were obtained from Kubashewski *et al.* (1993).

$\Delta J_{total}^{top} = \sum \Delta H_j^{top} \cdot n_j^{top\_out} - \sum \Delta H_j^{top} \cdot n_j^{top\_in}$ [J]

$\Delta J_{total} = \Delta J_{total}^{top} + \Delta J_{total}^{mid} + \Delta J_{total}^{bot}$ [J]

$\Delta W_{total} = \Delta J_{total} / 6000 \cdot t$ [kW]

$q_{HM} = \frac{\Delta W_{total}}{A_4}$ [kW/m^2]

$C_p(T)$ = heat capacity of component at constant pressure

ΔH = change in enthalpy of component material when heated from T_1 to T_2

t = total reaction time in minutes

q_{HM} = heat transfer to sample as calculated in heat-mass balance

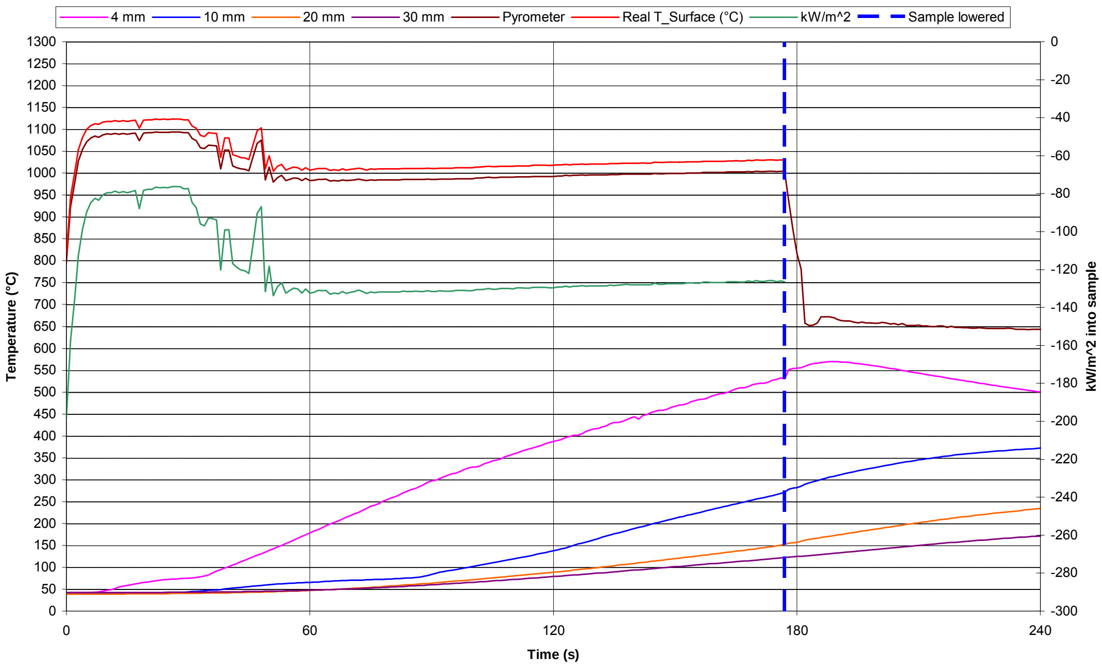
The enthalpy equation parameters used are shown below:

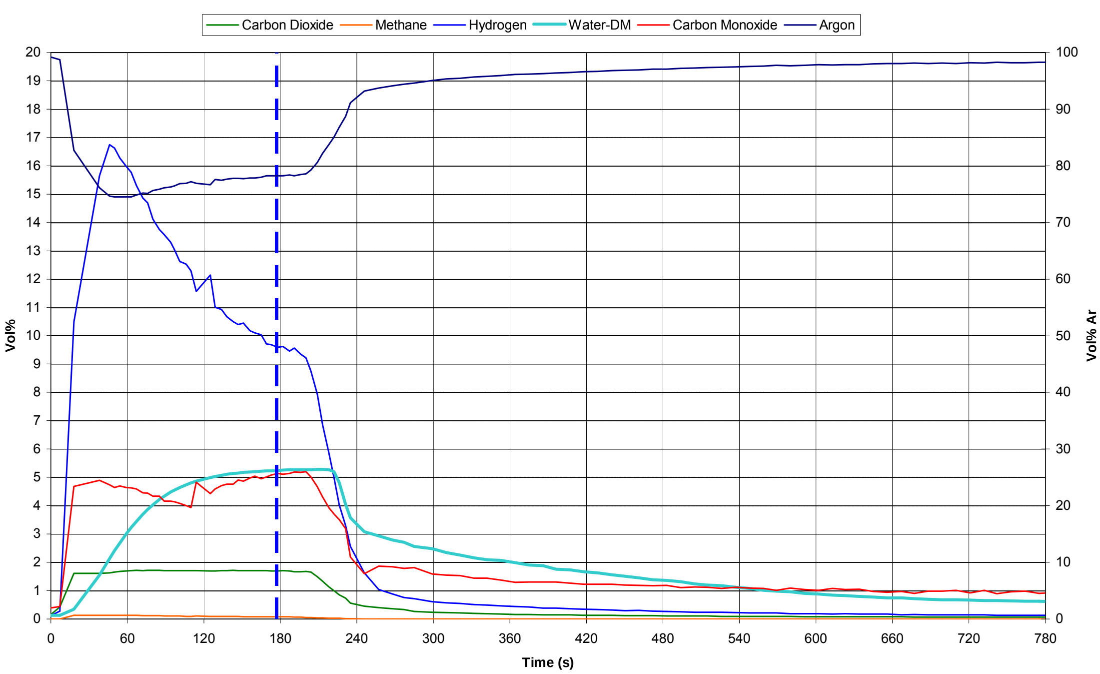
Component	$\Delta H_{T_1} [J/mol]$	$T_1[K]$	$T_2[K]$	[J/deg mol]			
				A	$B \cdot 10^3$	$C \cdot 10^{-5}$	$D \cdot 10^6$
Fe_2O_3	-823400	298	950	98.28	77.82	-14.85	---
	-731081	950	1050	150.62	---	---	---
	-716019	>=1050		132.67	7.36	---	---
Fe_3O_4	-1108800	298	900	91.55	202	---	---
	-980846	>=900		213.4	---	---	---
FeO	-263000	>=298		48.79	8.37	-2.8	---
Fe	0	298	800	28.18	-7.32	-2.9	---
	15571	800	1000	-263.45	255.81	619.23	---
	24408	1000	1042	-641.91	696.34	---	---
	27308	1042	1060	1946.25	-1787.5	---	---
	28525	1060	1184	-561.95	334.13	2912.11	---
	35002	1184	1665	23.99	8.36	---	---
	53069	1665	1809	24.64	9.9	---	---
	72893	1809	2000	46.02	---	---	---
SiO_2	-908300	298	540	46.9	31.51	-10.08	---
	-893971	540	2000	71.63	1.88	-39.06	---
	-781586	>=2000		86.19	---	---	---
Al_2O_3	-1675700	298	2325	117.49	10.38	-37.11	---
CaO	-634900	298	2900	50.42	4.18	-8.49	---
MgO	-601600	298	3105	48.99	3.43	11.34	---
CO	-110500	>=298		28.41	4.1	-0.46	---
CO_2	-393500	>=298		44.14	9.04	-8.54	---
C(graphite)	0	298	1100	0.11	38.94	-1.48	---
	13998	>=1100		24.43	0.44	-31.63	---
MnO	-384900	298	2058	46.48	8.12	-3.68	---
H_2	0	298		27.37	3.33	---	---
H_2O (liquid)	-285800	>=298		75.44	---	---	---
H_2O (gas)	-241800	>=298		30	10.71	0.33	---
TiO_2	-944000	>=298		73.35	3.05	-17.03	---
Na_2O	-415100	298	1023	55.48	70.21	-4.14	-30.54
	-351070	1023	1243	82.3	12.76	---	---
	-317883	1243	1405	84.85	10.71	---	---
	-254140	>=1405		104.6	---	---	---
K_2O	-363200	>=298		95.65	-4.94	-11.05	23.68
P_2O_5	-1505000	>=298		74.89	162.34	-15.61	---
Mullite ($3Al_2O_3.2SiO_2$)	-6820800	298	600	233.59	633.88	-55.86	385.77
	-6698110	600		503.46	35.1	-230.12	-2.51

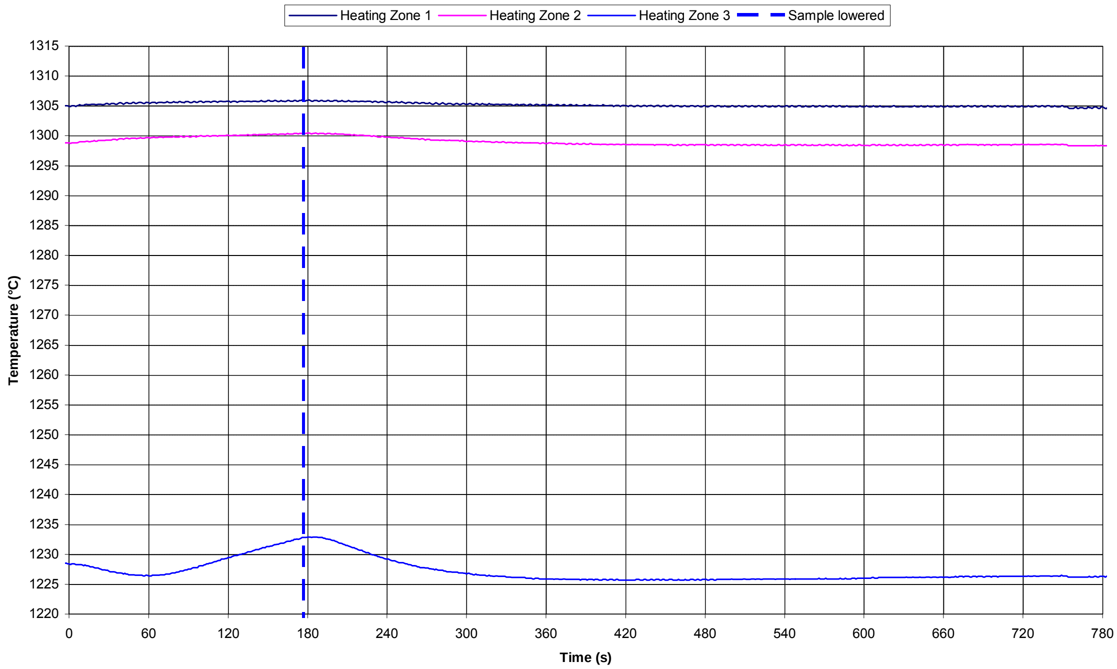
$C_p(T)$ of Argon taken as 20.786 J/mol K from Chase, M.W., Jr., *NIST-JANAF Thermochemical Tables, Fourth Edition*, 1998. American Institute of Physics, Woodbury, New York.

Appendix VIII: Experimental data graphs

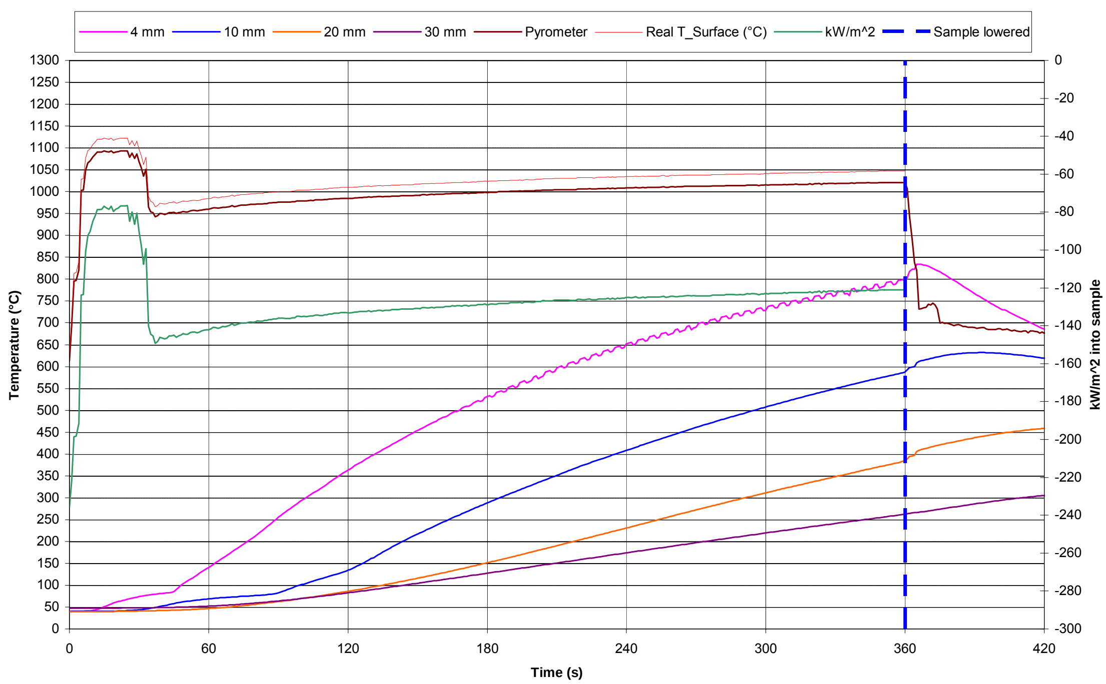
Coal-Ore; 40mm layer, 1300°C, 3minutes

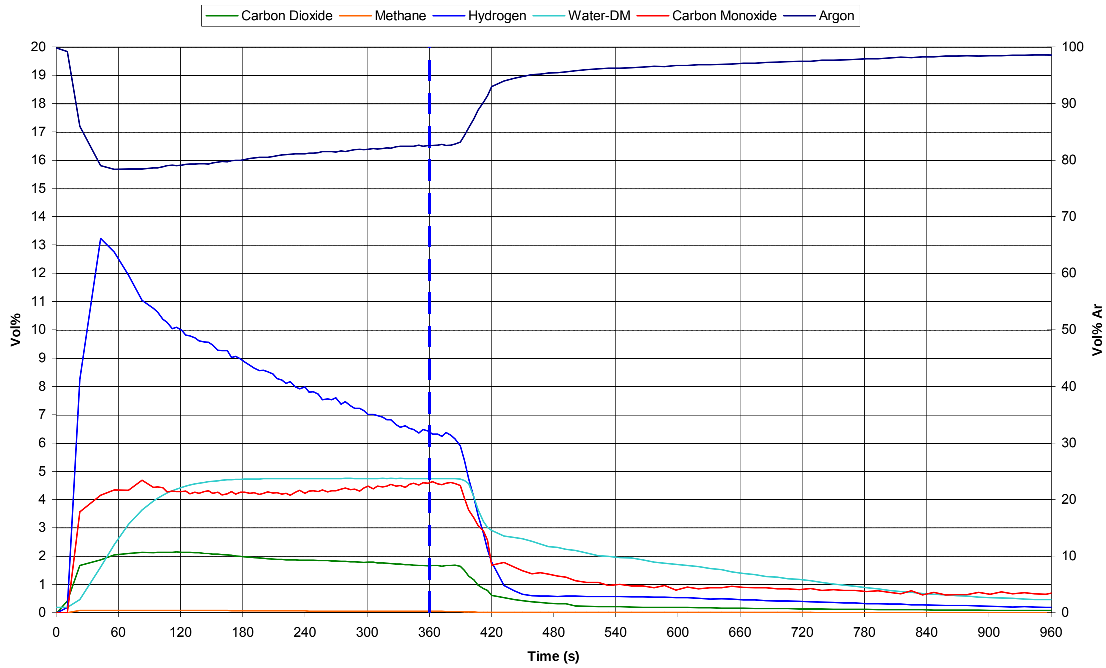




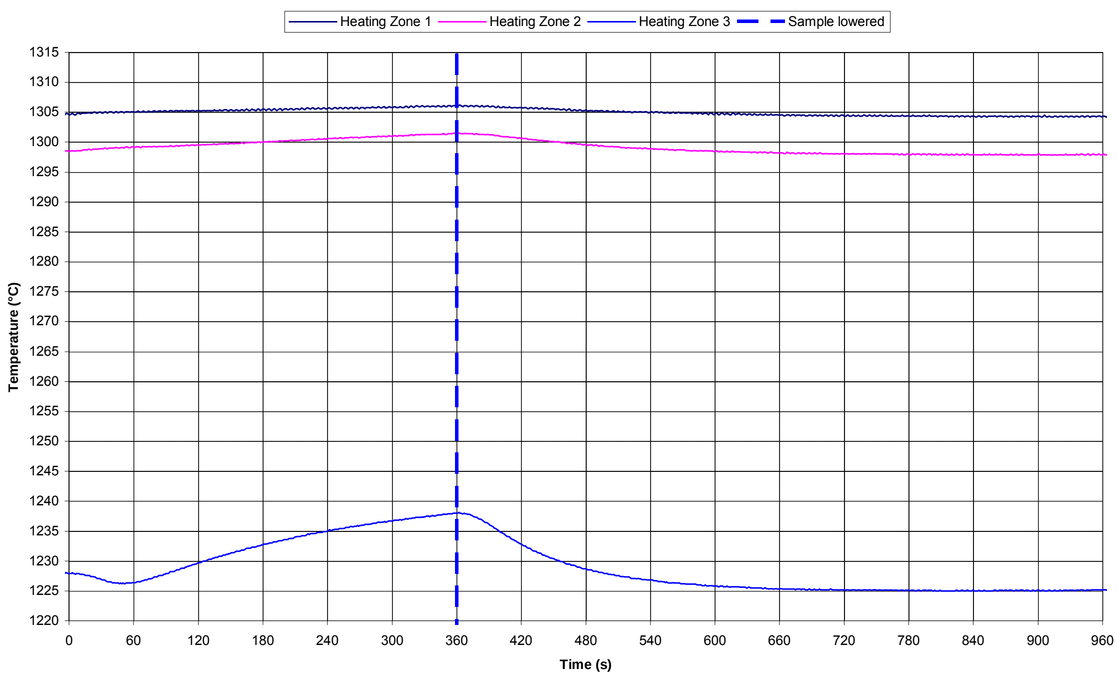


Coal-Ore; 40mm layer, 1300°C, 6minutes



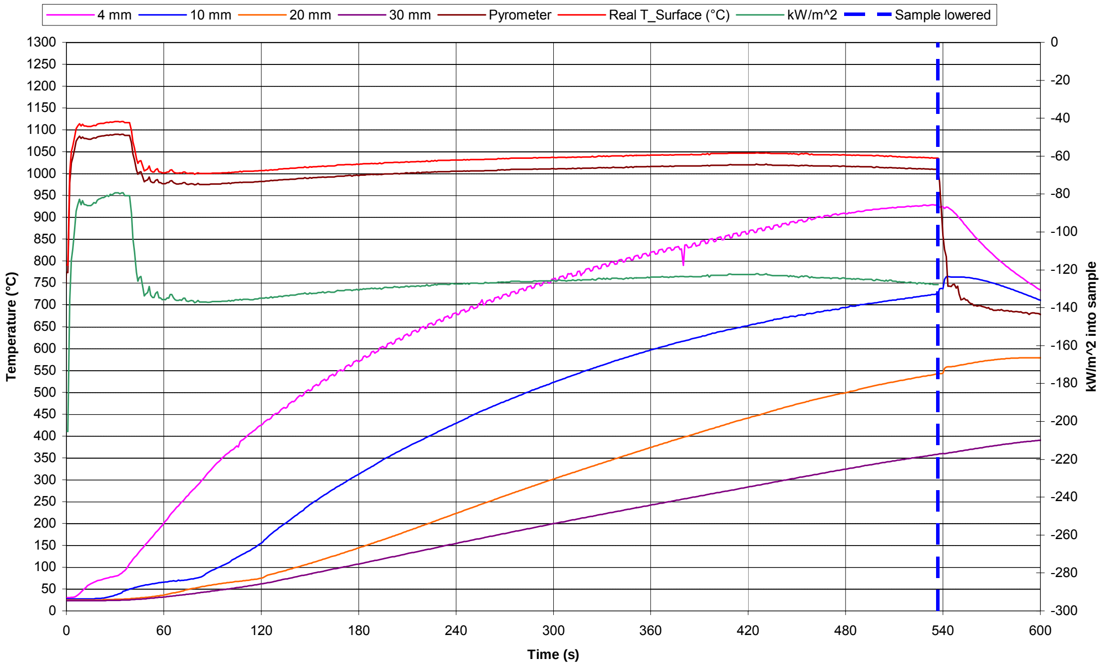


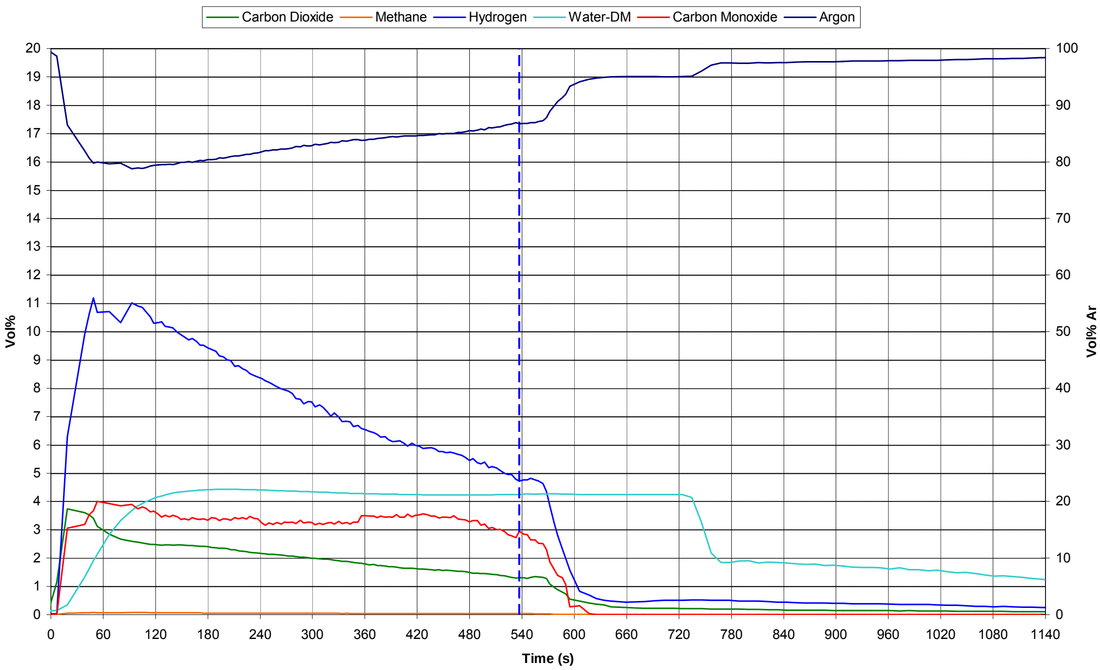
Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Argon
Vol%
Vol% Ar
Time (s)

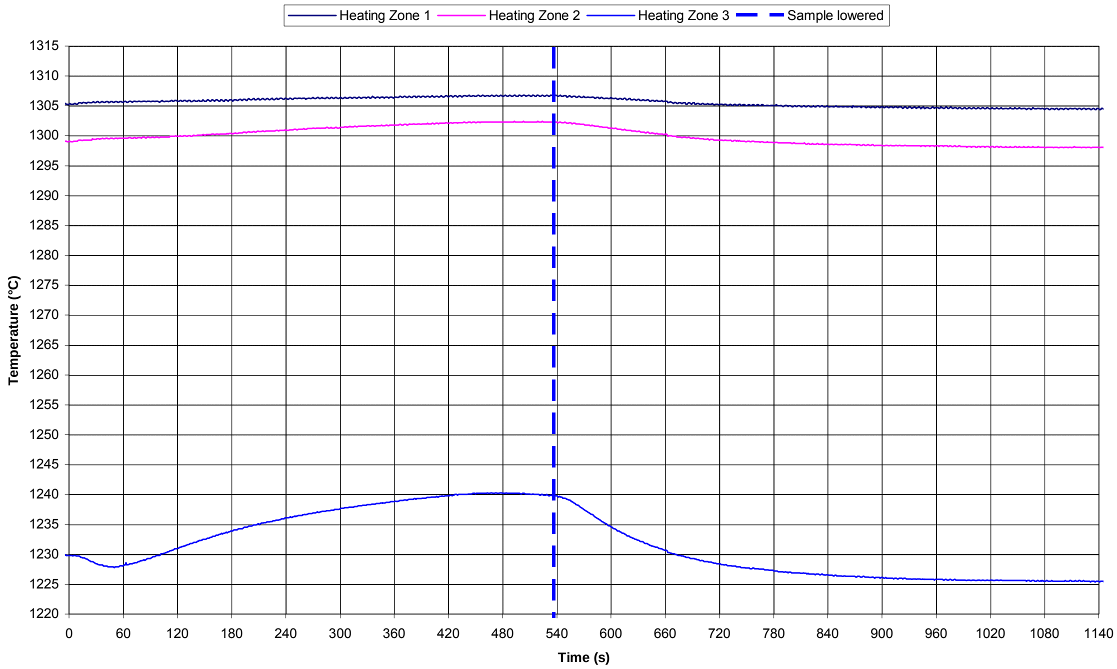


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

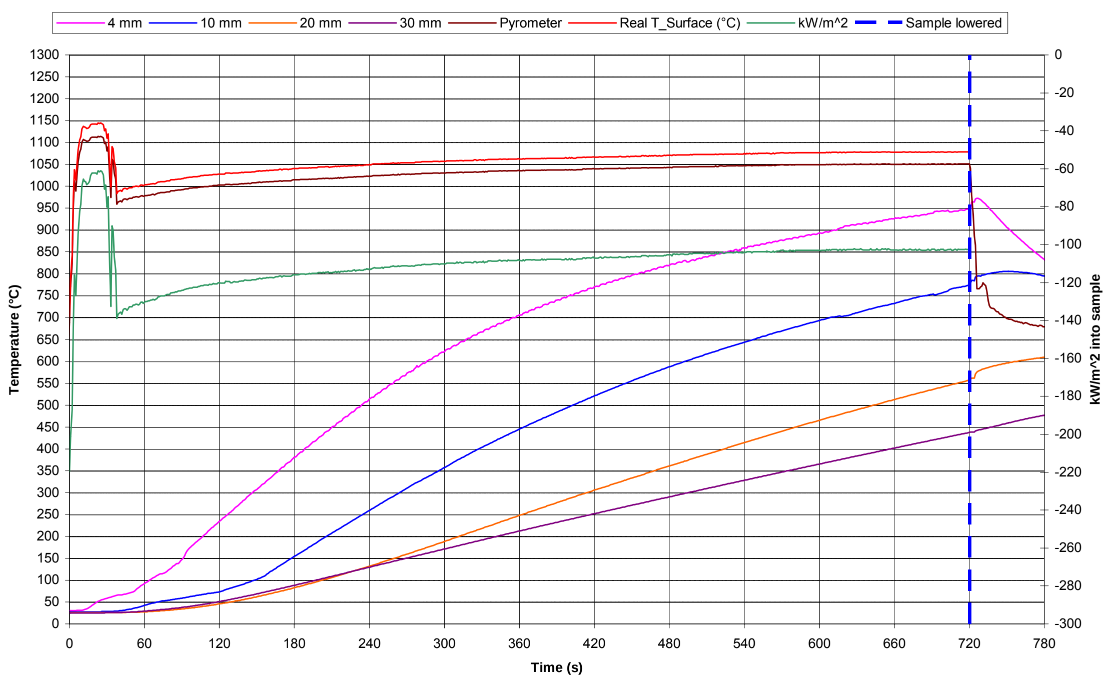
Coal-Ore; 40mm layer, 1300°C, 9minutes

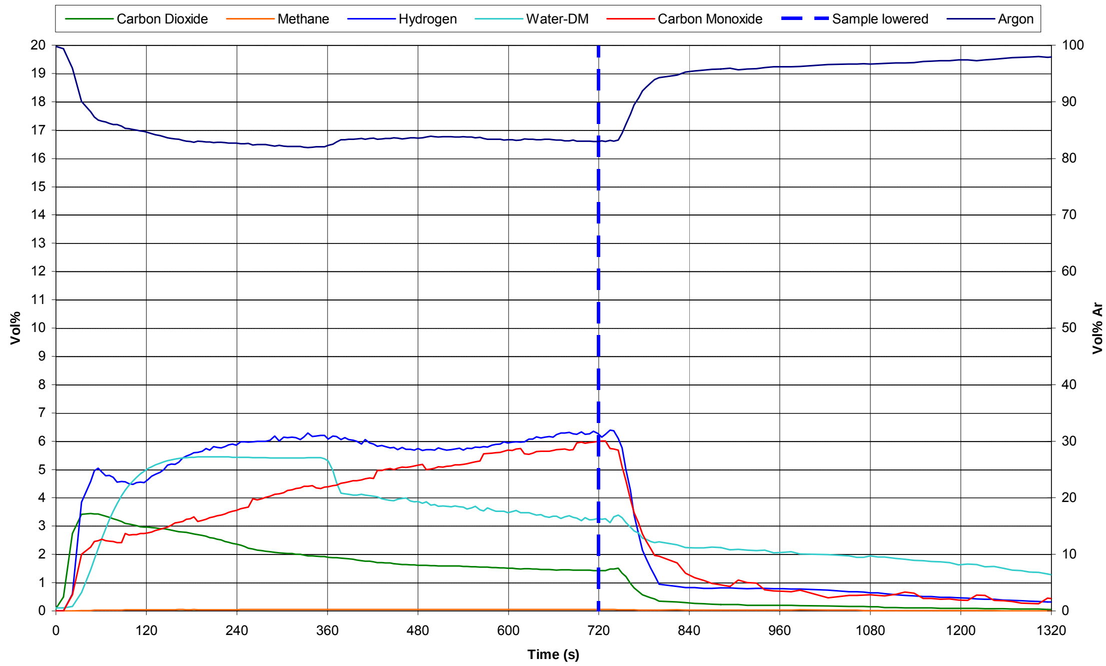


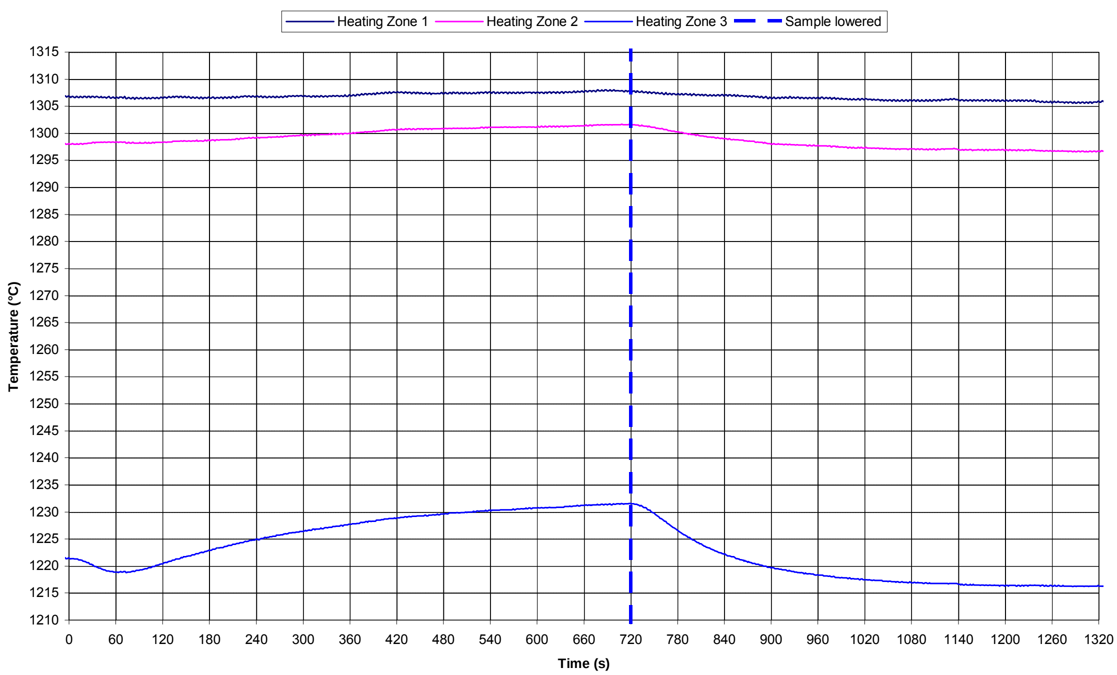




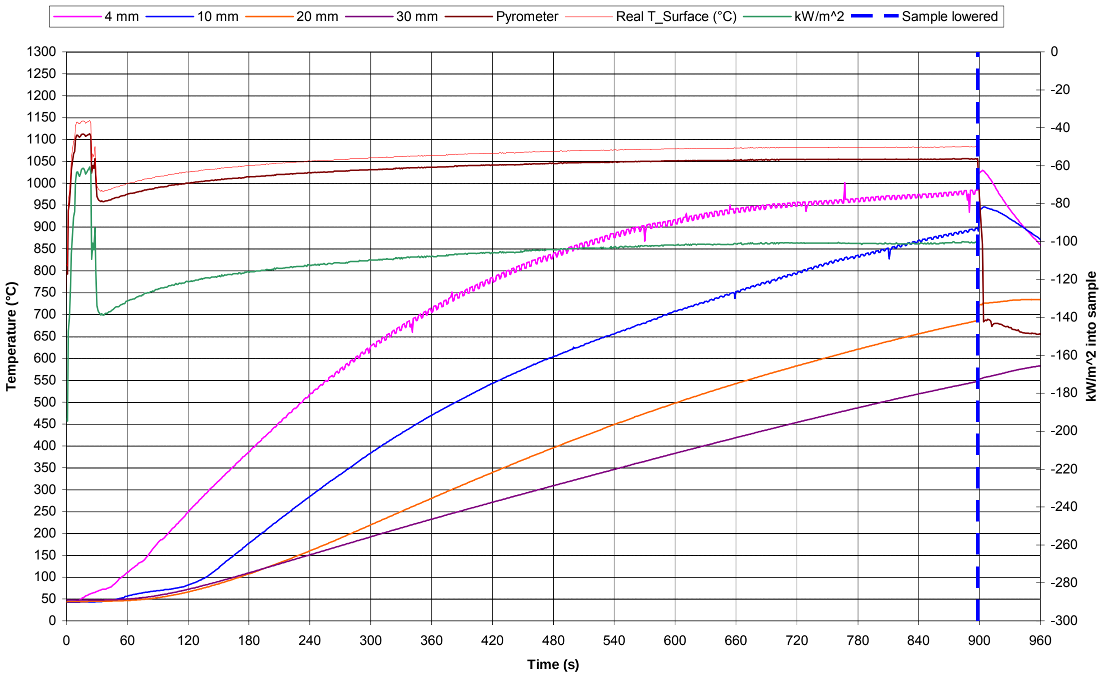
Coal-Ore; 40mm layer, 1300°C, 12minutes

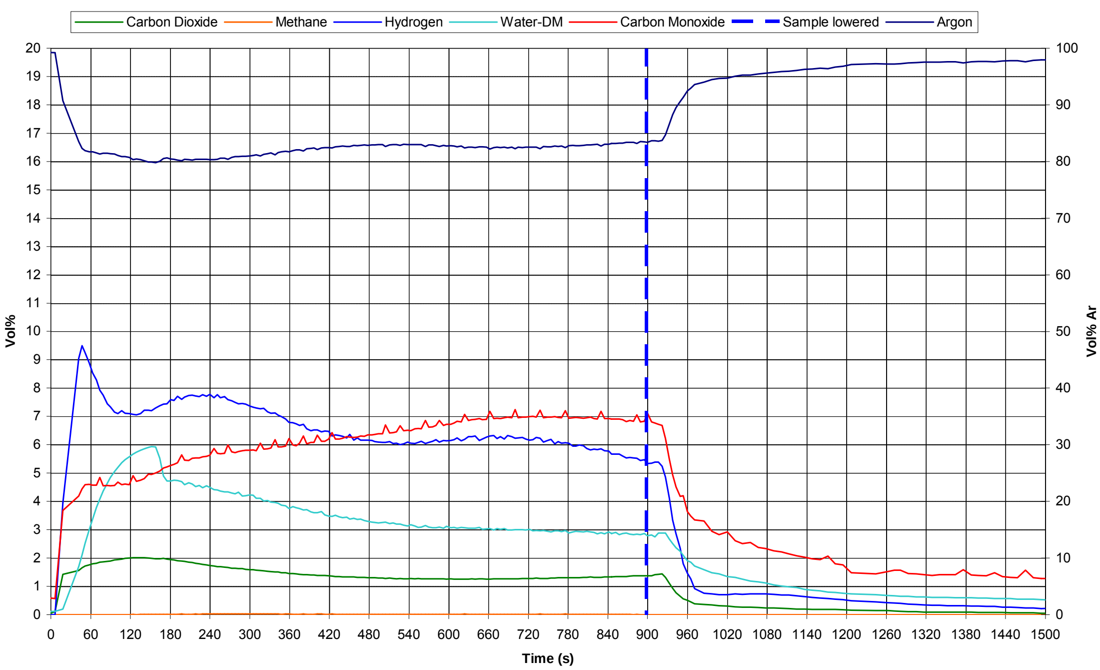


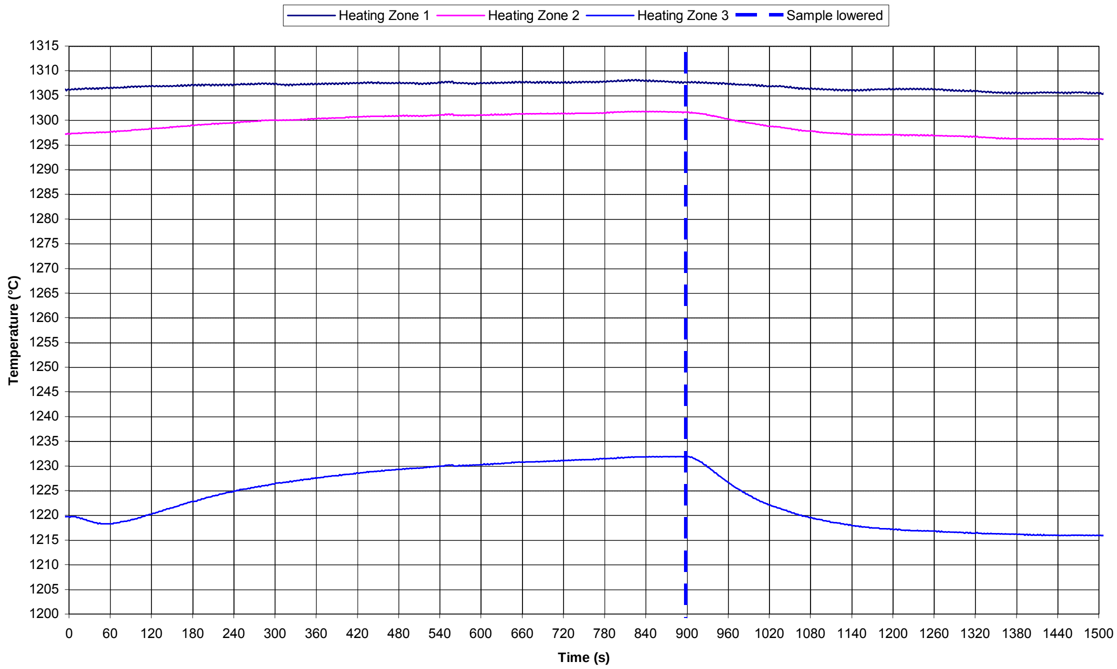

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Sample lowered
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

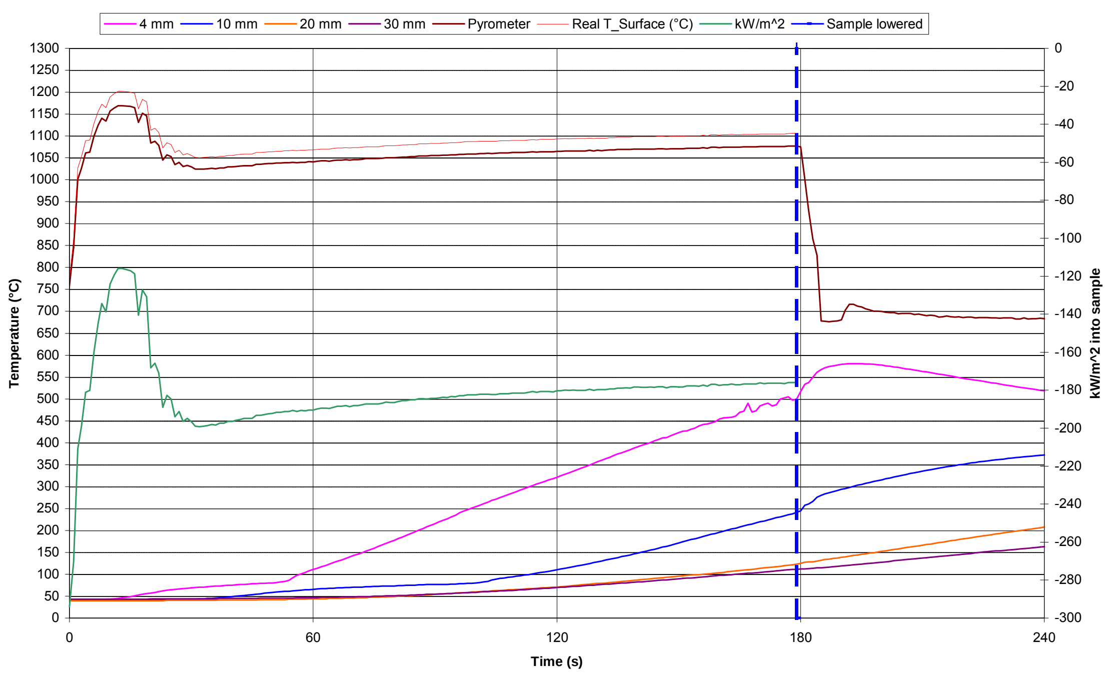
Coal-Ore; 40mm layer, 1300°C, 15minutes

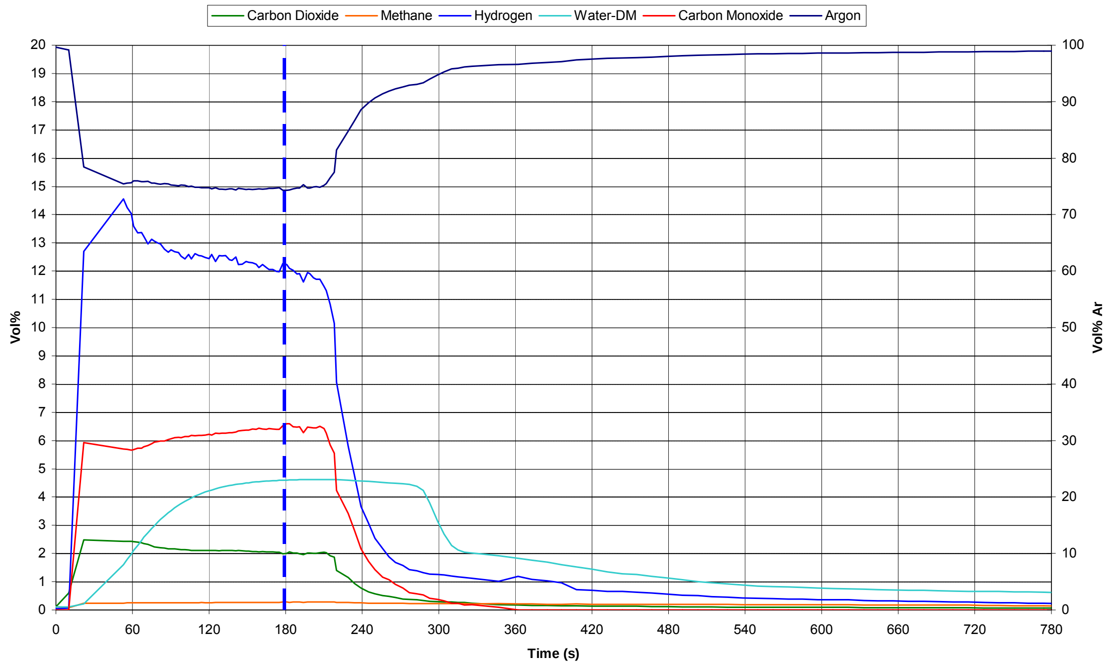


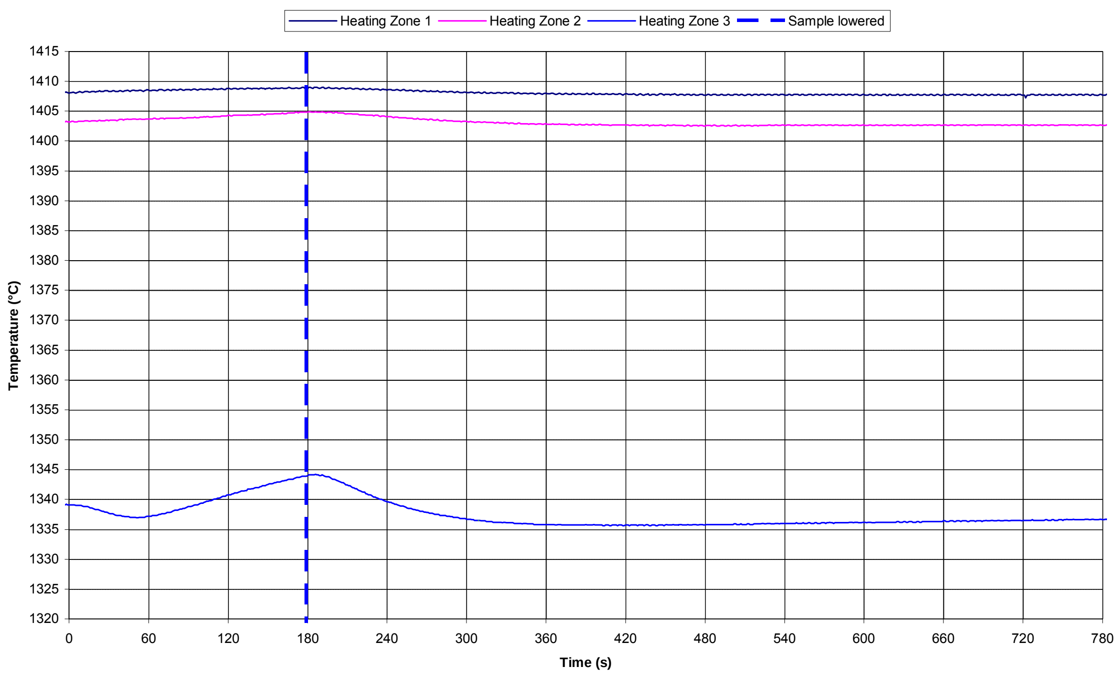




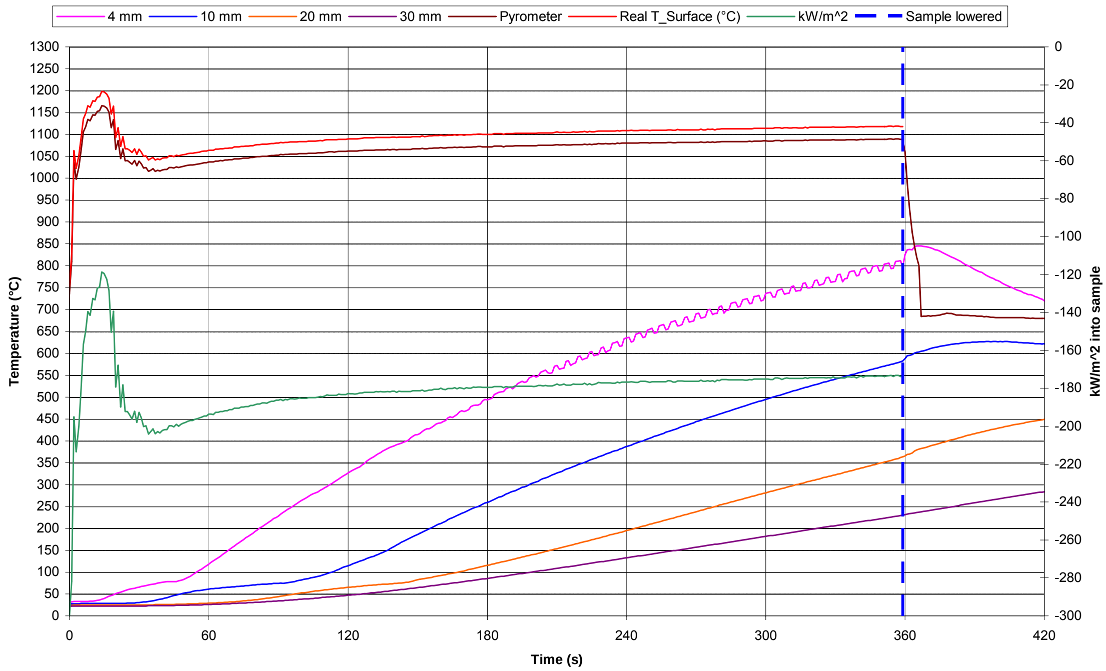
Coal-Ore; 40mm layer, 1400°C, 3minutes

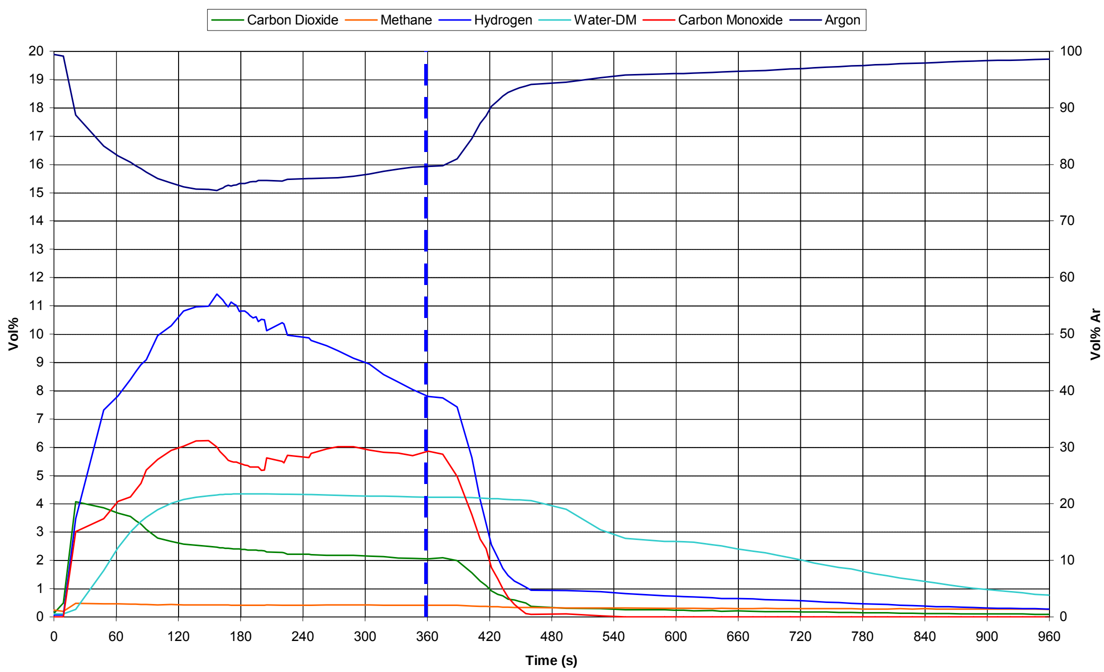


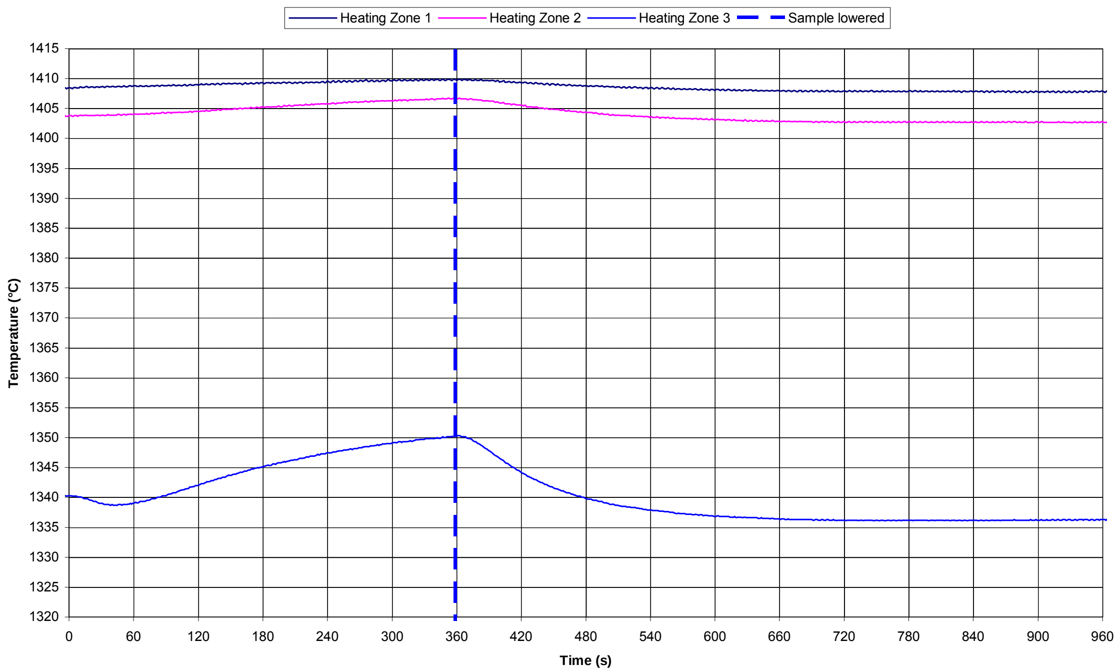

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

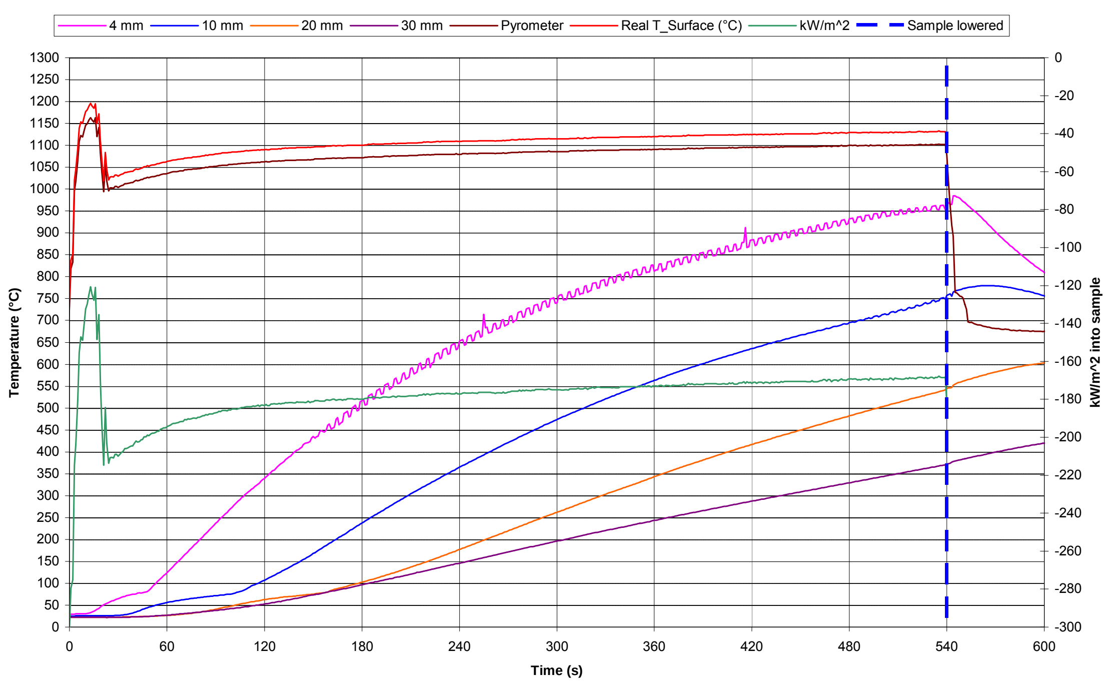
Coal-Ore; 40mm layer, 1400°C, 6minutes

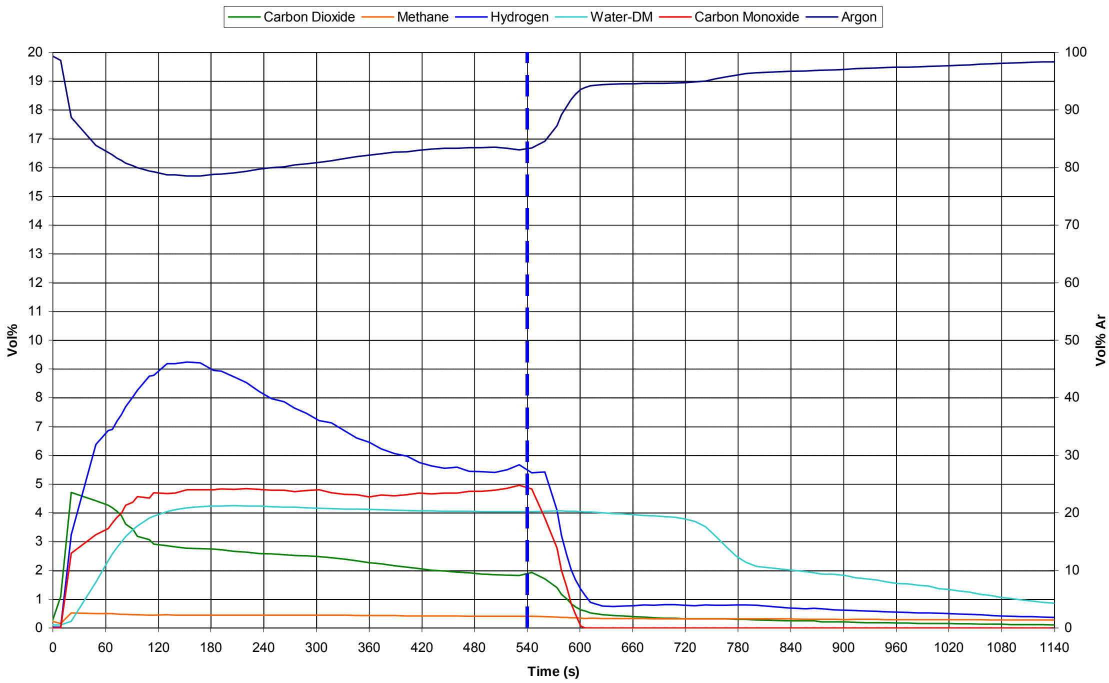




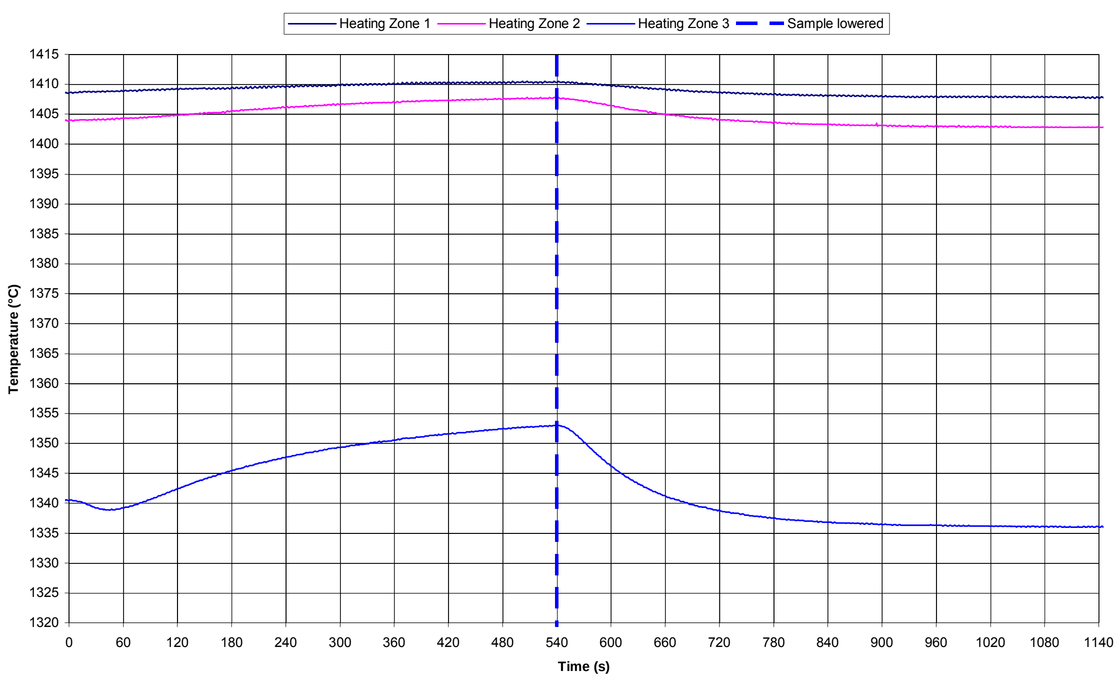


Coal-Ore; 40mm layer, 1400°C, 9minutes



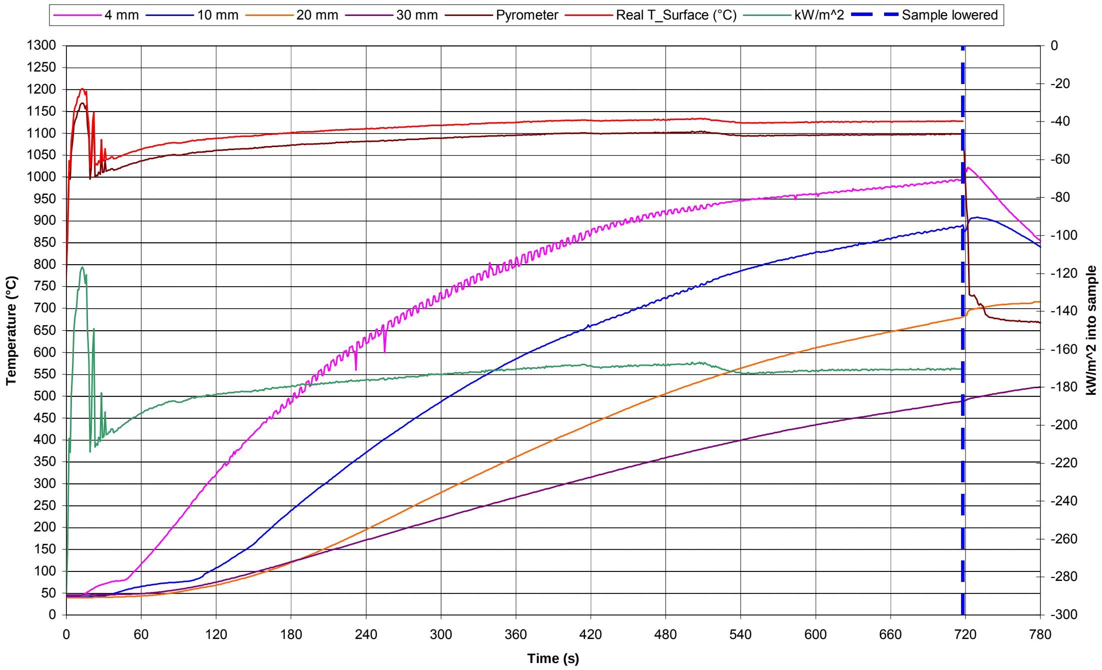


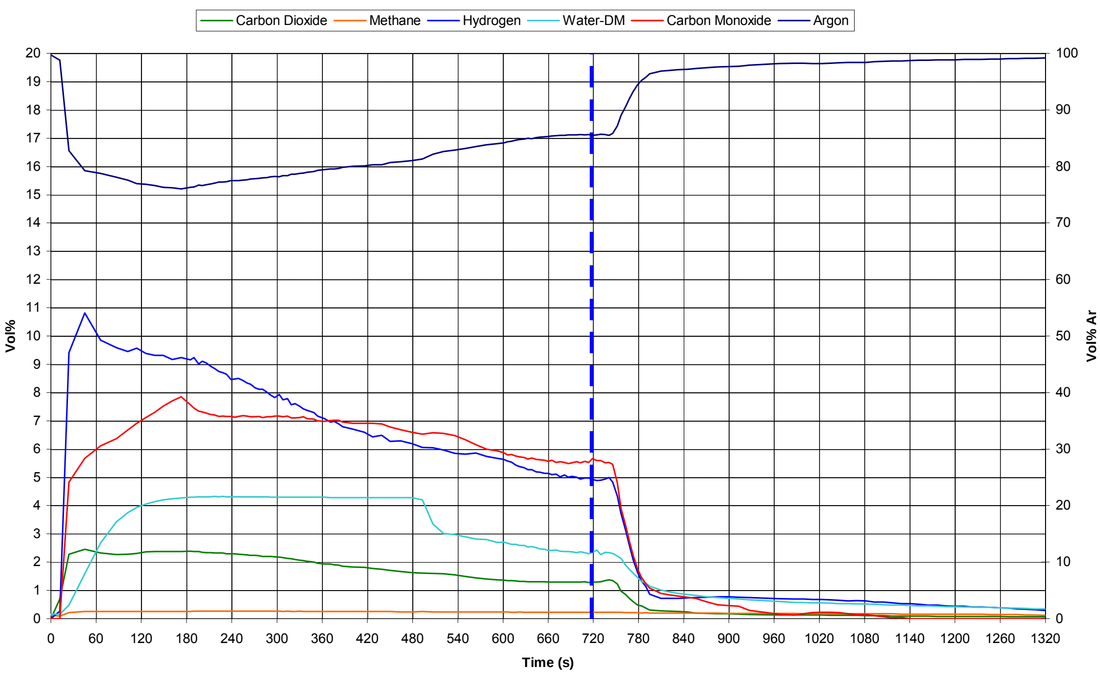
Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Argon
Vol%
Vol% Ar
Time (s)

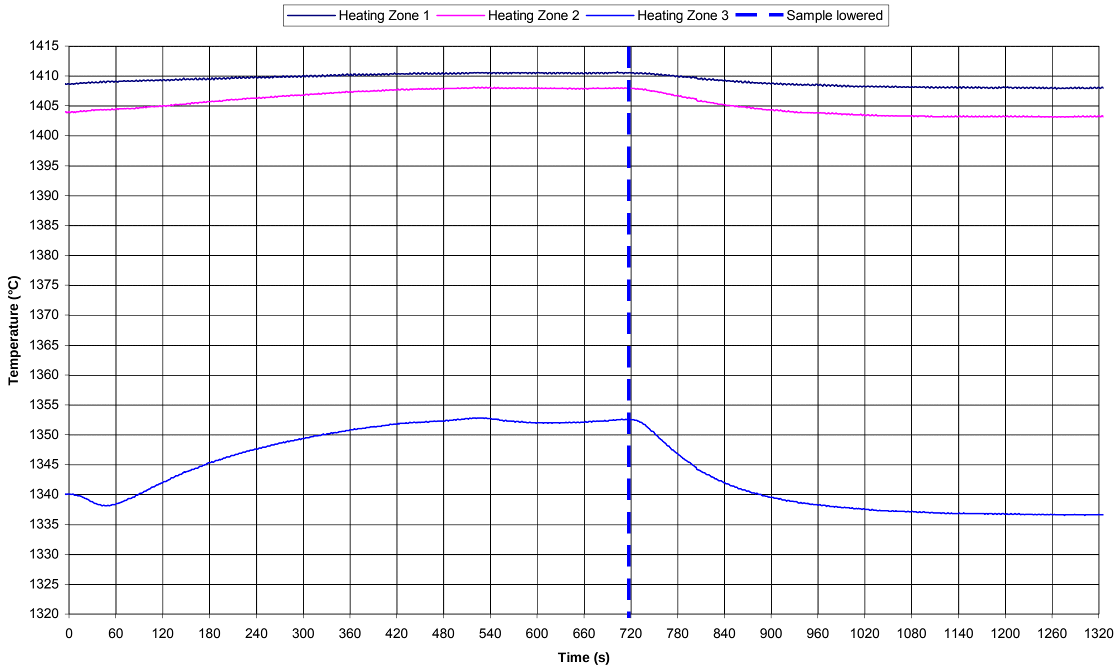


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

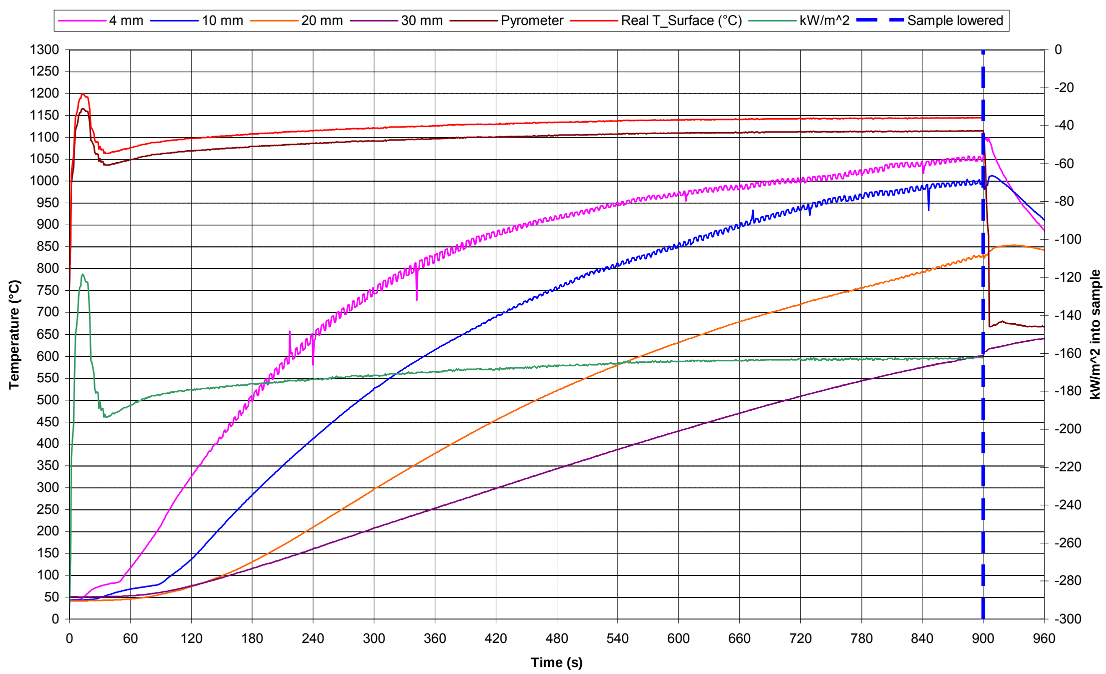
Coal-Ore; 40mm layer, 1400°C, 12minutes

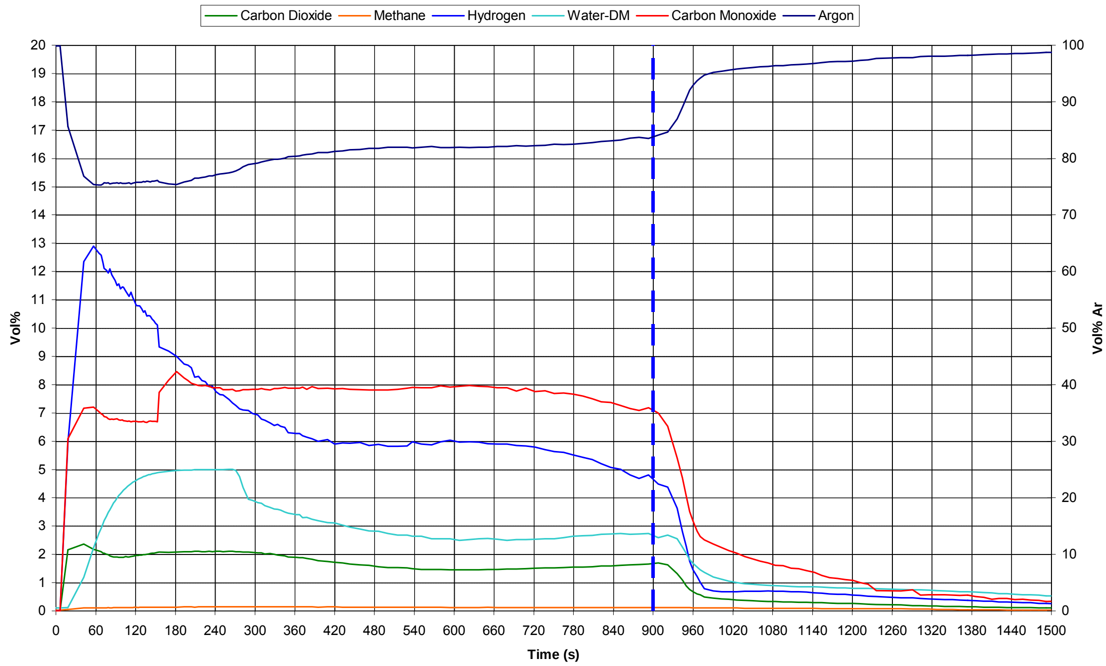




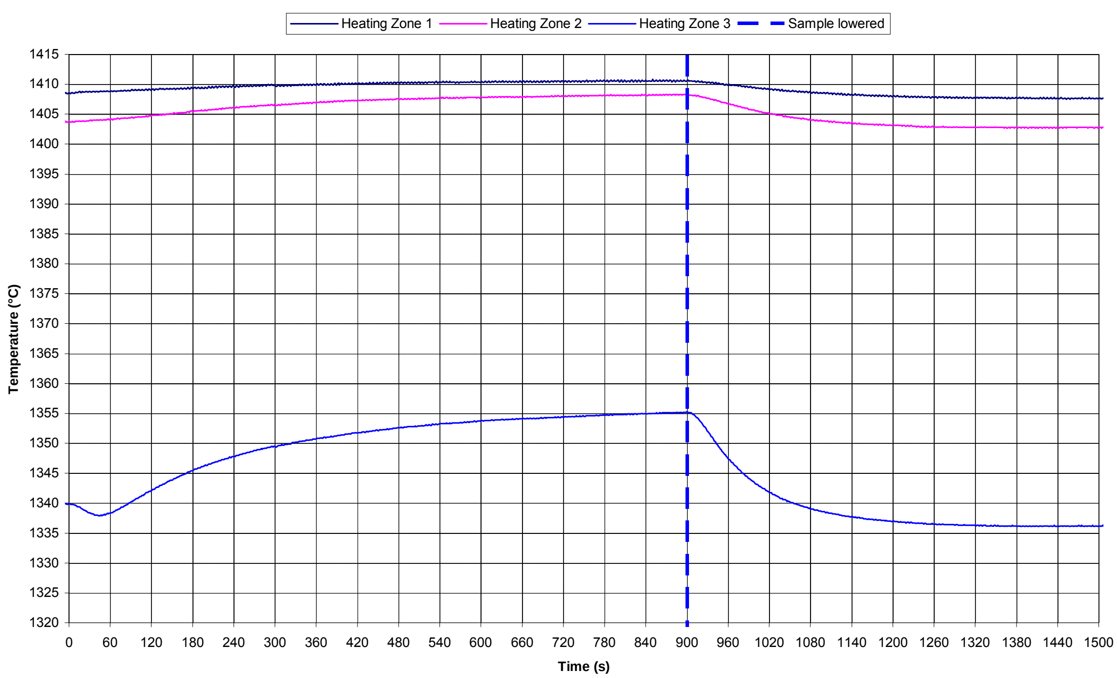


Coal-Ore; 40mm layer, 1400°C, 15minutes



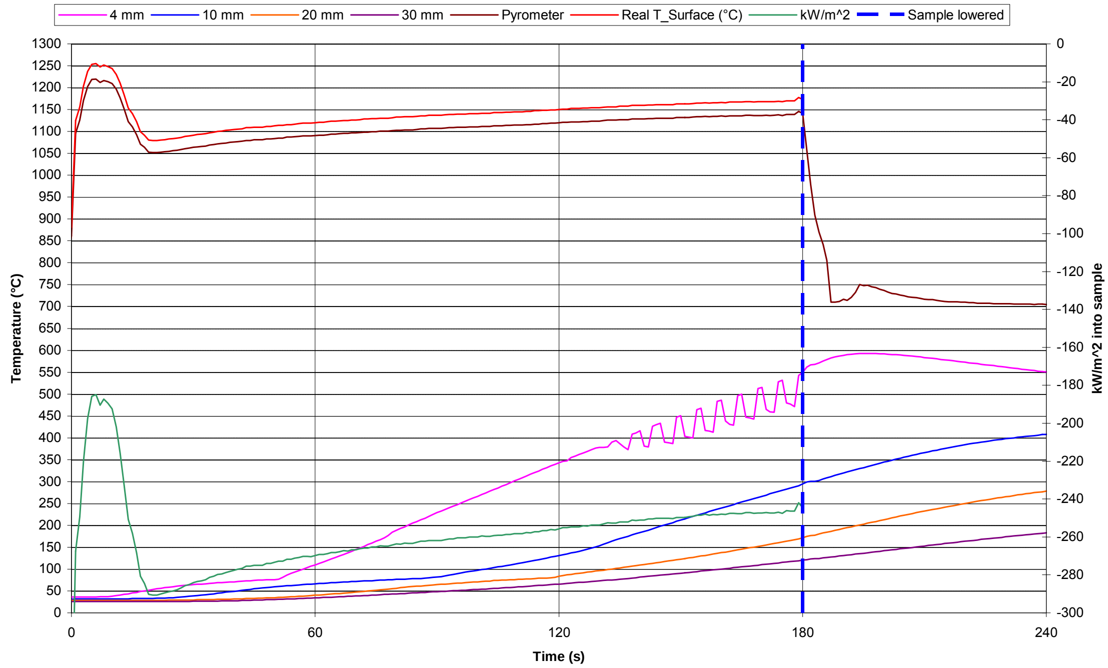


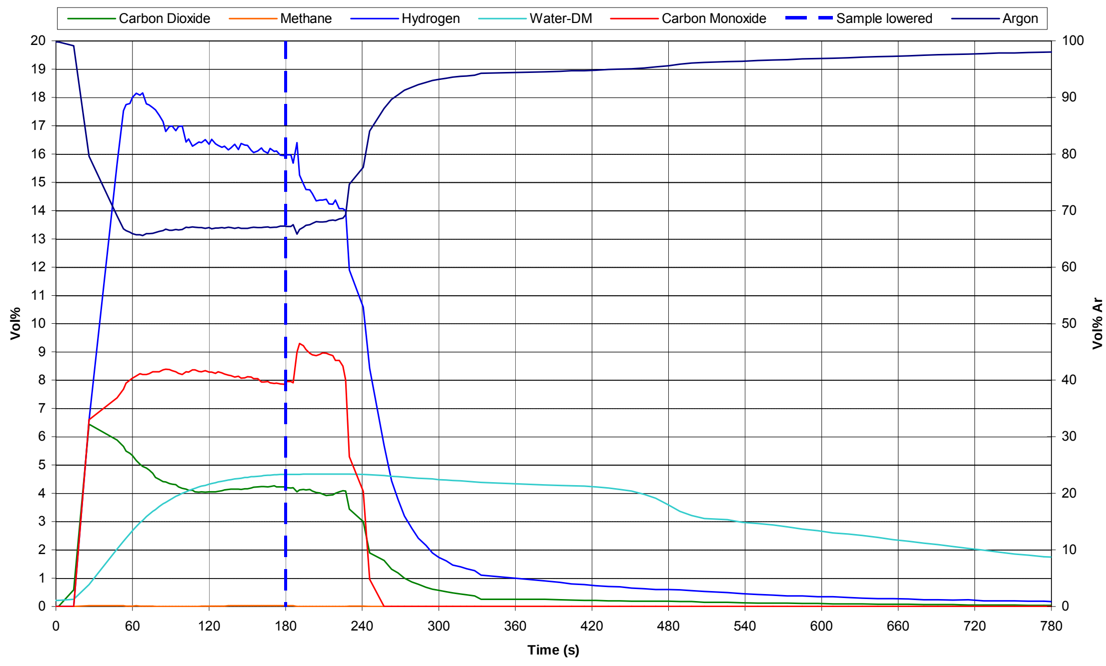
Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Argon
Vol%
Vol% Ar
Time (s)

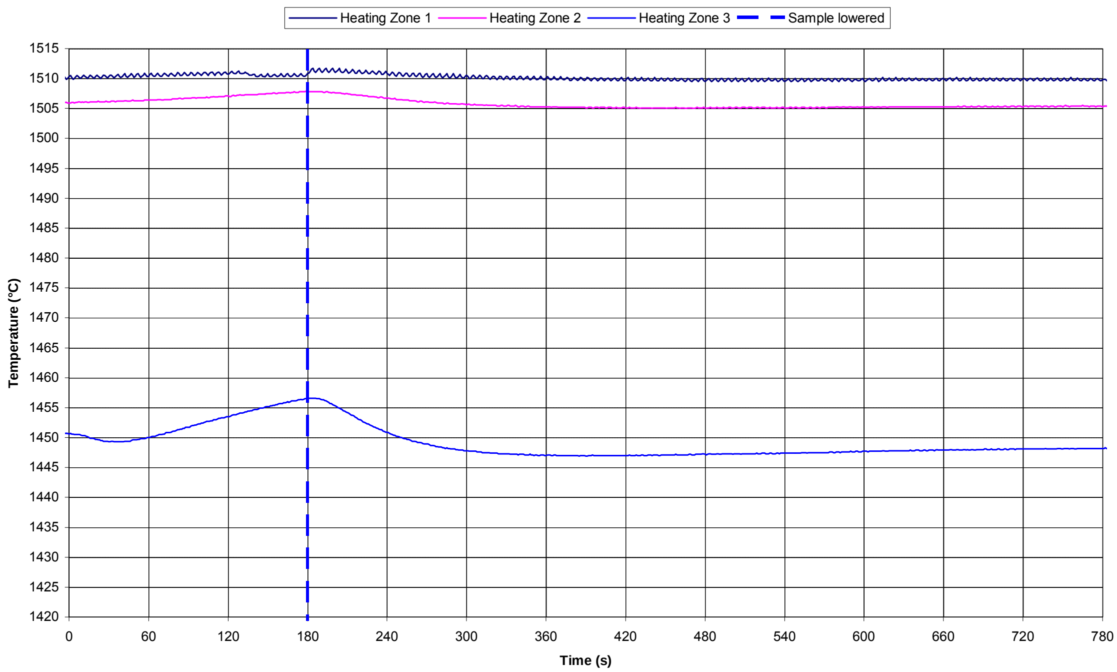


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

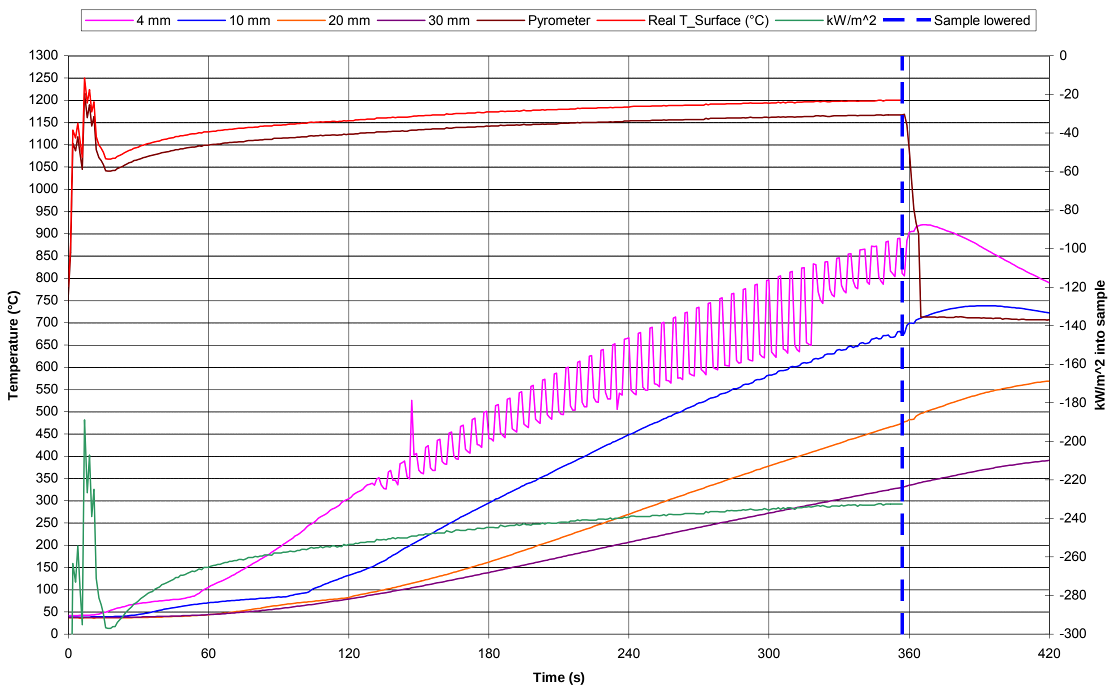
Coal-Ore; 40mm layer, 1500°C, 3minutes

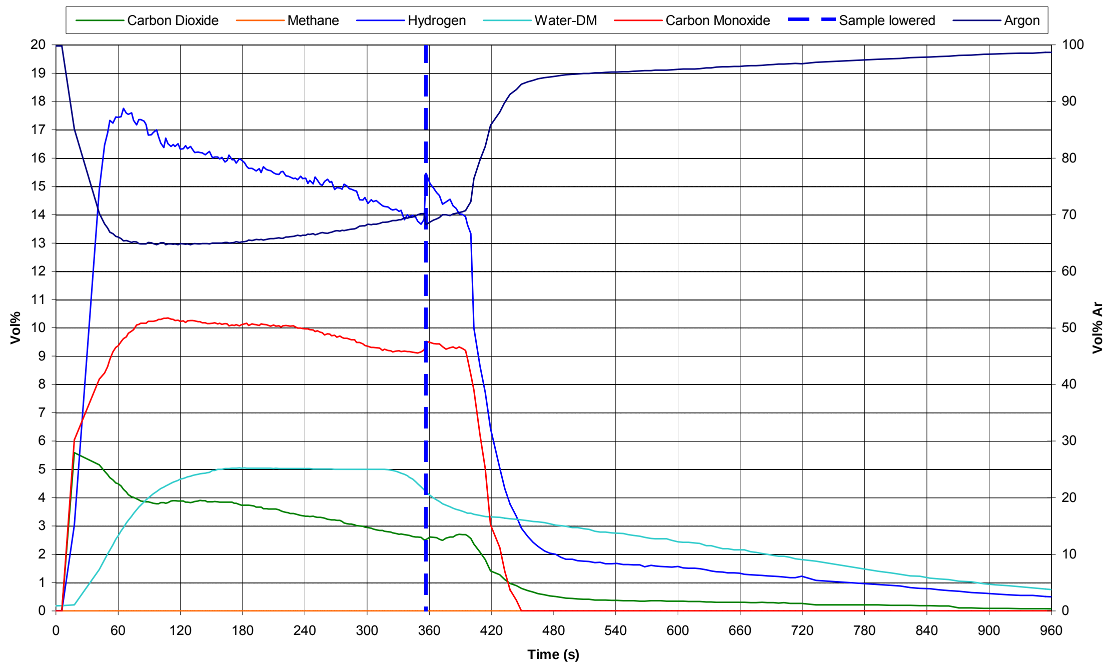


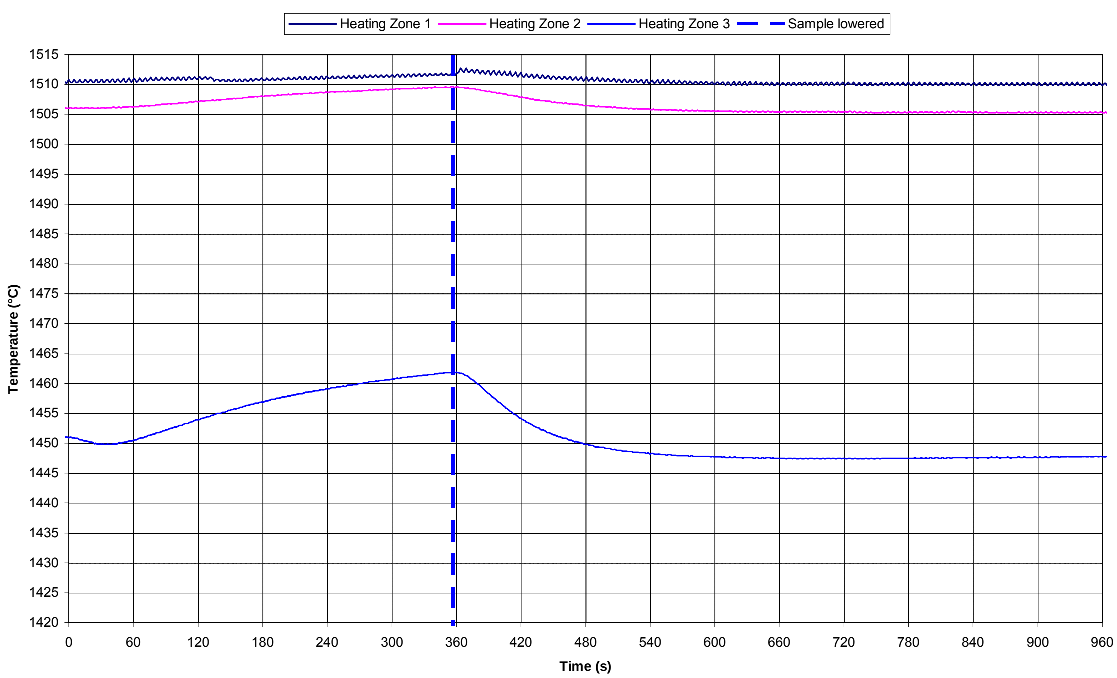




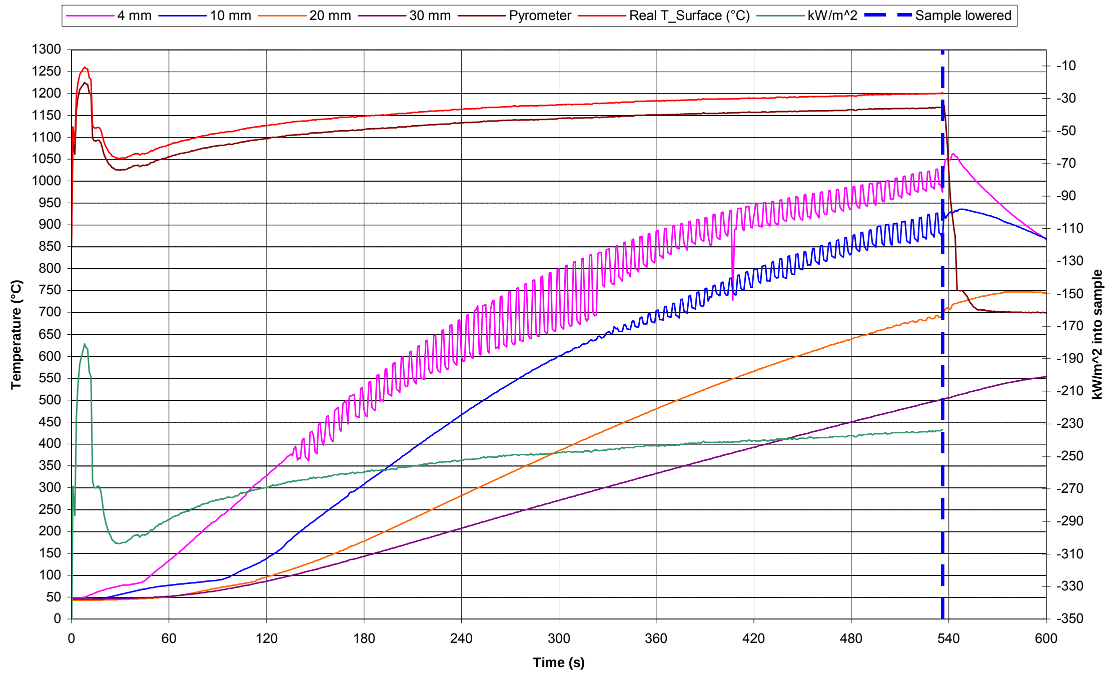
Coal-Ore; 40mm layer, 1500°C, 6minutes

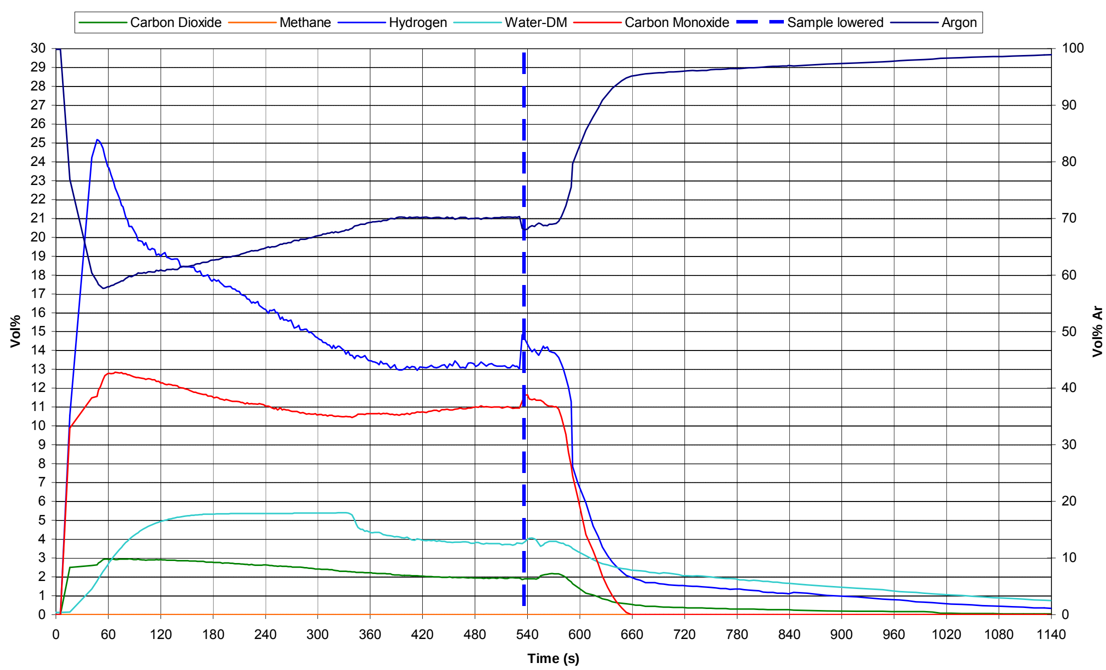


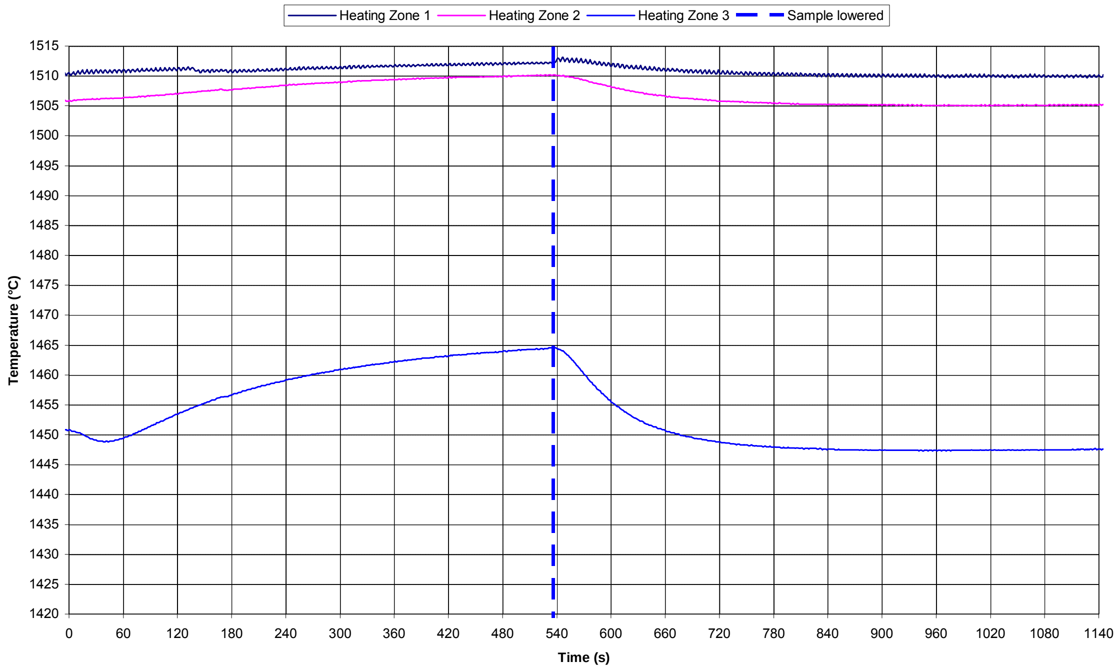

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Sample lowered
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

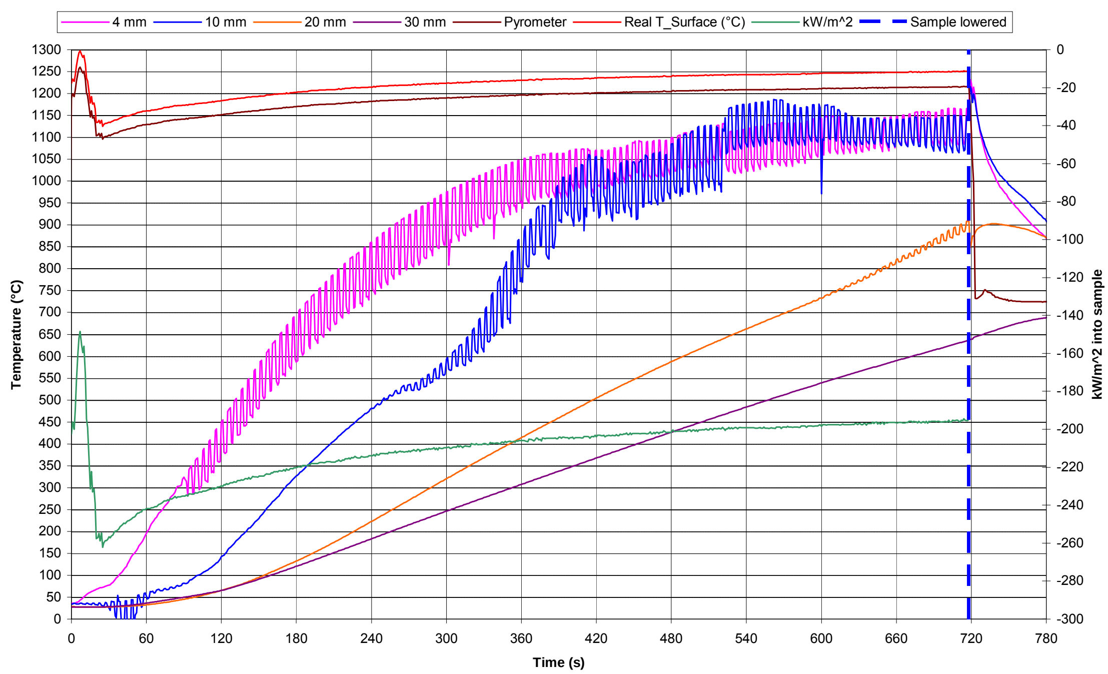
Coal-Ore; 40mm layer, 1500°C, 9minutes

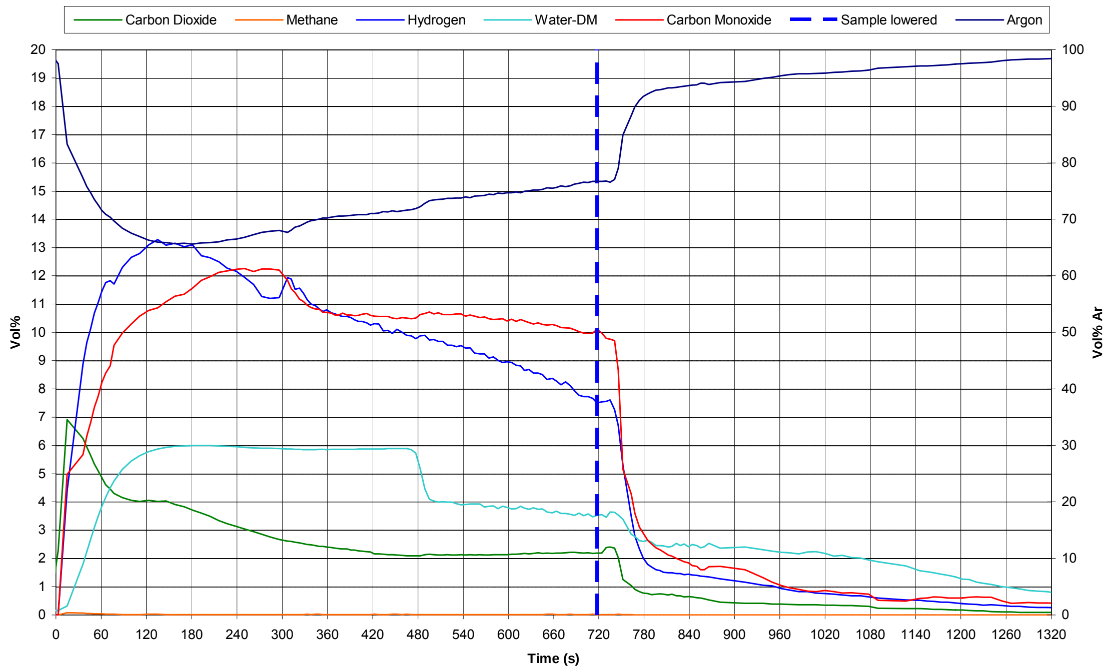


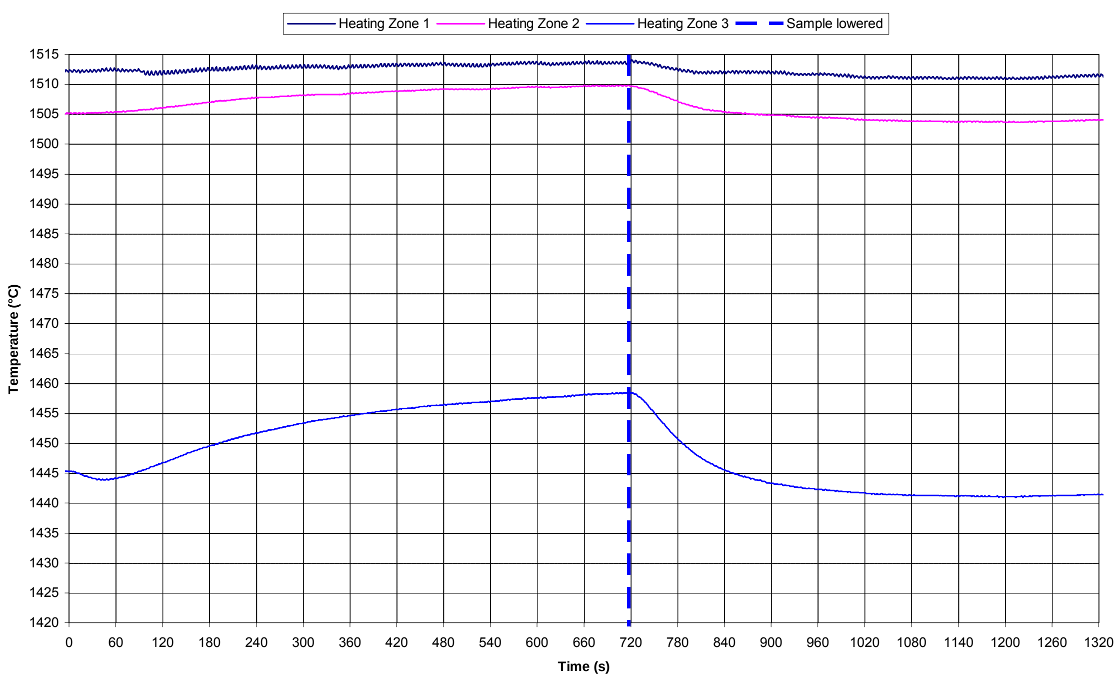




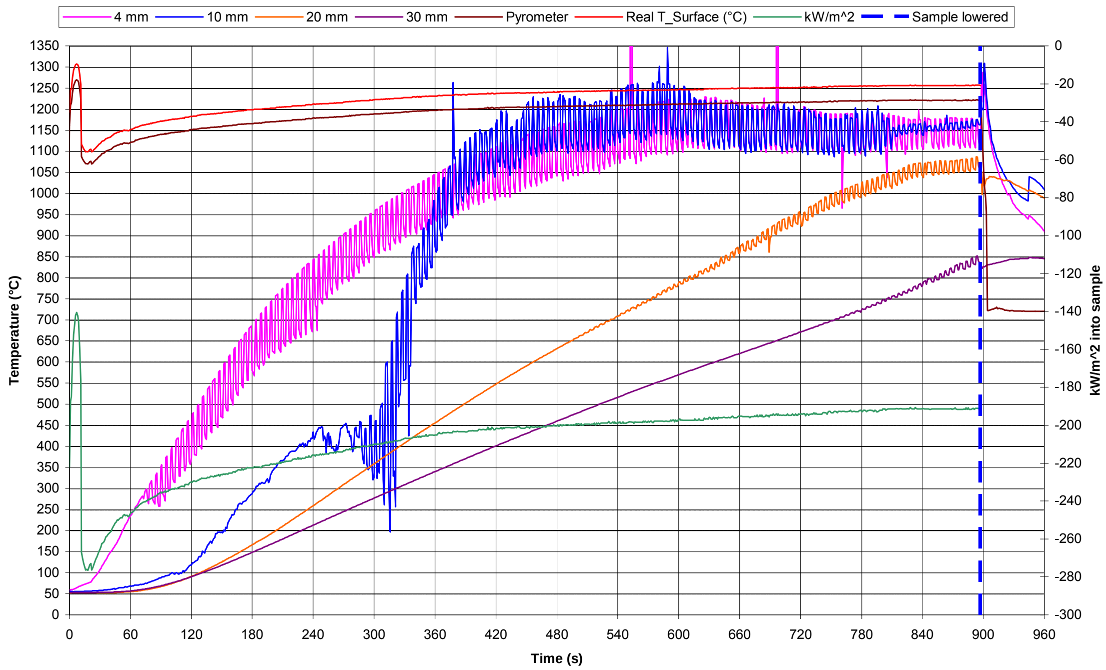
Coal-Ore; 40mm layer, 1500°C, 12minutes

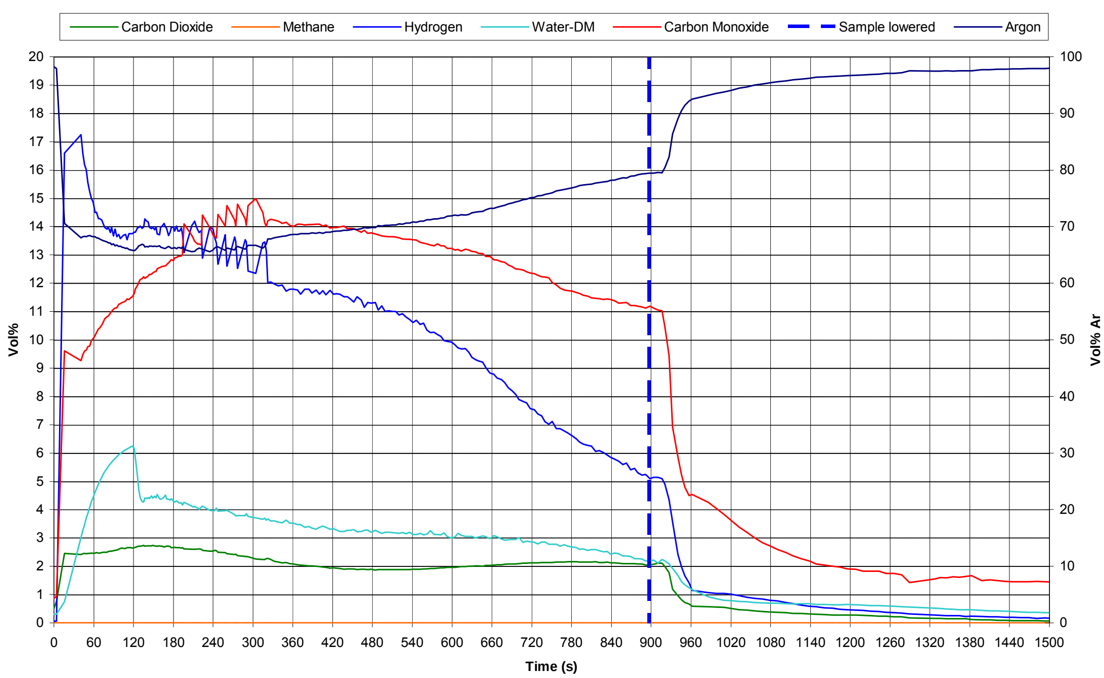


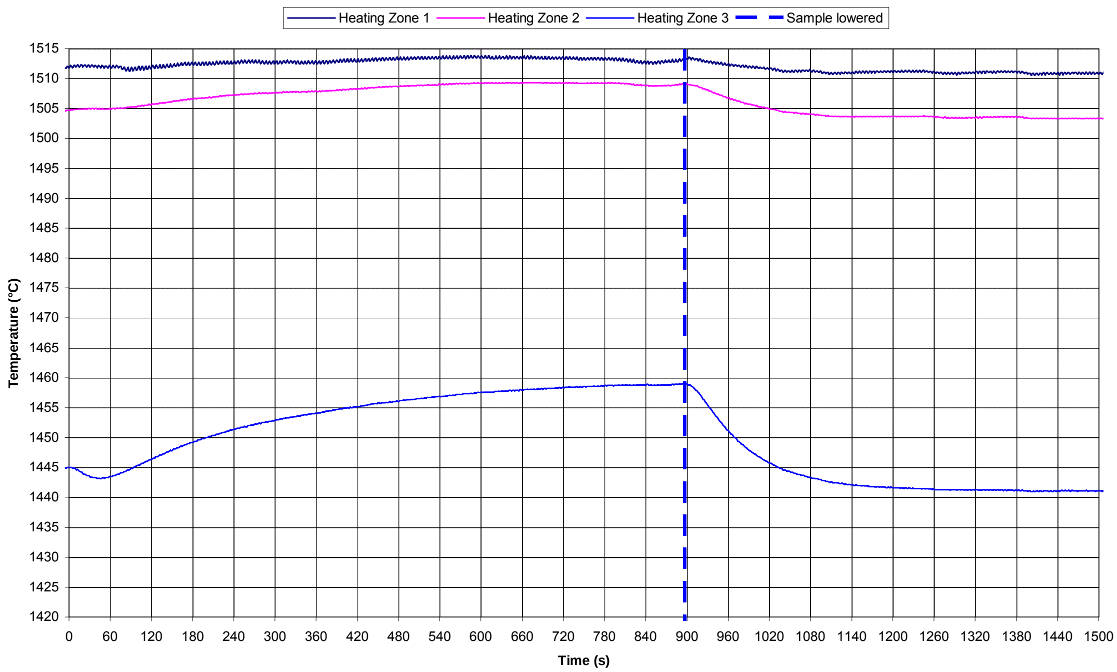

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Sample lowered
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

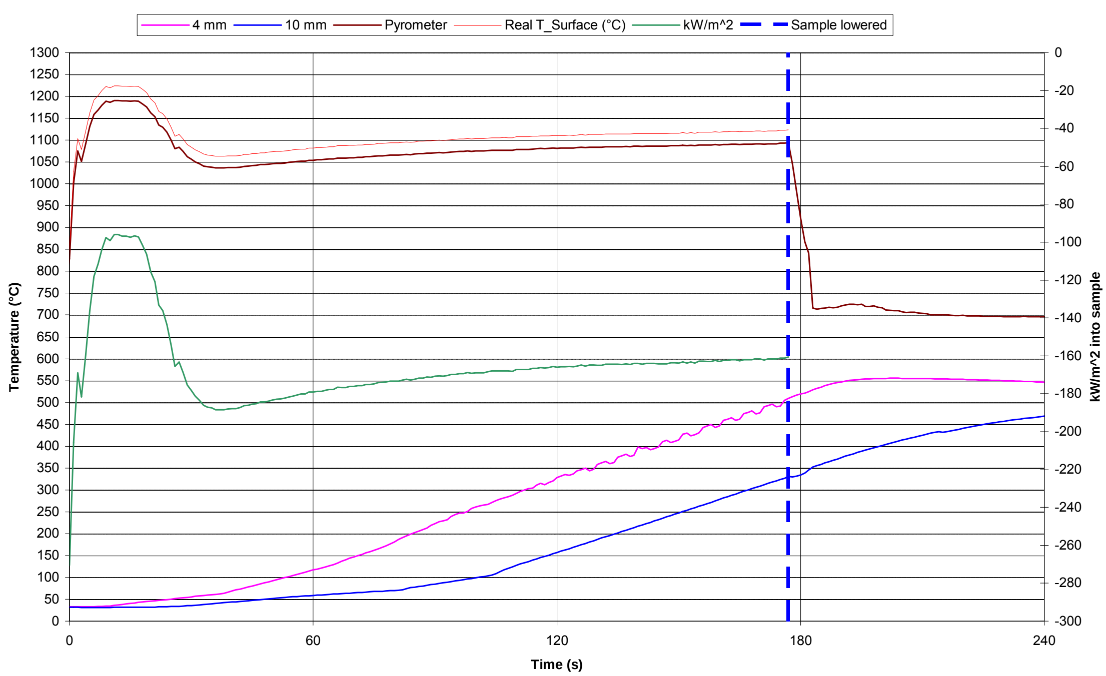
Coal-Ore; 40mm layer, 1500°C, 15minutes

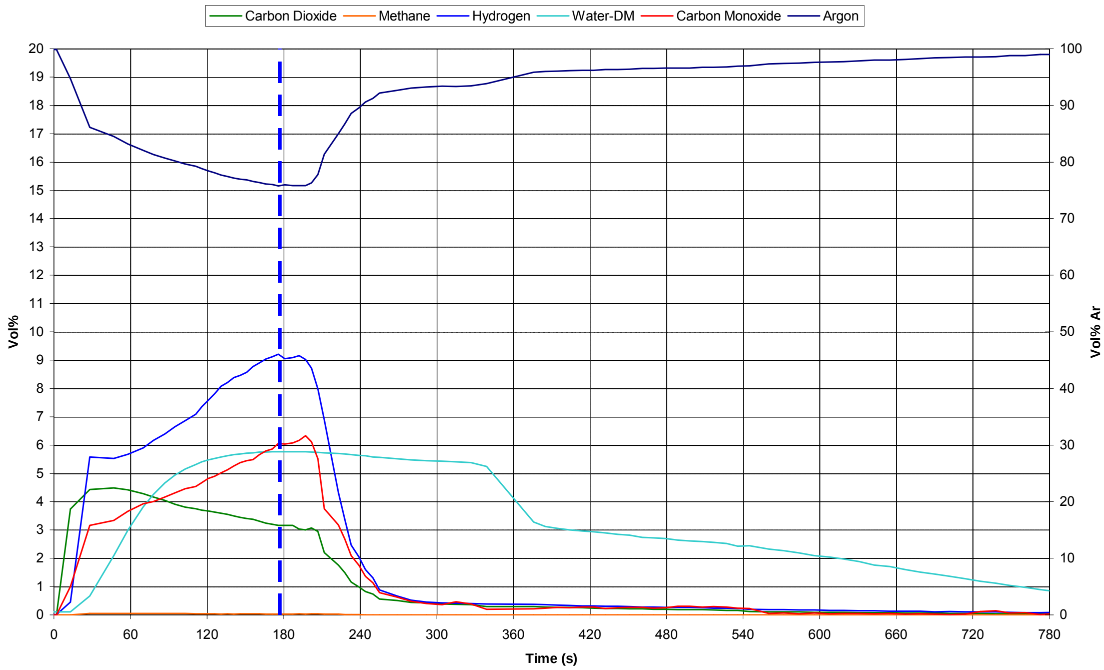


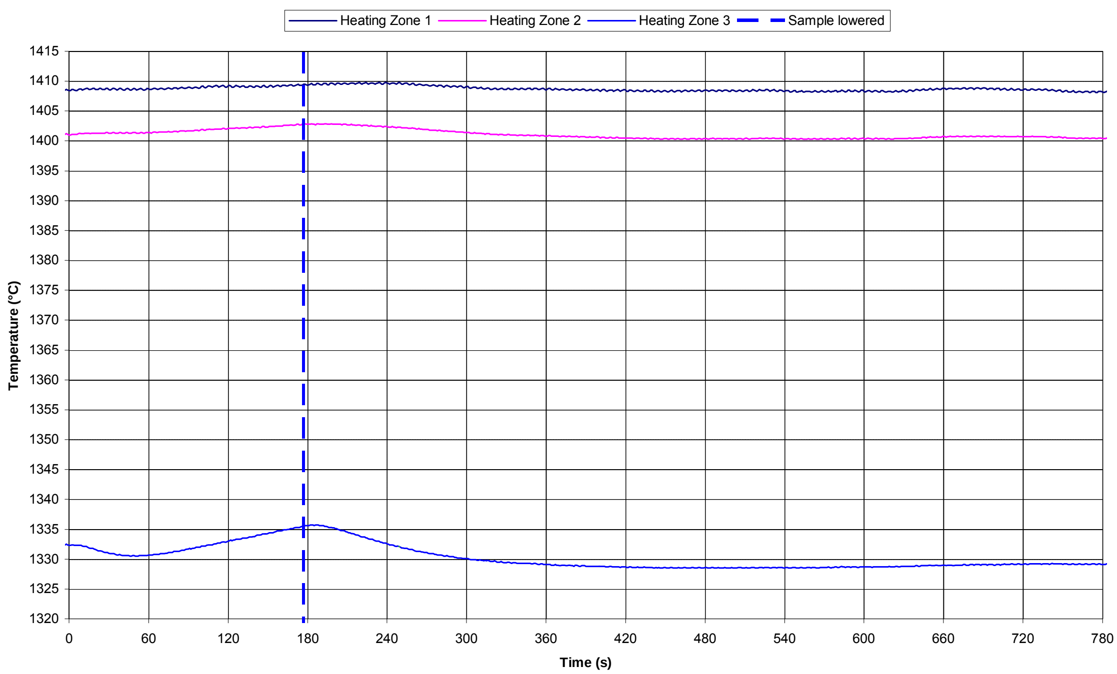




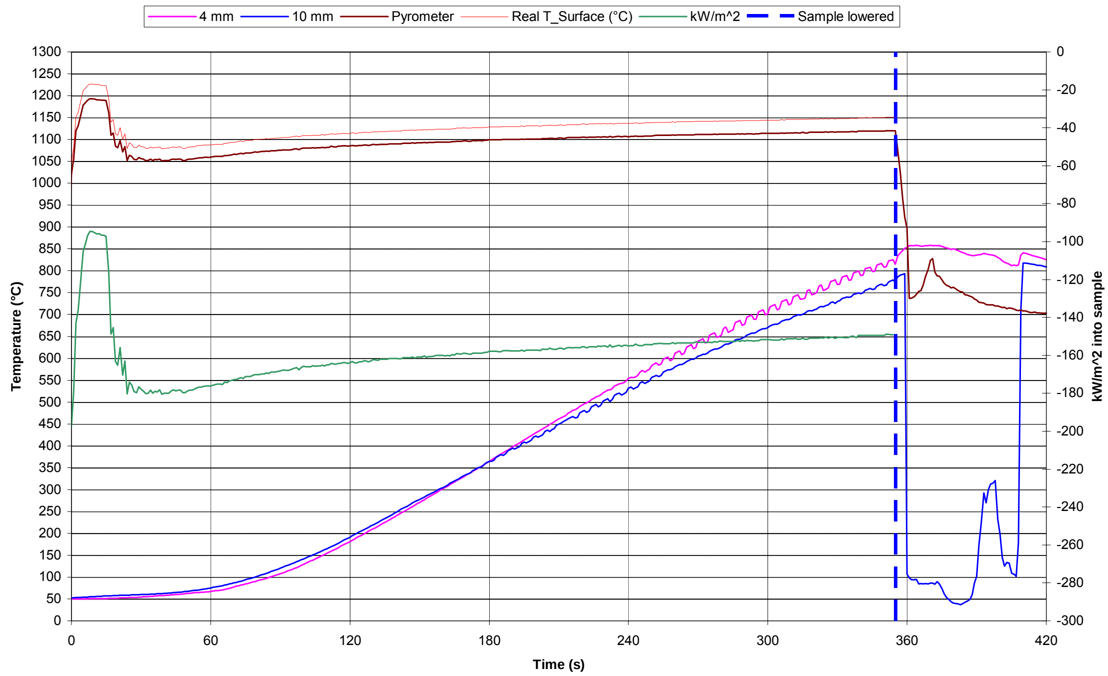
Coal-Ore; 16 mm layer, 1400°C, 3minutes

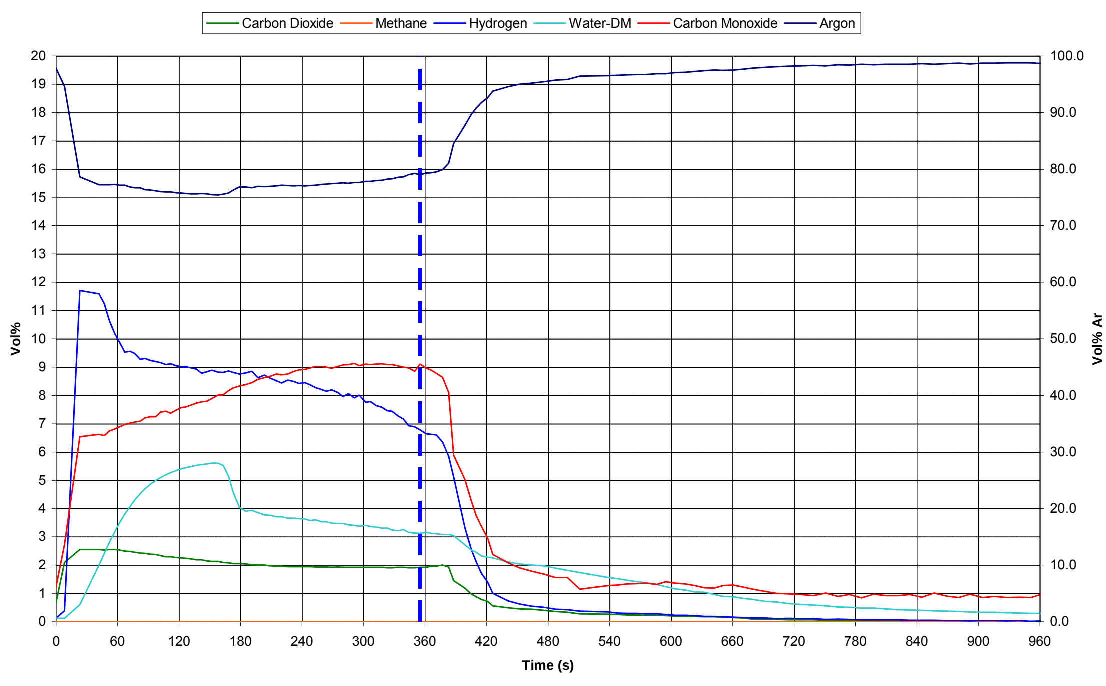


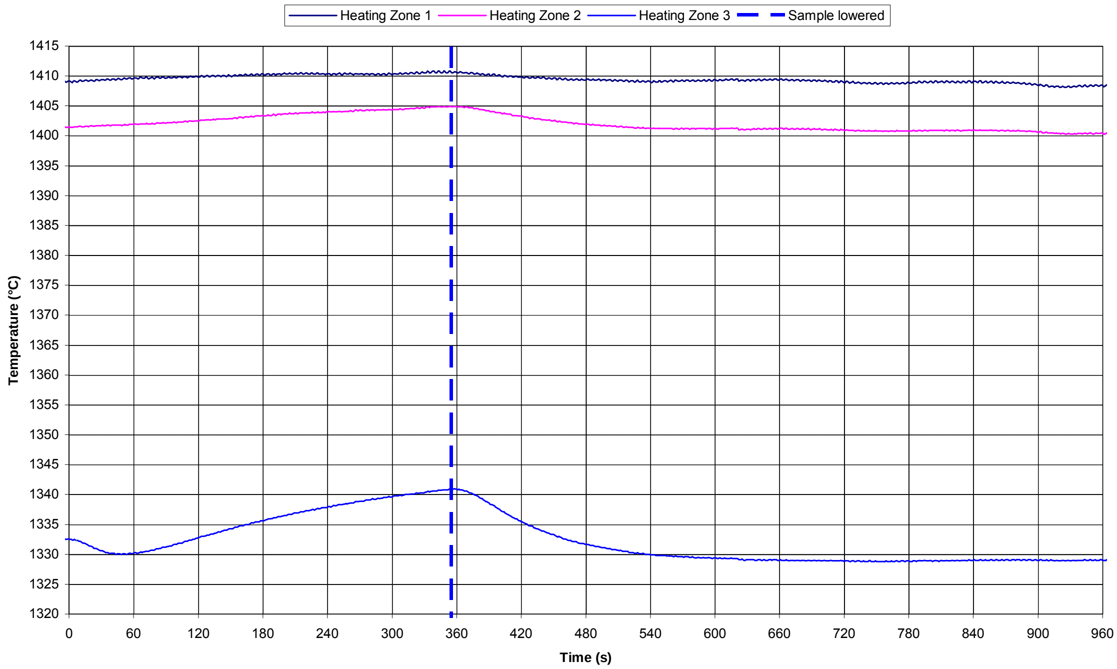

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Argon
Vol%
Vol% Ar
Time (s)
0 60 120 180 240 300 360 420 480 540 600 660 720 780
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
0 10 20 30 40 50 60 70 80 90 100


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)
0 60 120 180 240 300 360 420 480 540 600 660 720 780
1320 1325 1330 1335 1340 1345 1350 1355 1360 1365 1370 1375 1380 1385 1390 1395 1400 1405 1410 1415

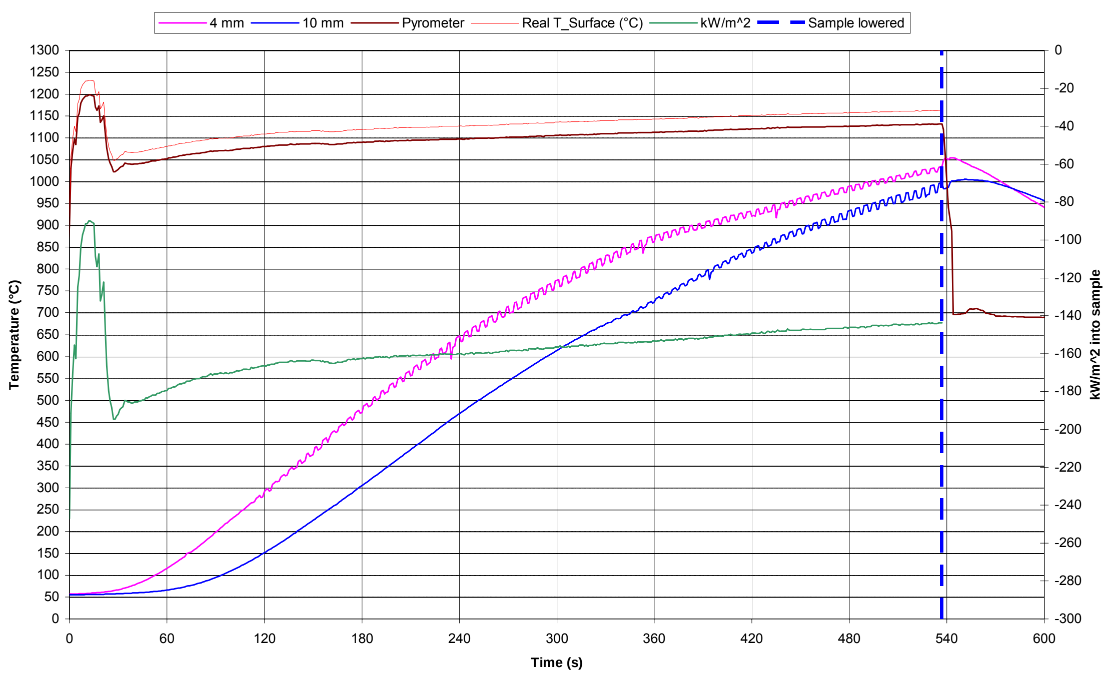
Coal-Ore; 16 mm layer, 1400°C, 6minutes

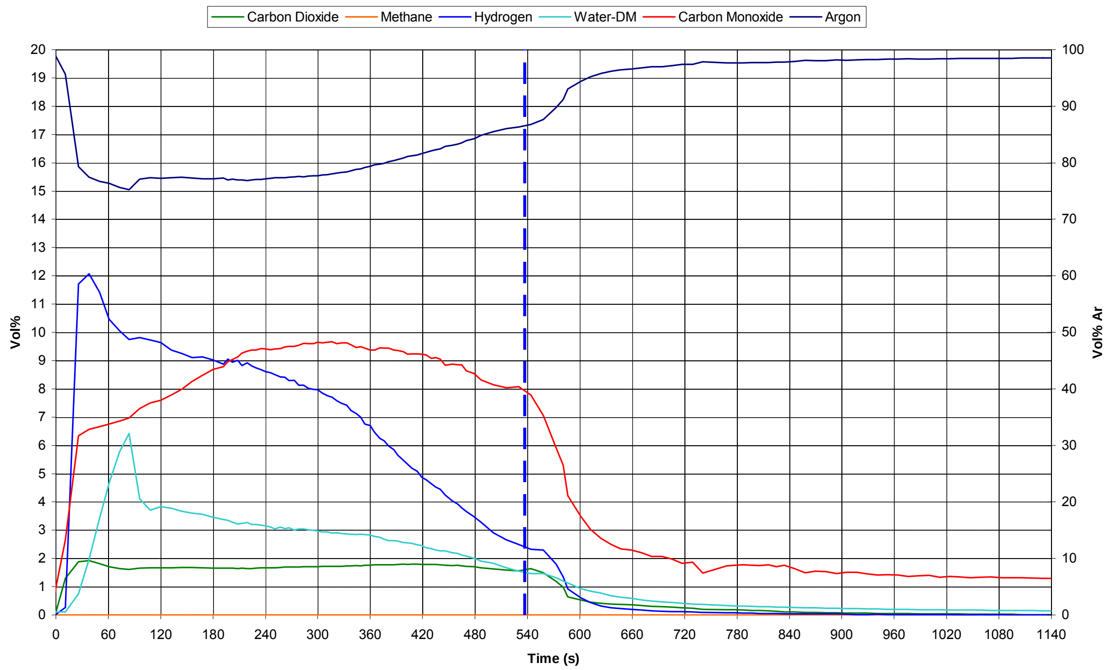




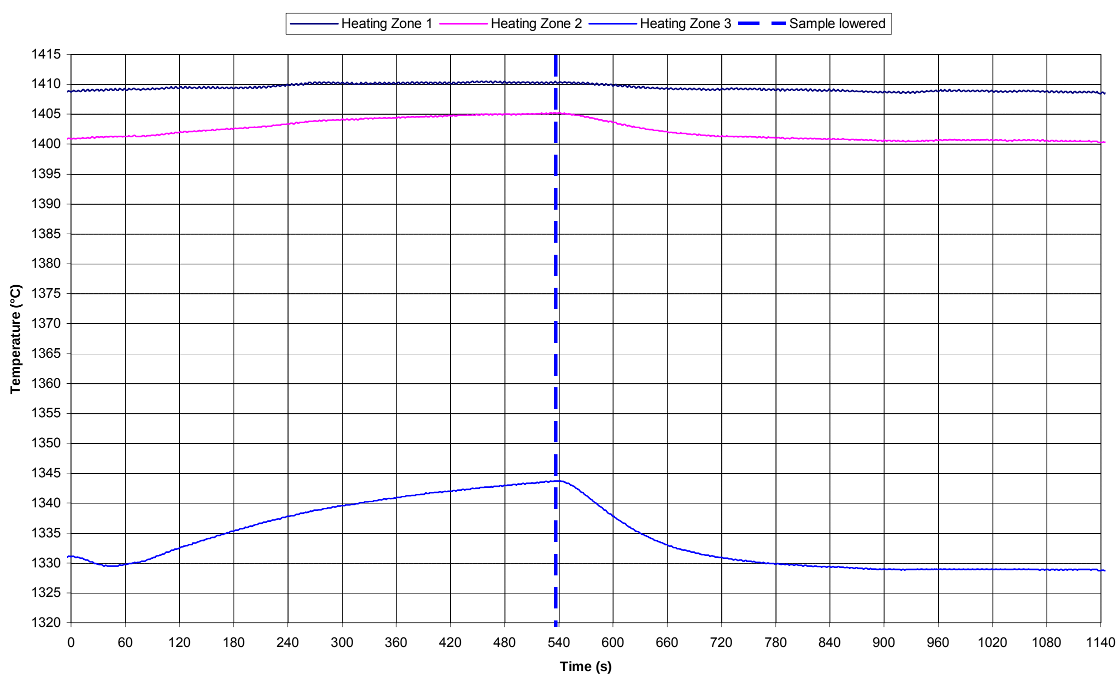


Coal-Ore; 16 mm layer, 1400°C, 9minutes



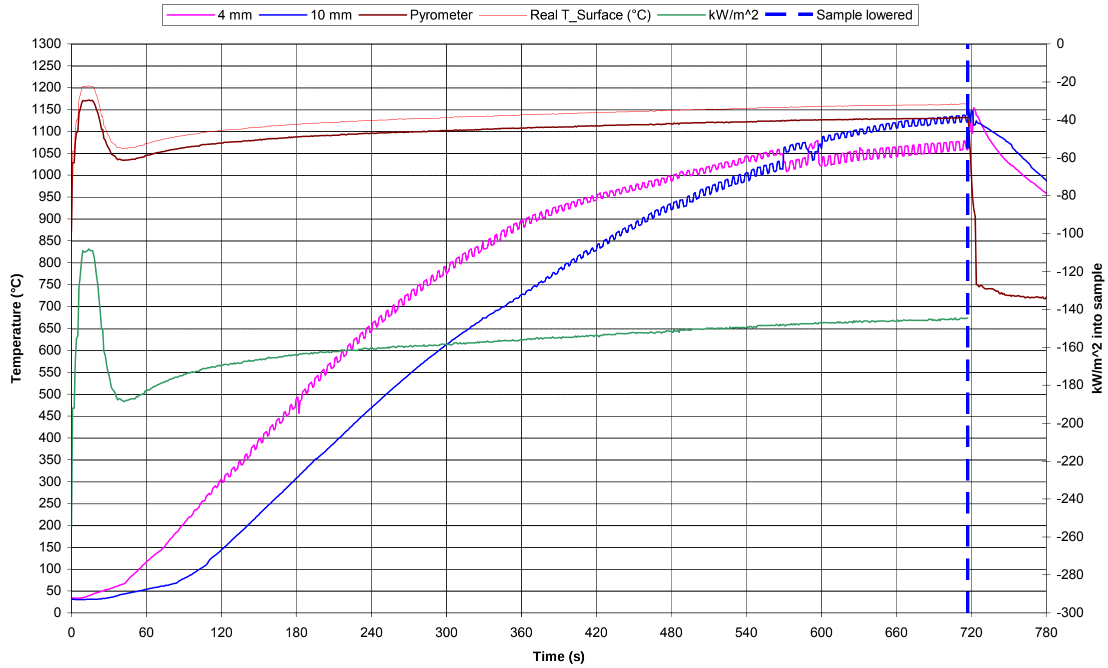


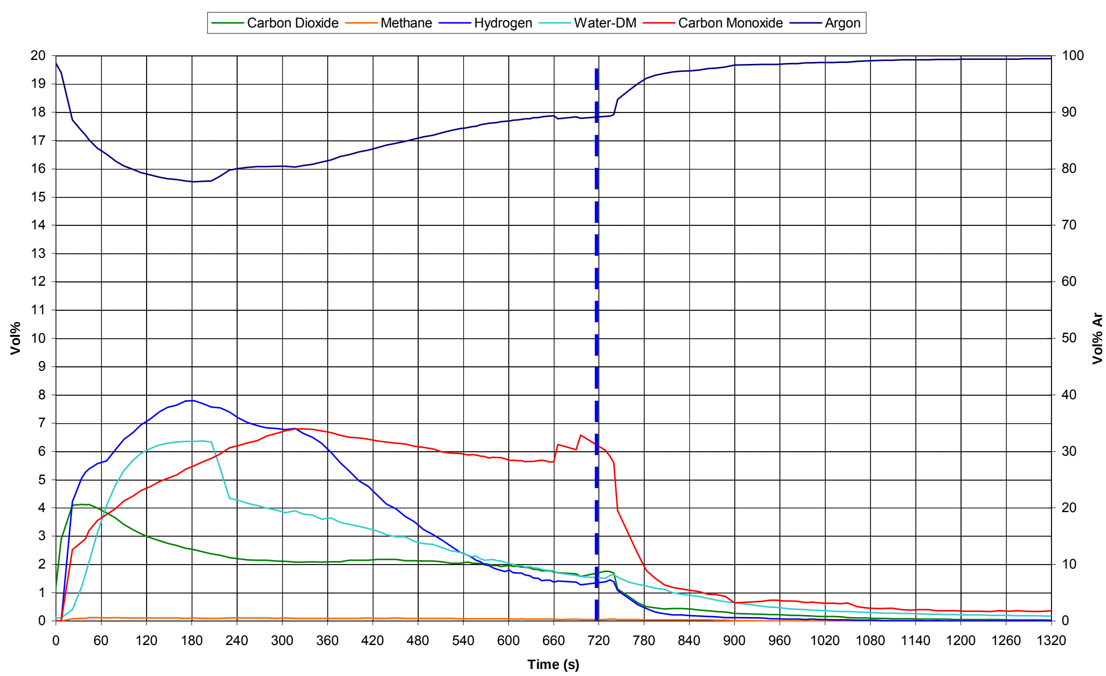
Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Argon
Vol%
Vol% Ar
Time (s)

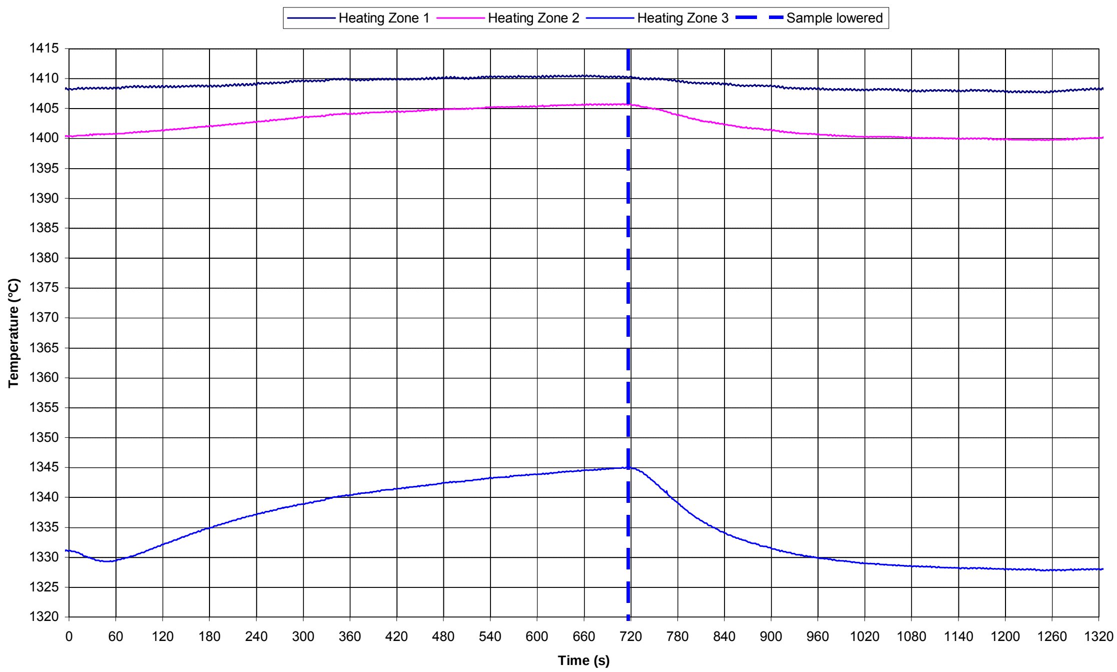


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

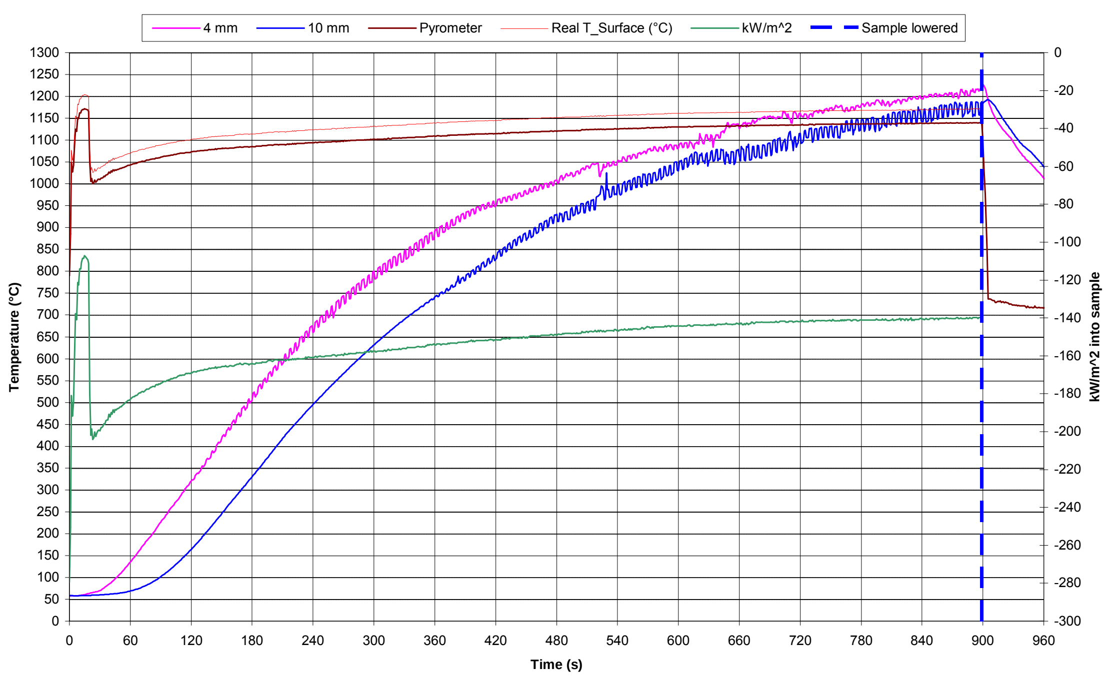
Coal-Ore; 16 mm layer, 1400°C, 12minutes

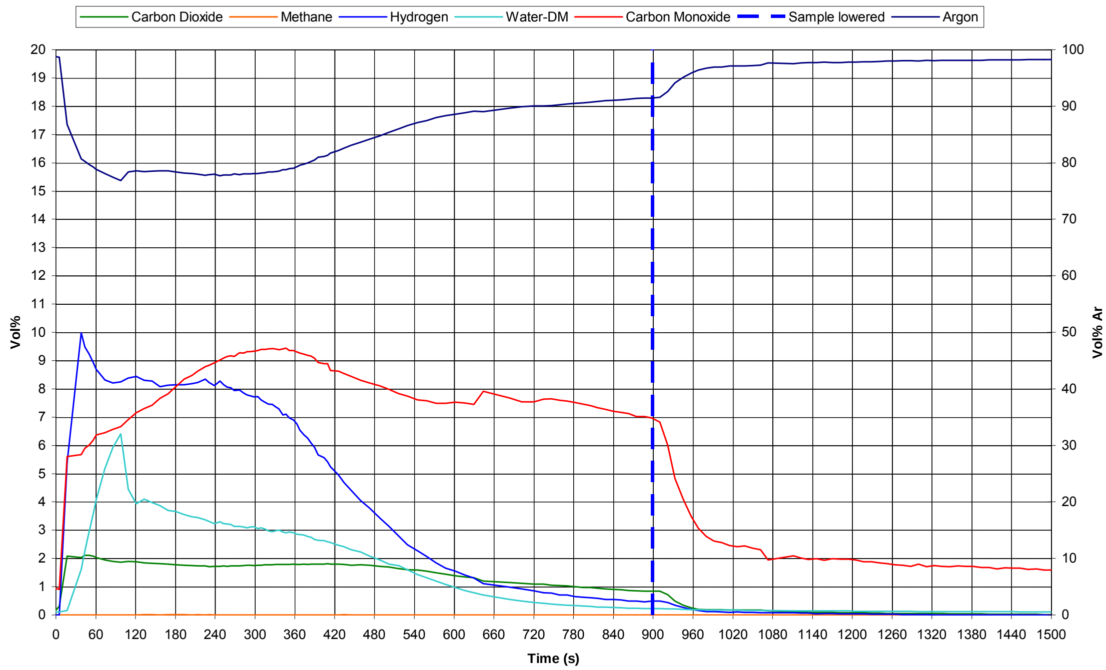


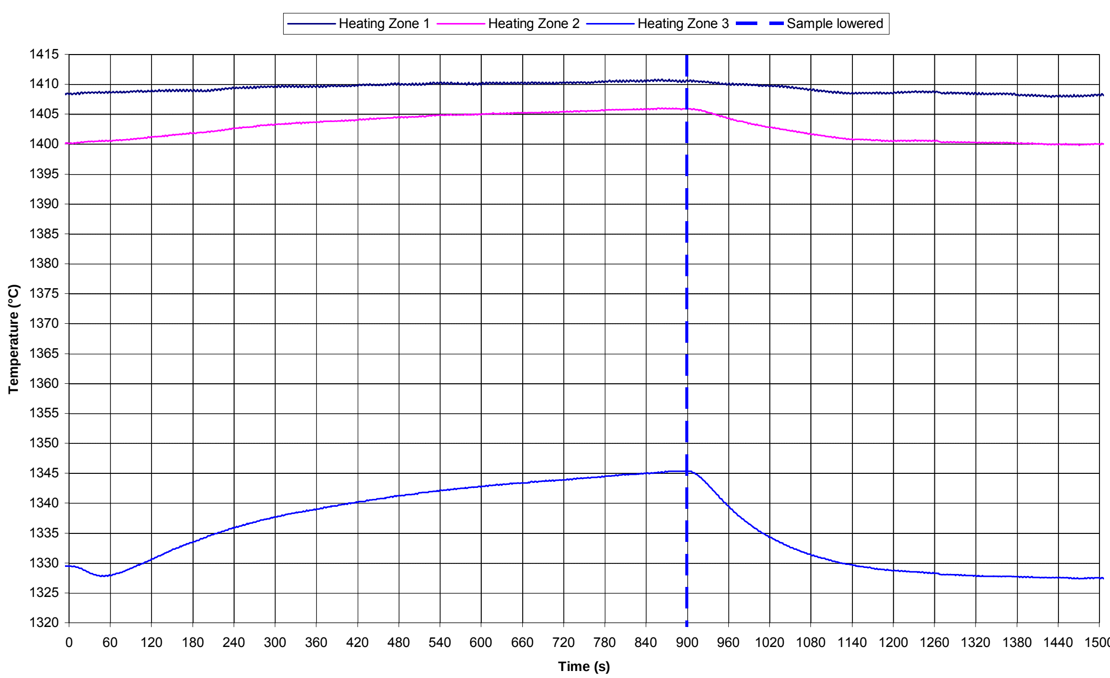




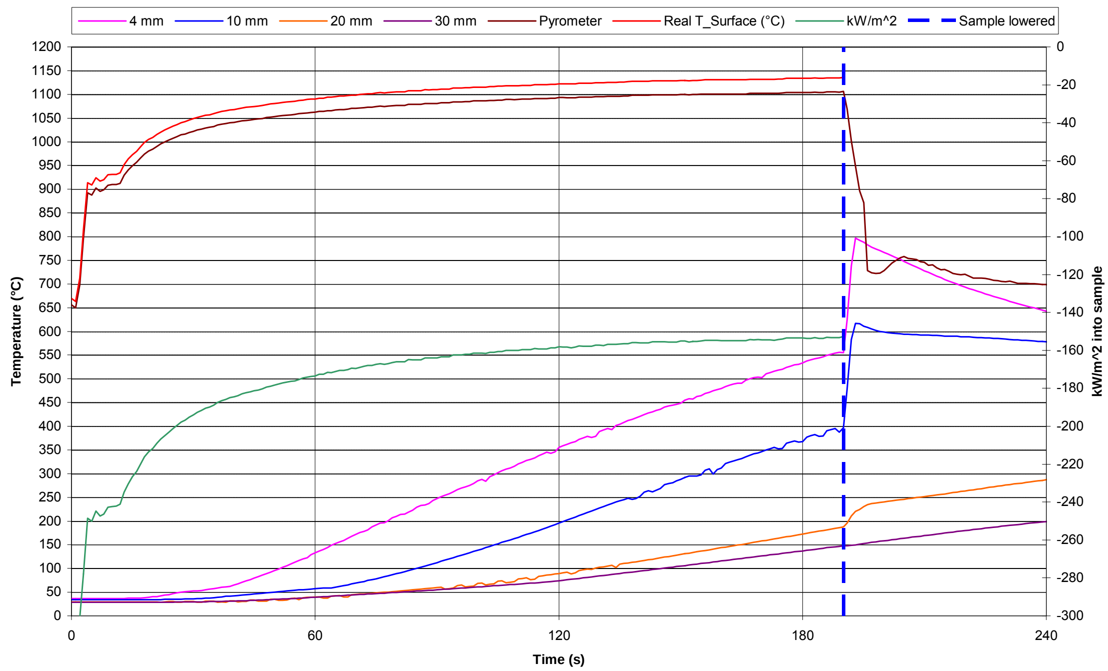
Coal-Ore; 16 mm layer, 1400°C, 15minutes

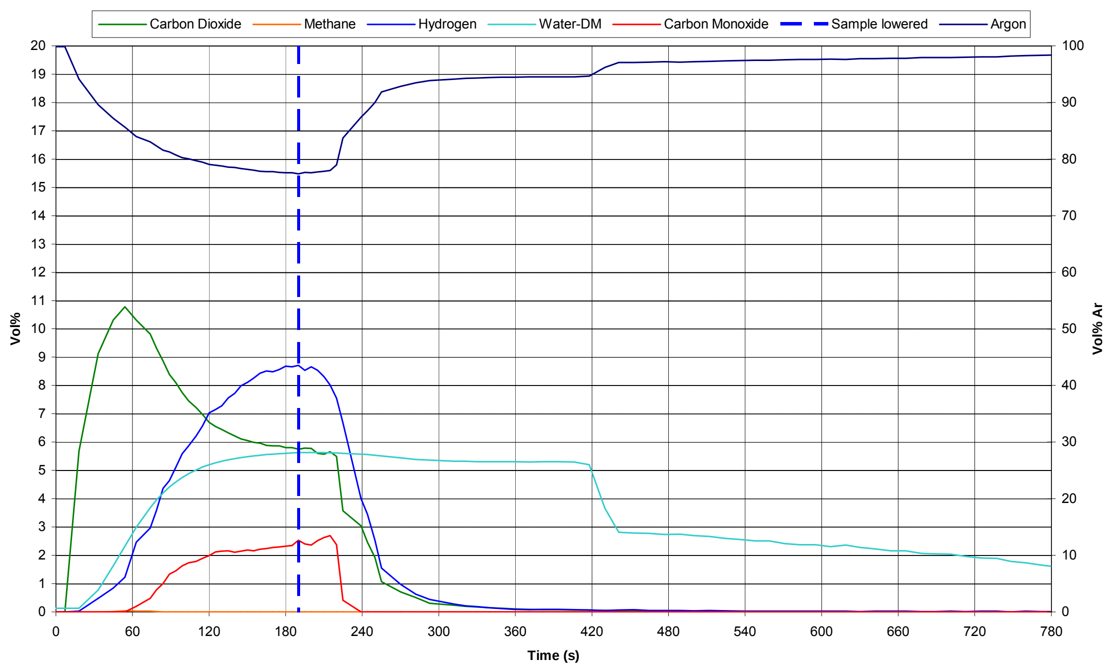


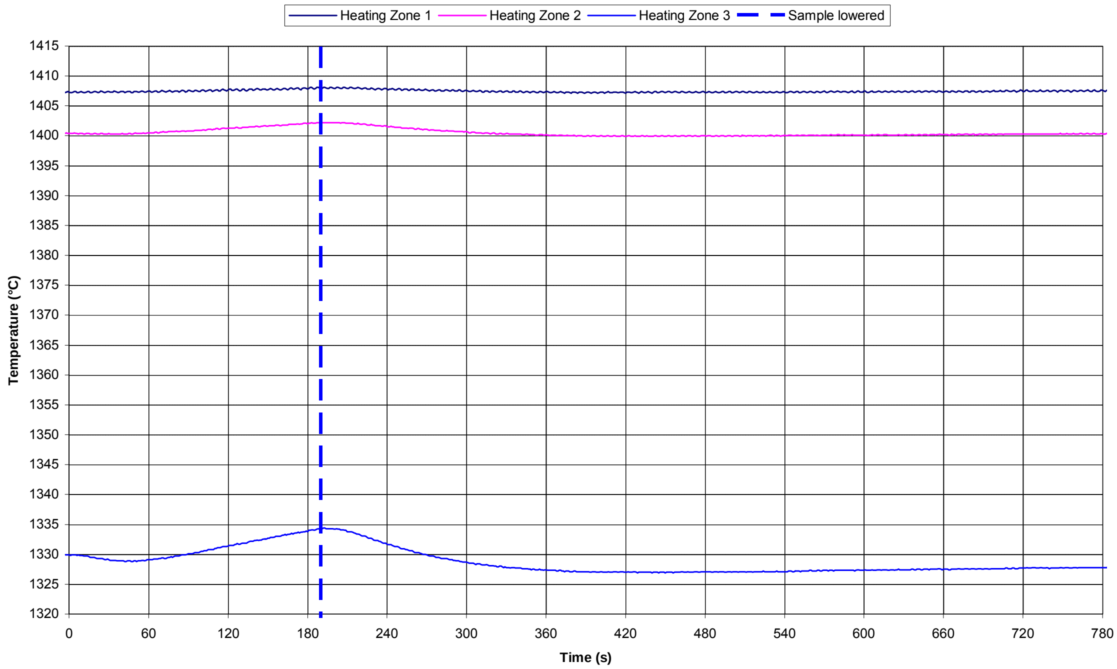

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Sample lowered
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

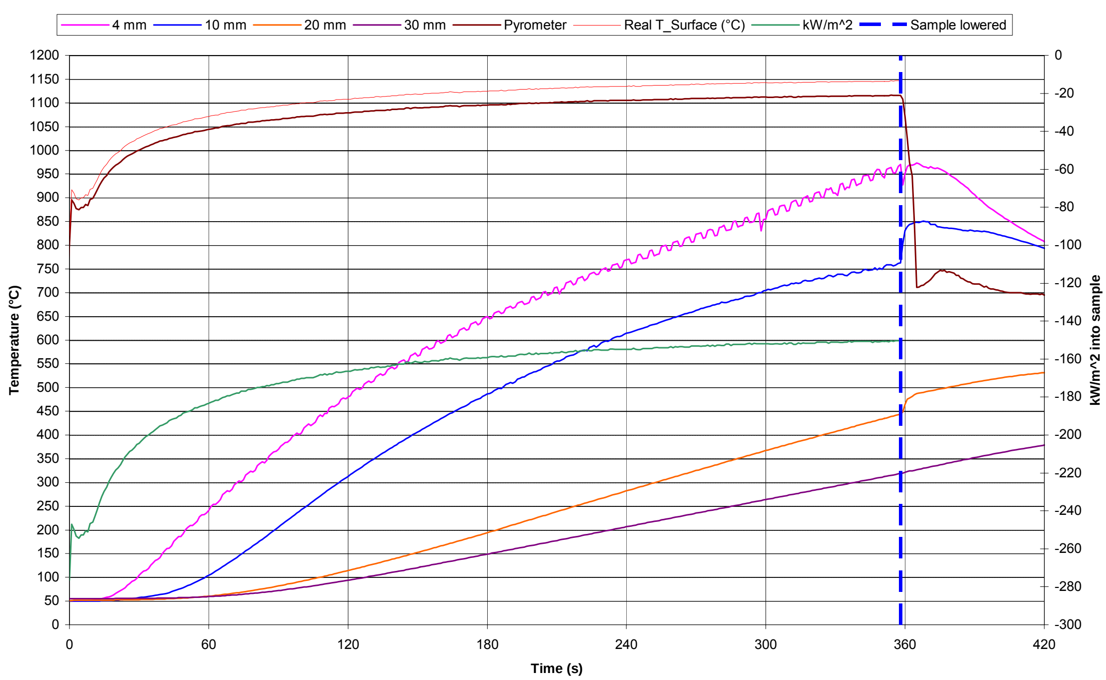
Char-Ore; 40 mm layer, 1400°C, 3minutes

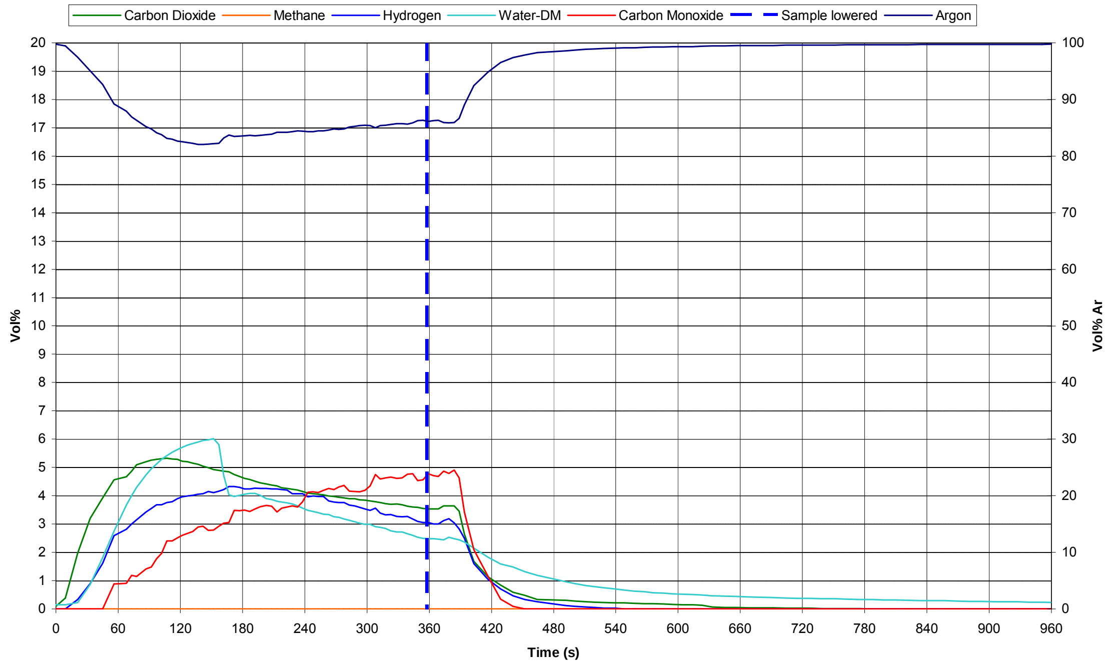




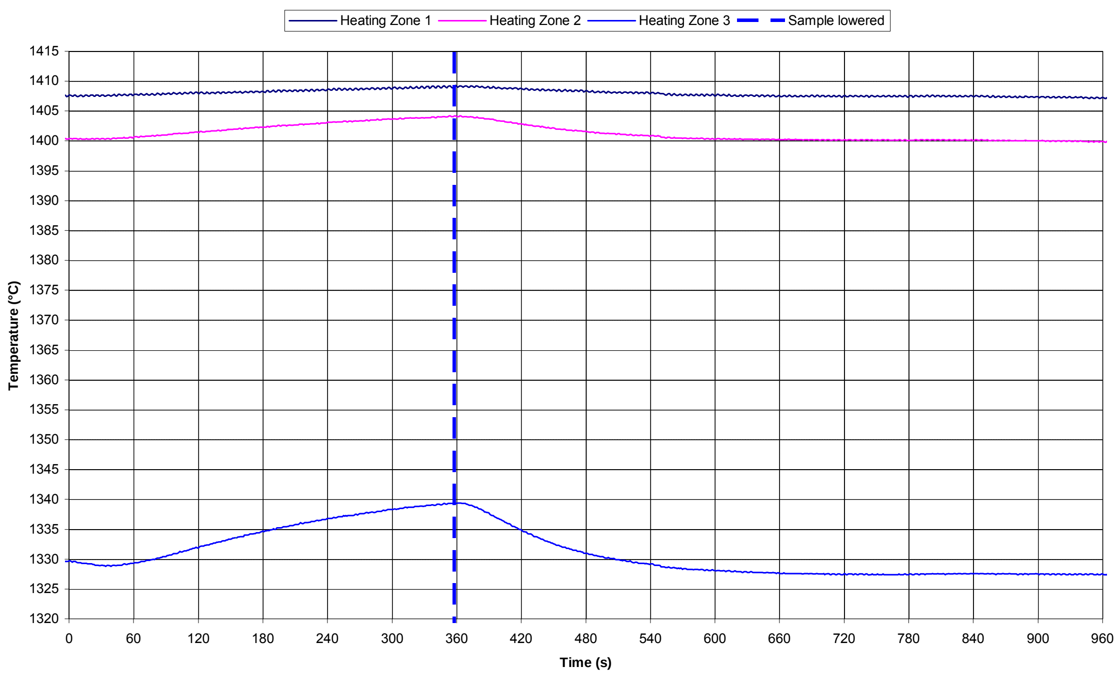


Char-Ore; 40 mm layer, 1400°C, 6minutes



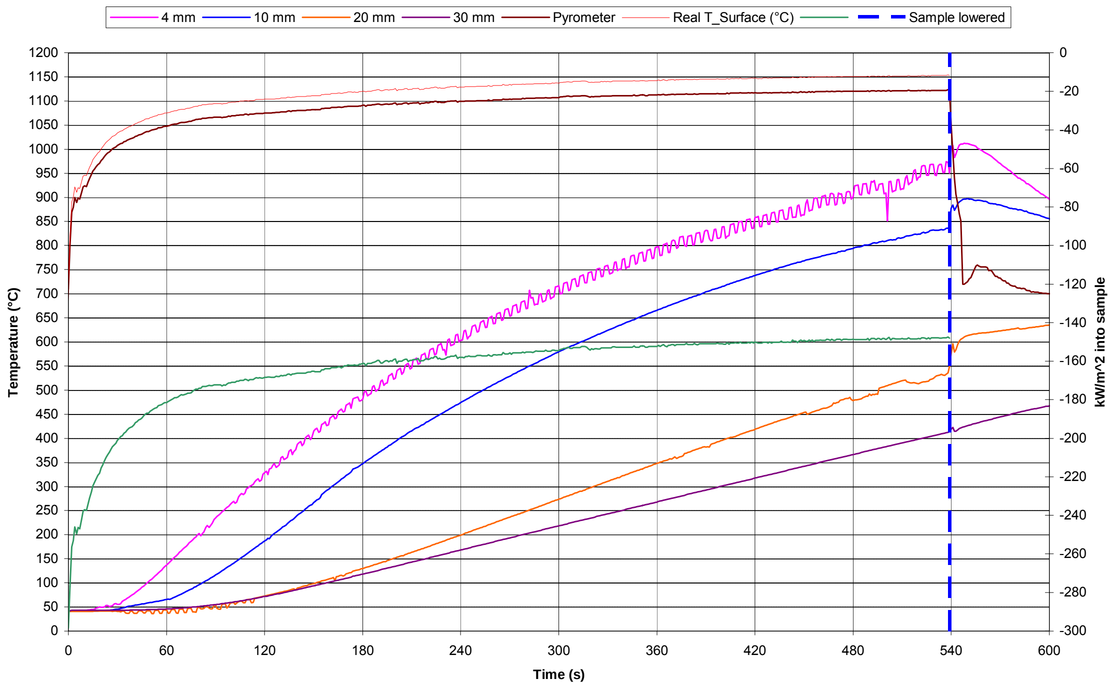


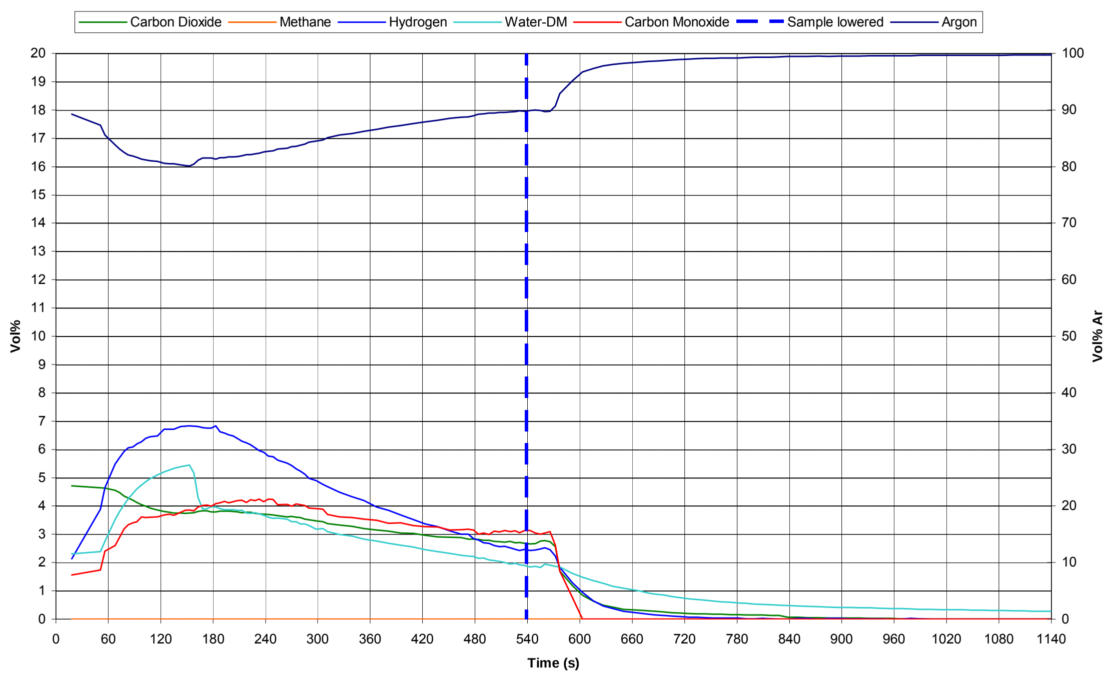
Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Sample lowered
Argon
Vol%
Vol% Ar
Time (s)

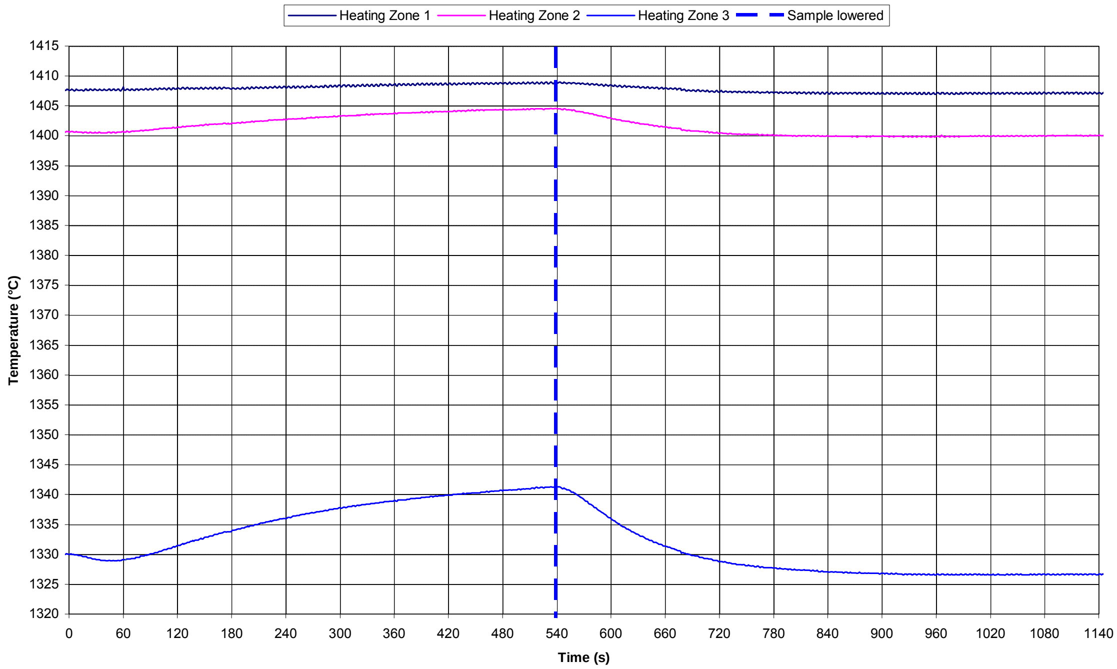


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

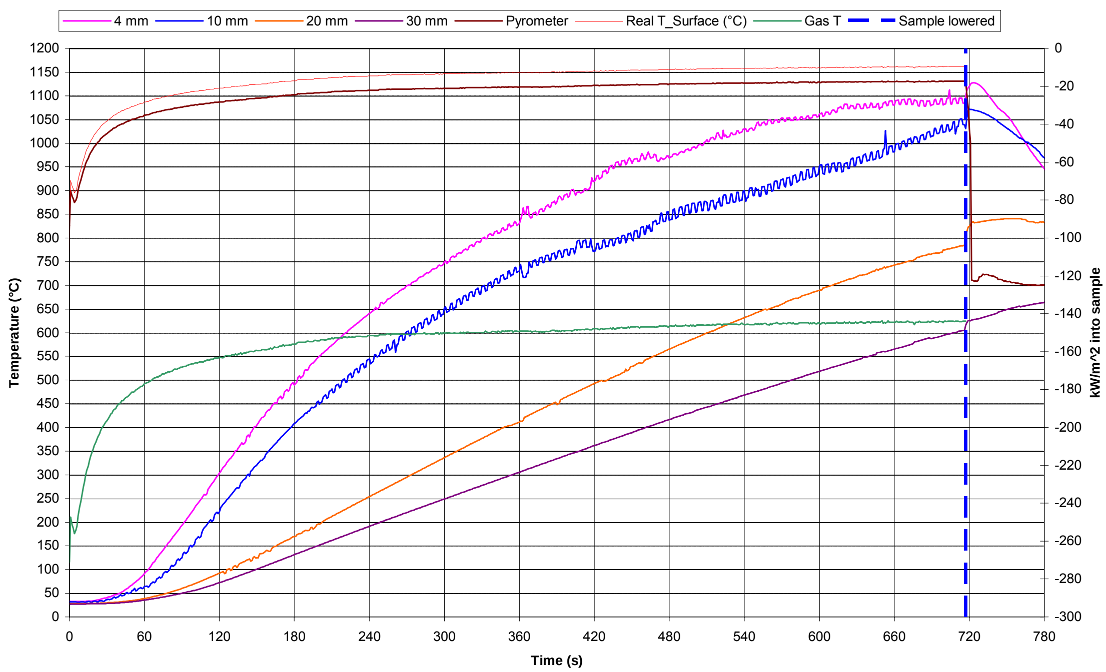
Char-Ore; 40 mm layer, 1400°C, 9minutes

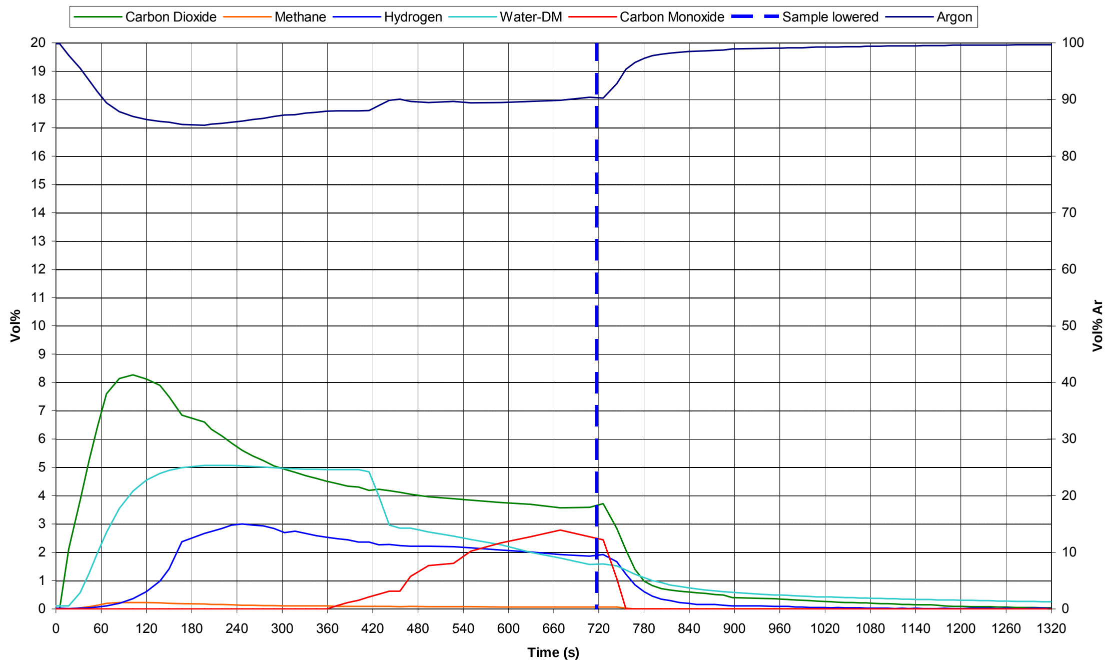


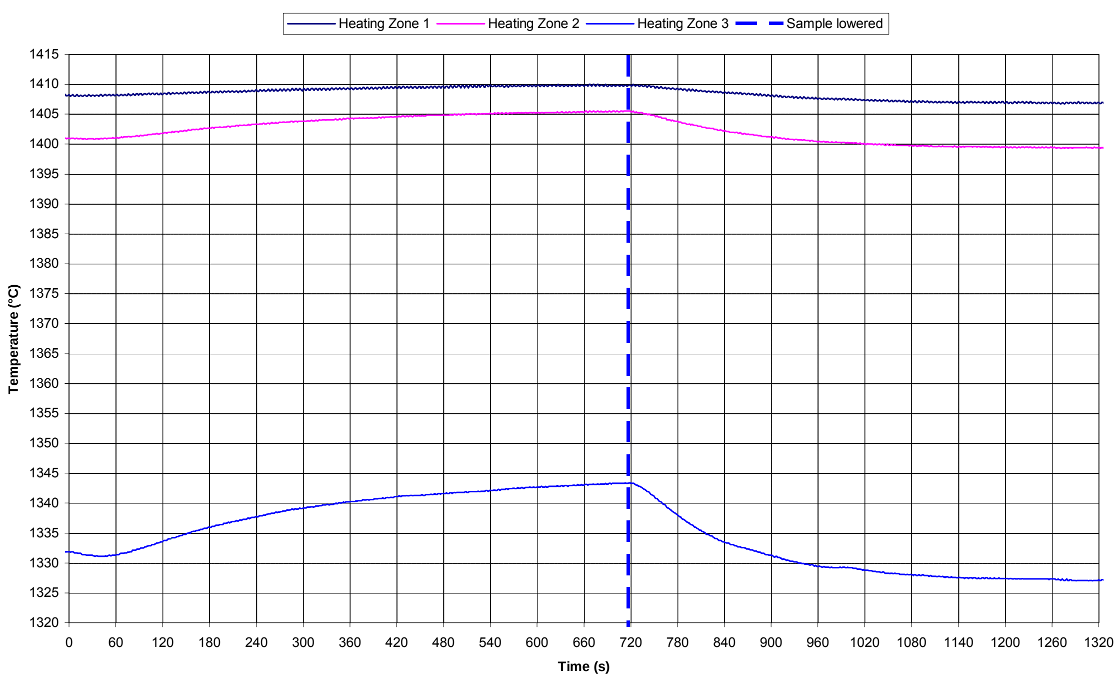




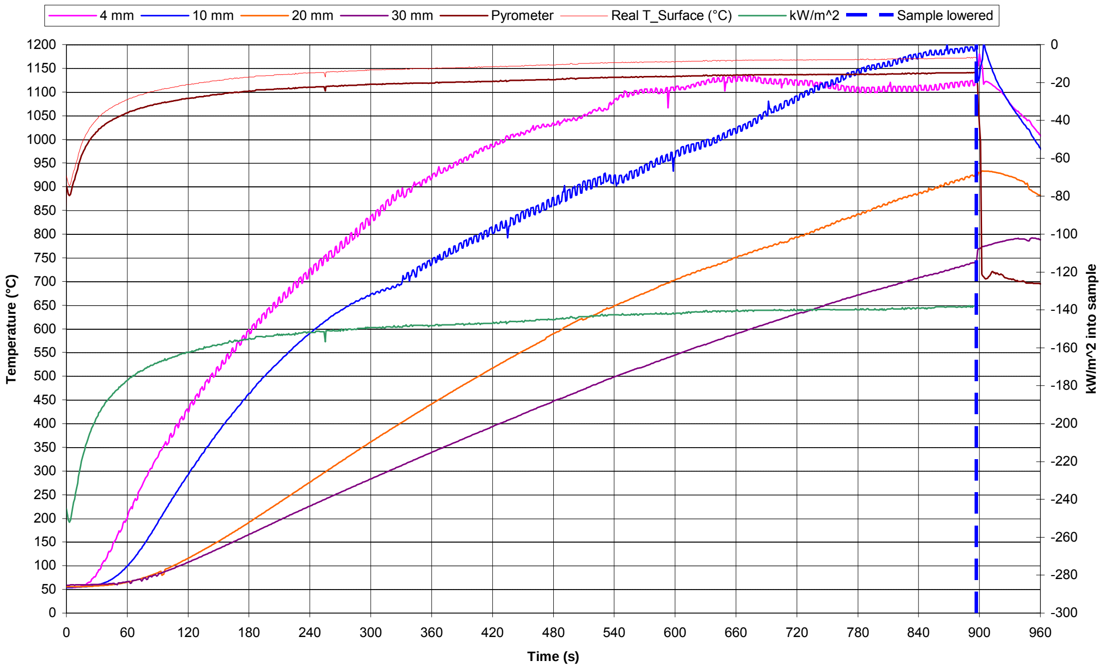
Char-Ore; 40 mm layer, 1400°C, 12minutes

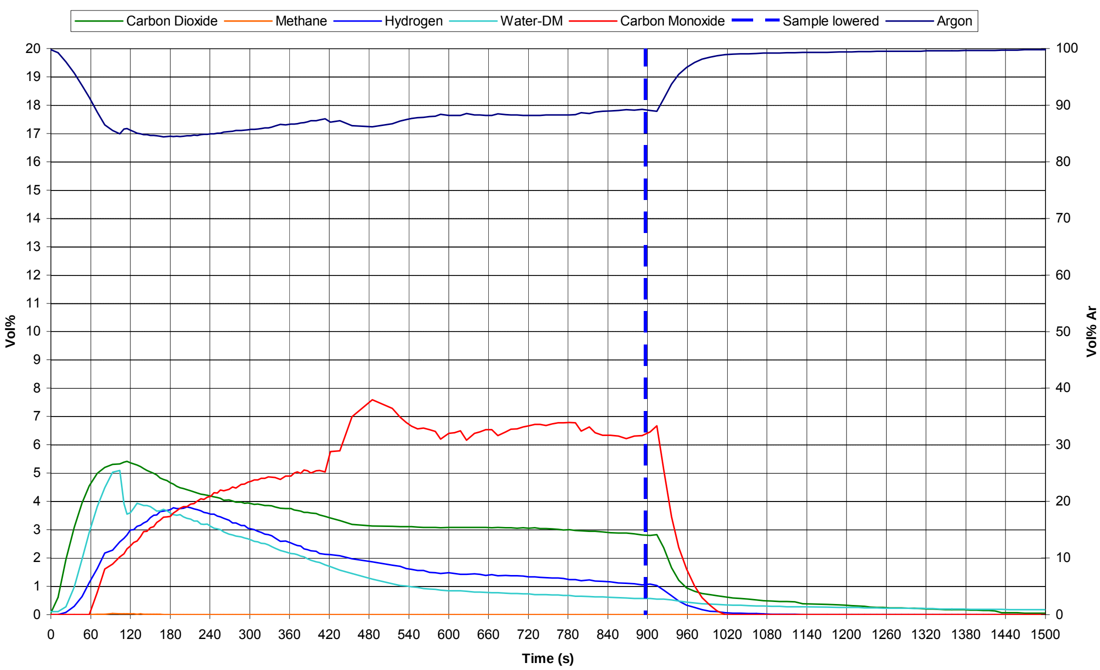


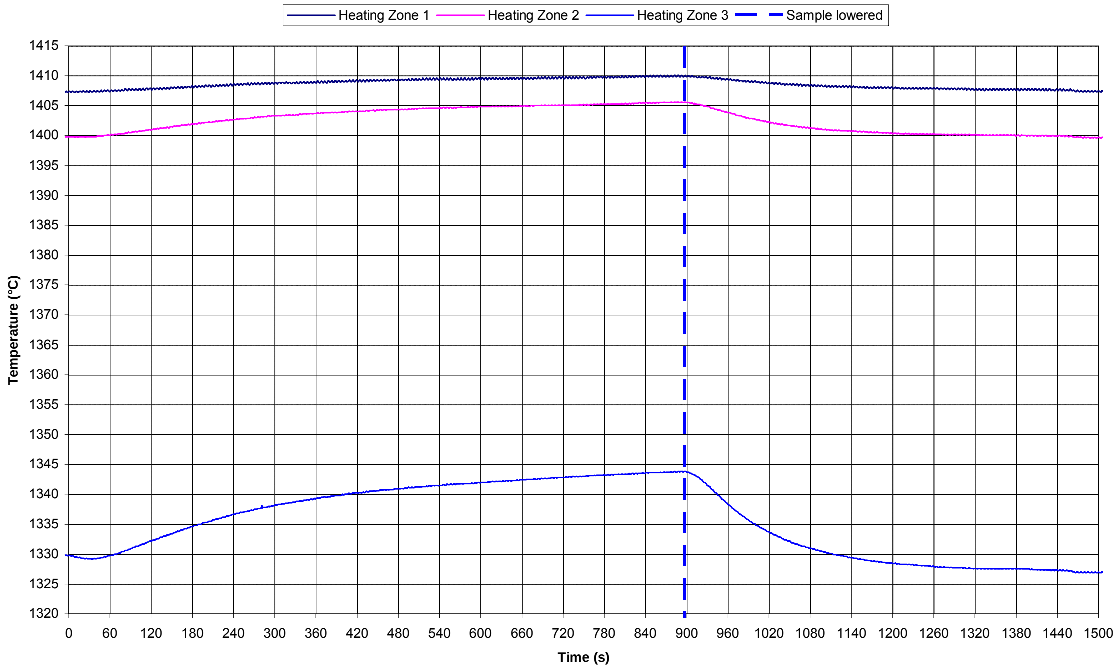

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Sample lowered
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

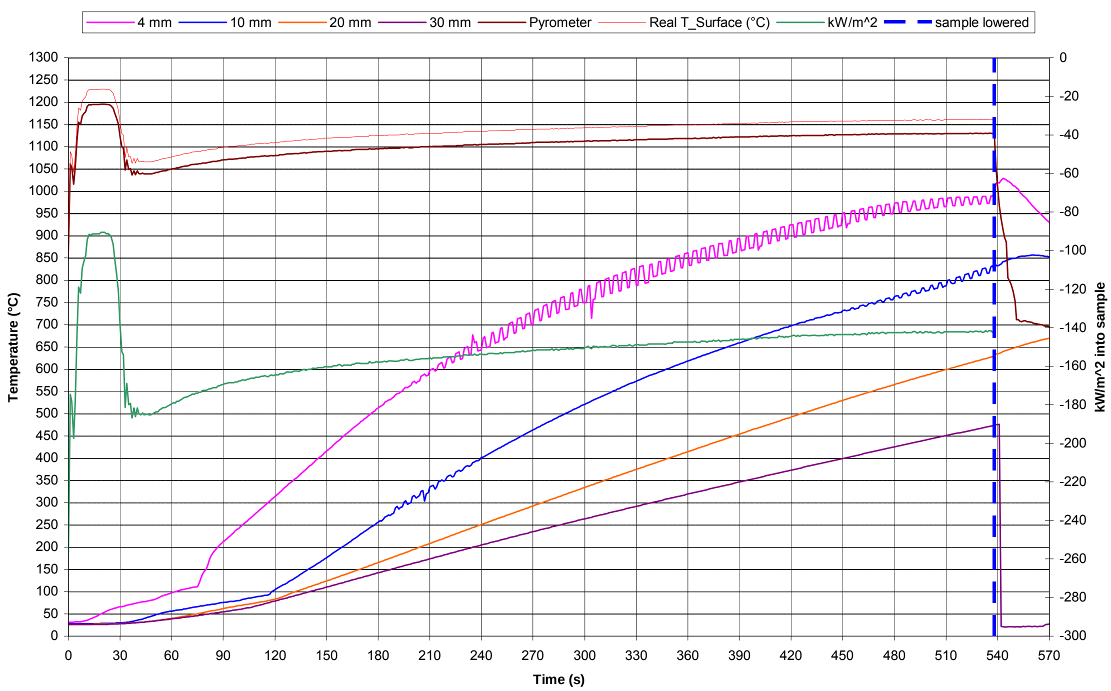
Char-Ore; 40 mm layer, 1400°C, 15minutes

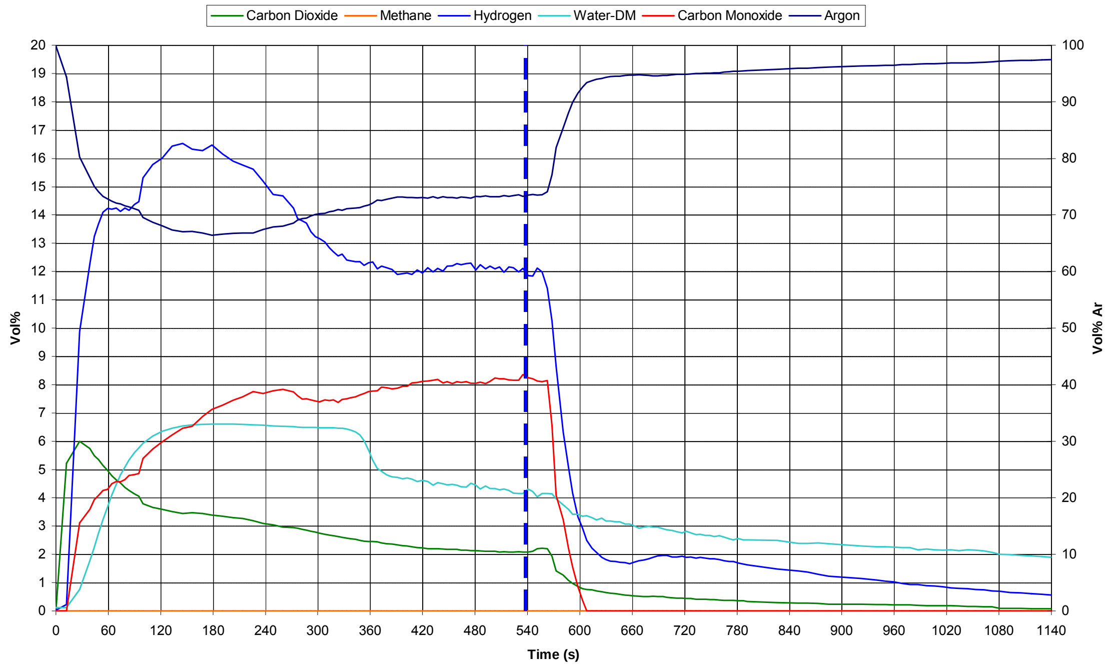


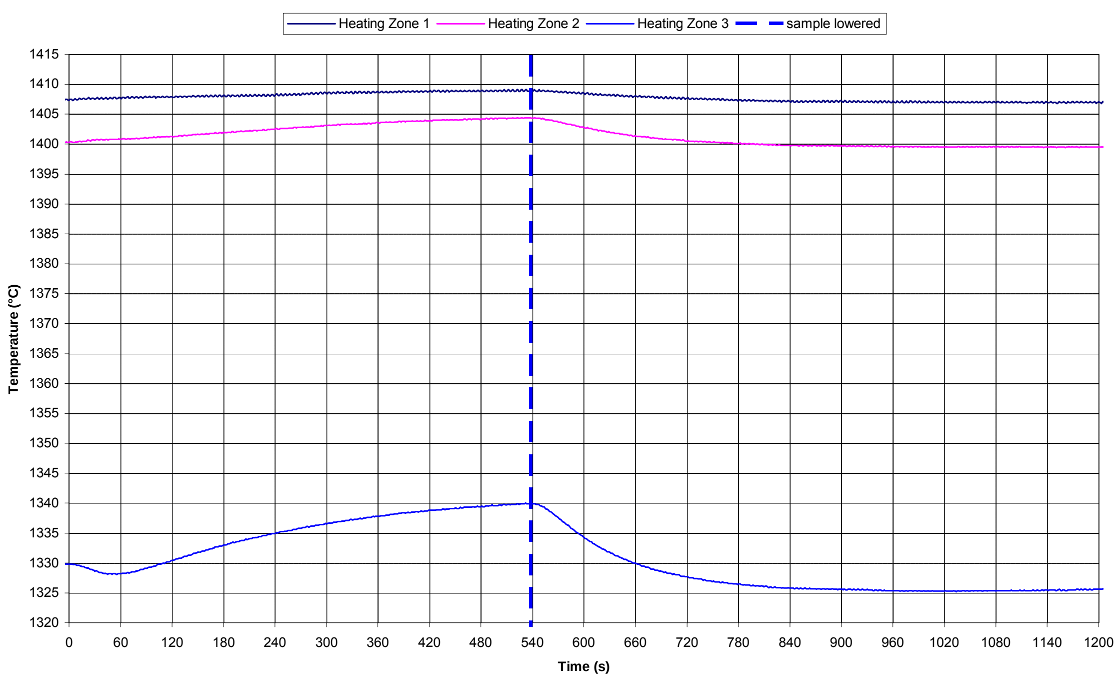




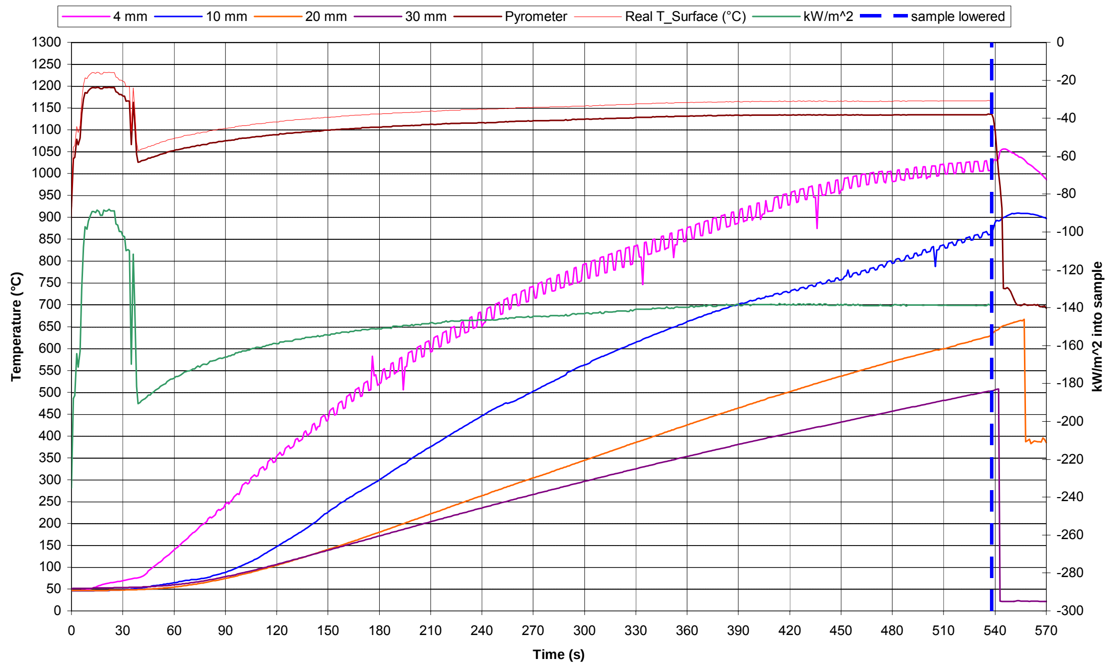
-850 +425 µm Coal & -2000 +1400 µm Ore; 40 mm layer, 1400°C, 9minutes

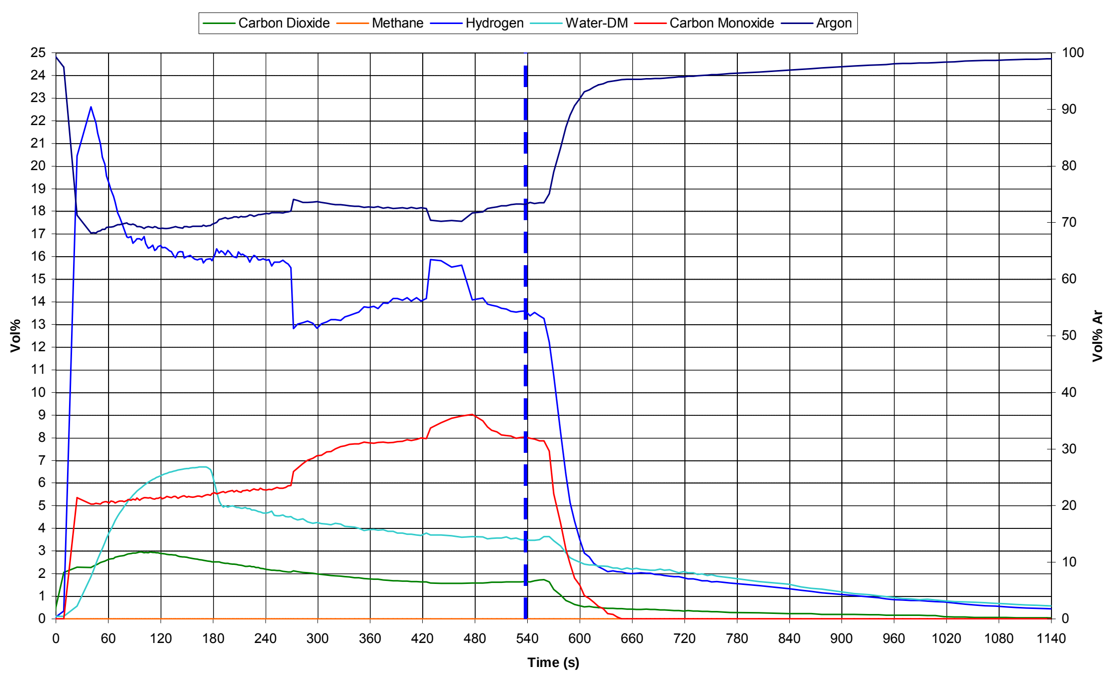


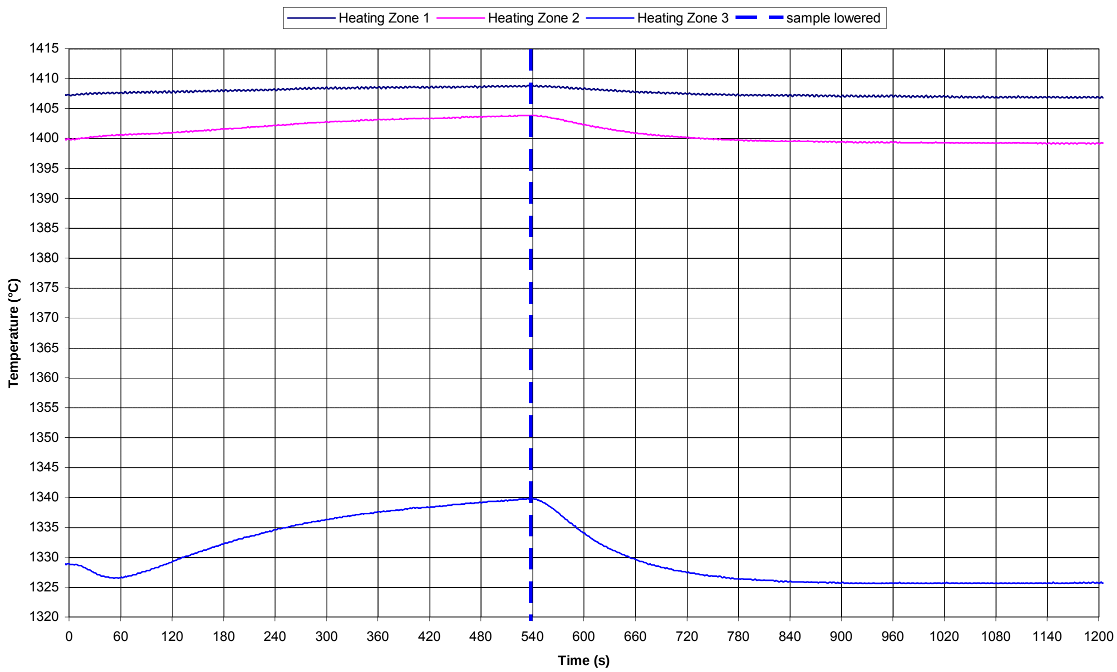

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
sample lowered
Temperature (°C)
Time (s)

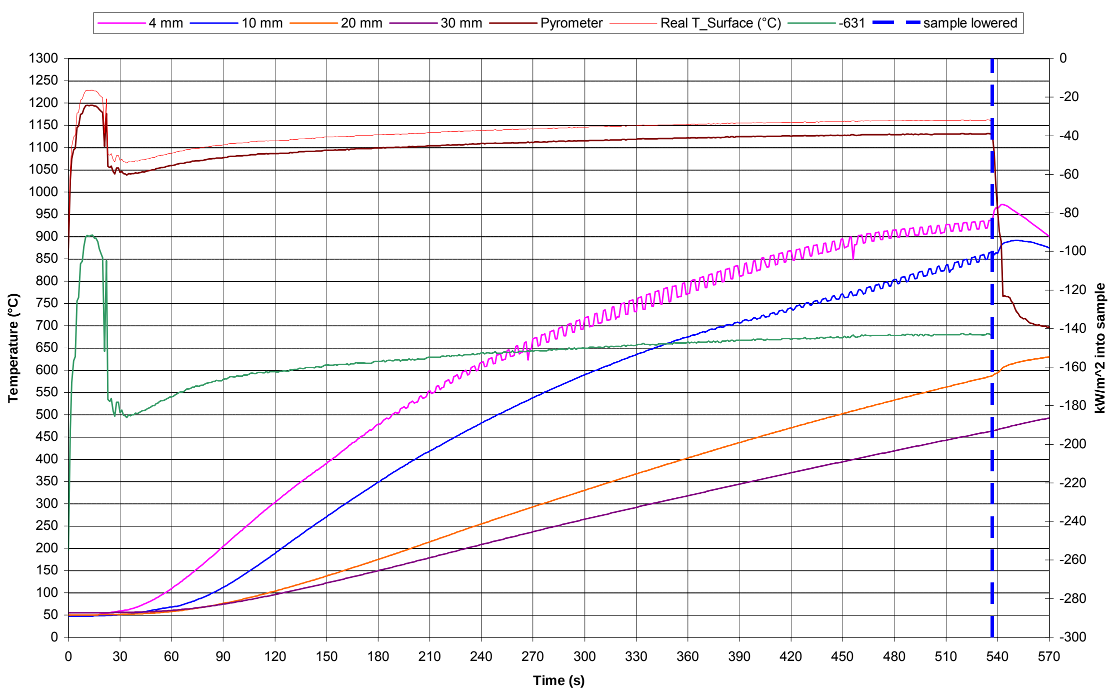
-2000 +1400 μm Coal & -850 +425 μm Ore; 40 mm layer, 1400°C, 9minutes

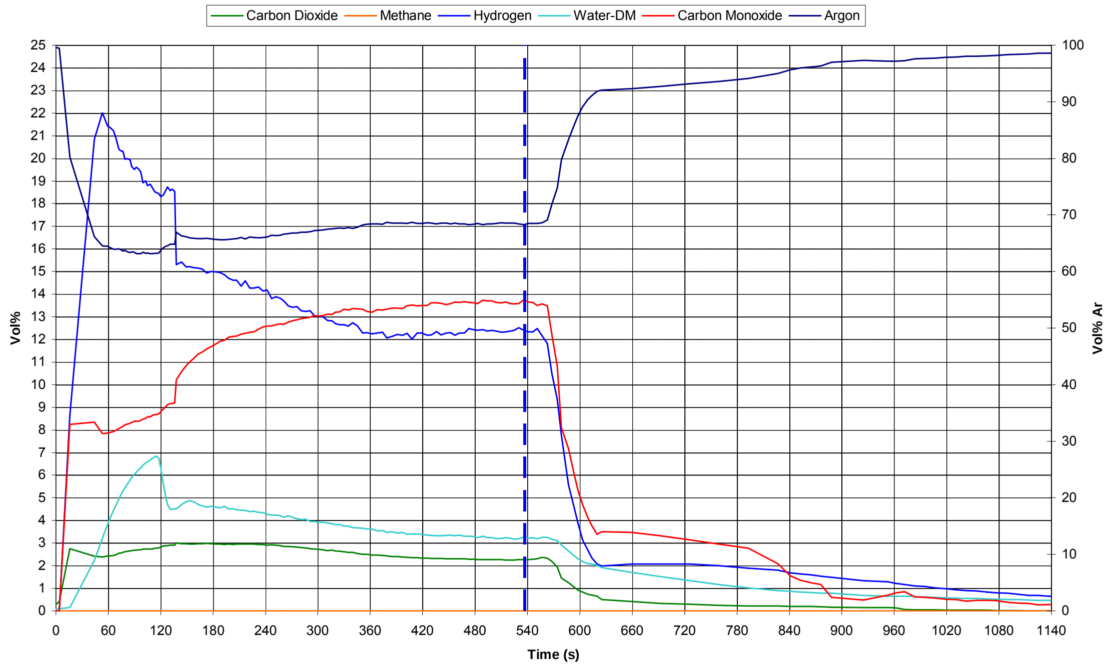


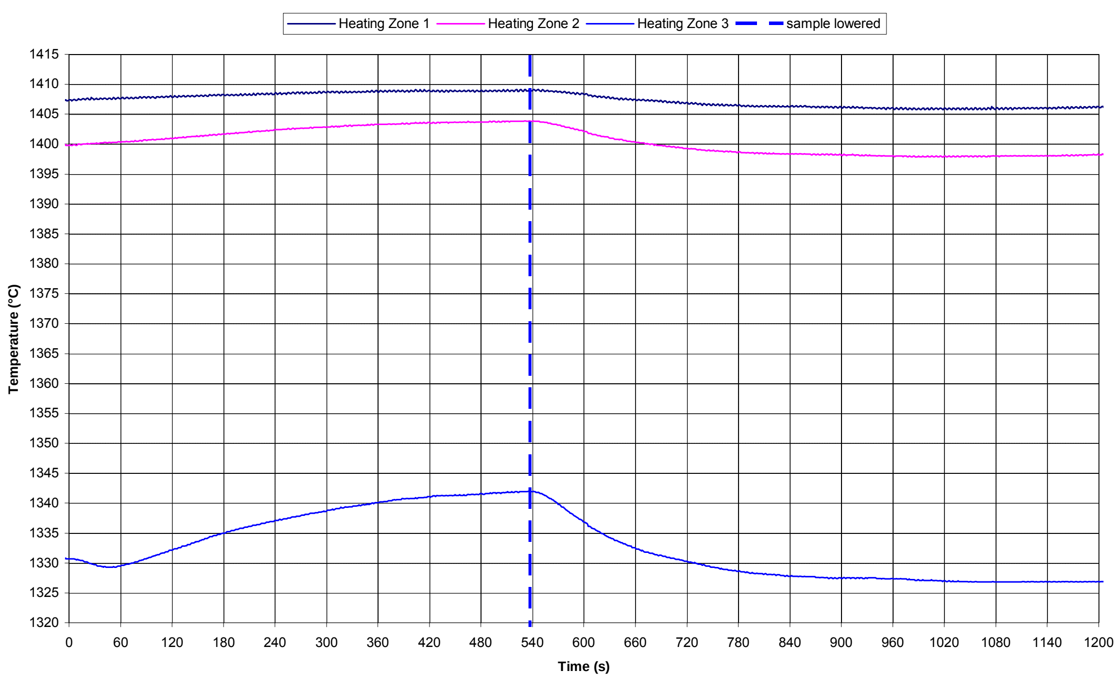




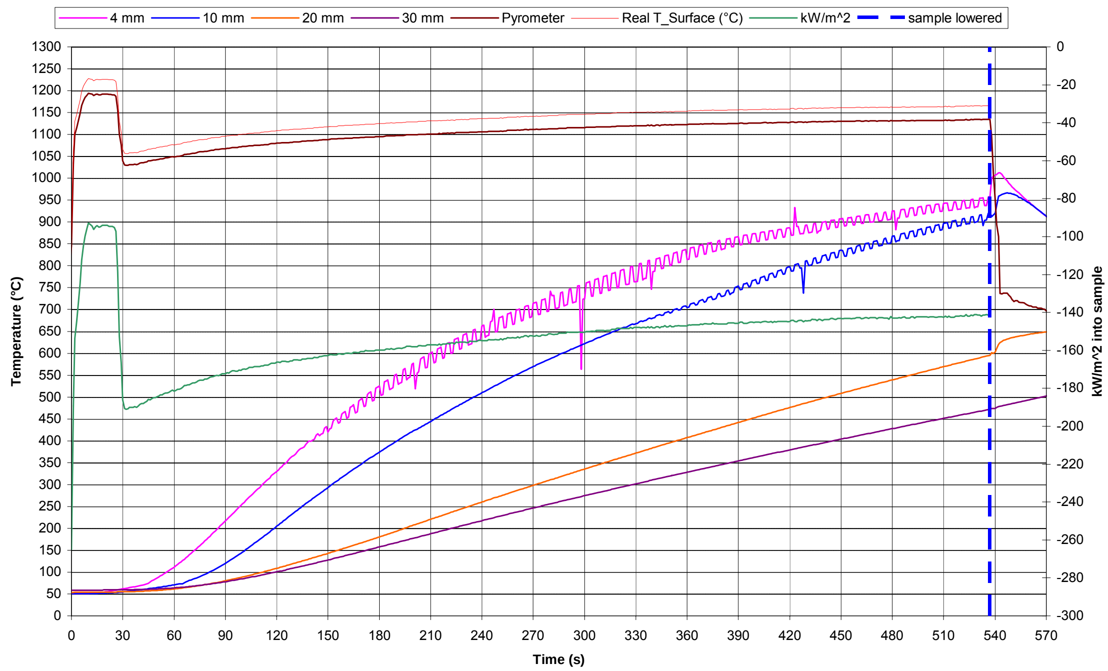
-425 +300 µm Coal & -850 +425 µm Ore; 40 mm layer, 1400°C, 9minutes

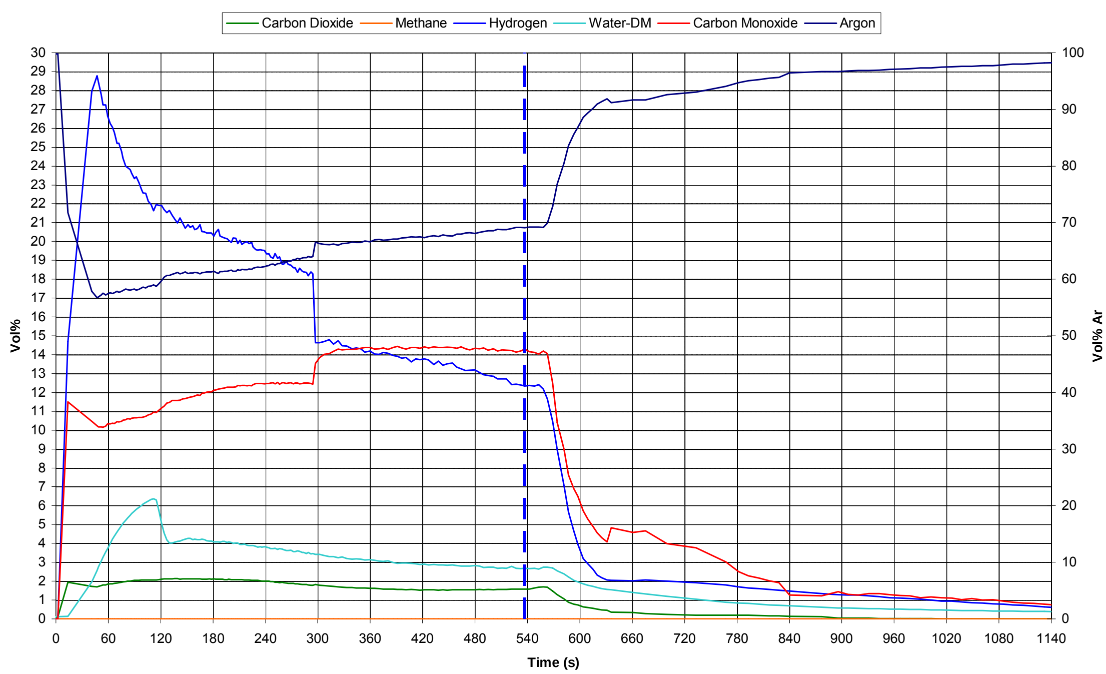


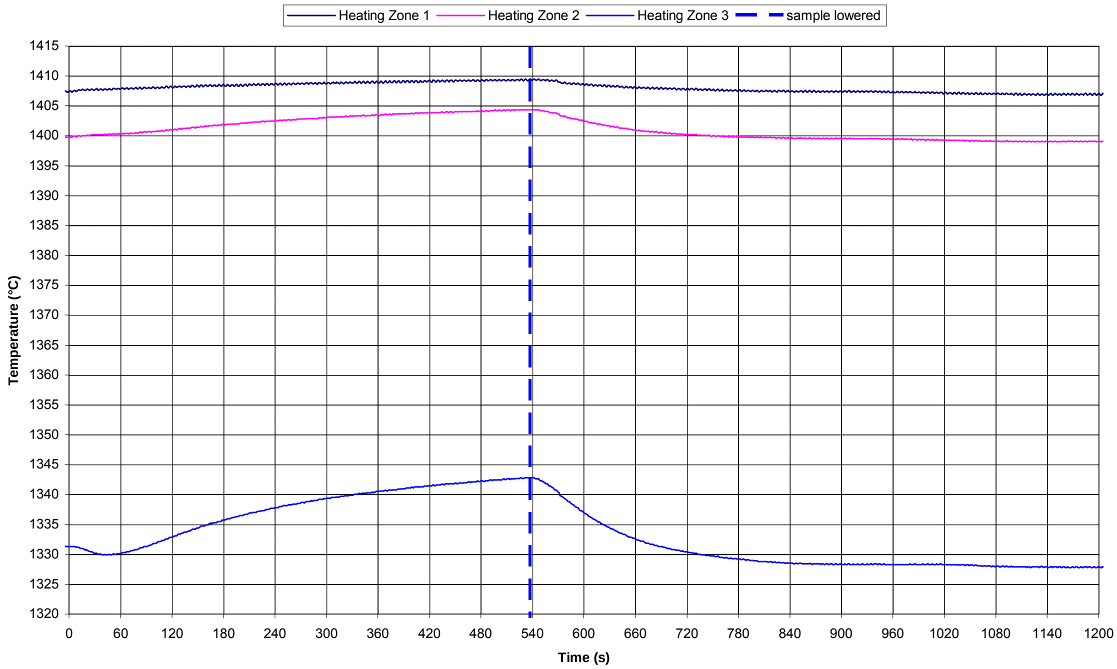

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
sample lowered
Temperature (°C)
Time (s)

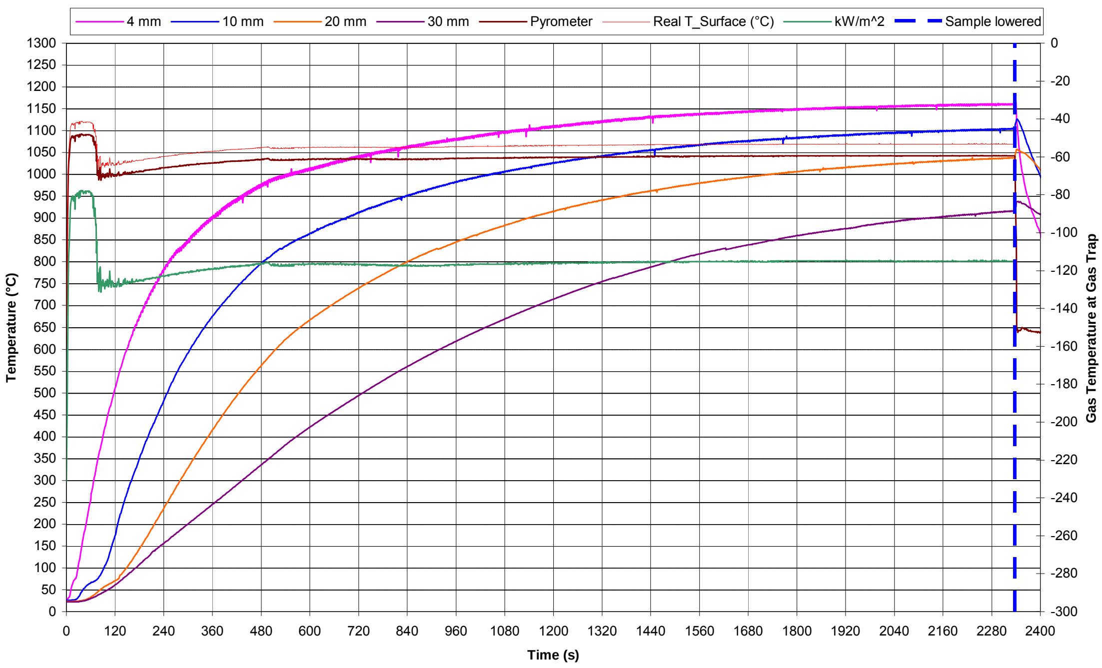
-850 +425 µm Coal & -425 +300 µm Ore; 40 mm layer, 1400°C, 9minutes

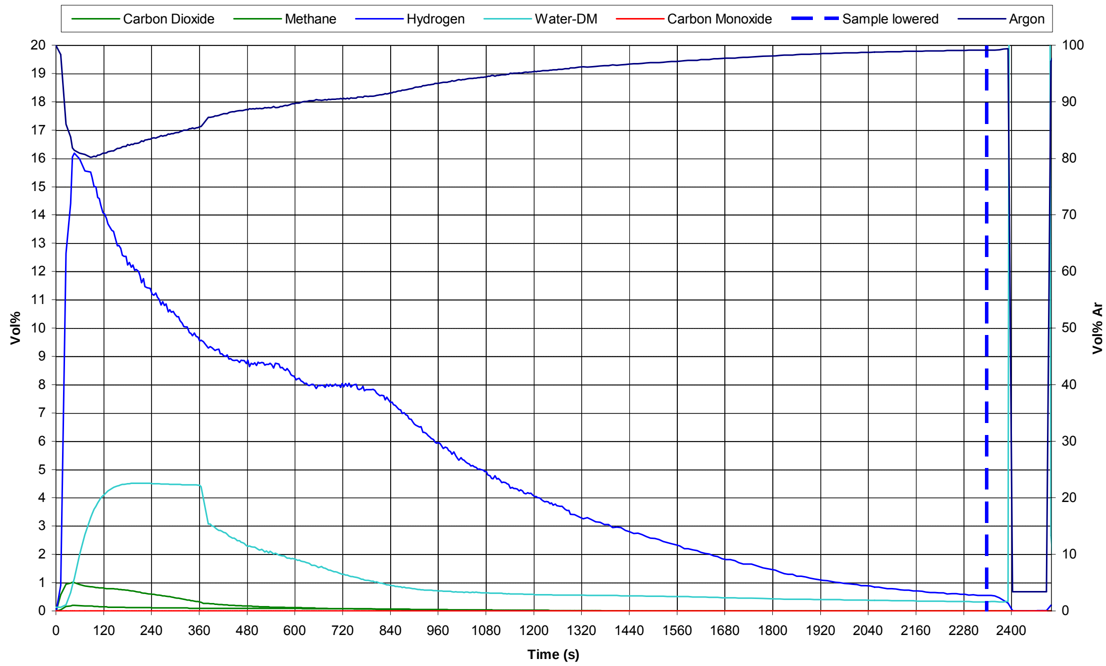


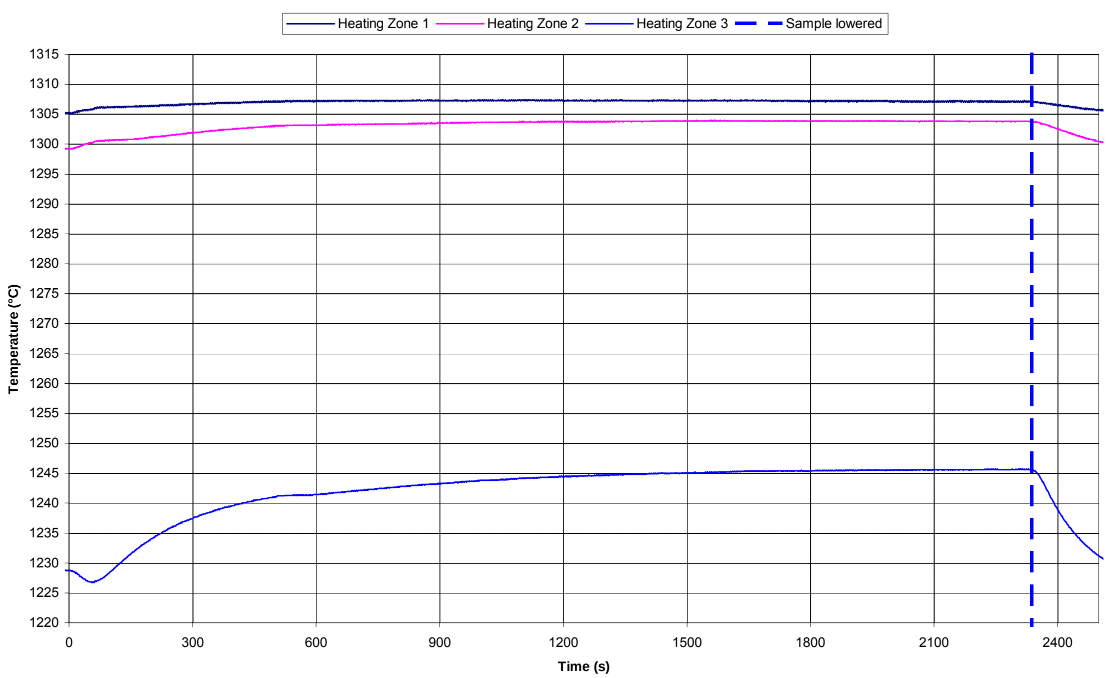




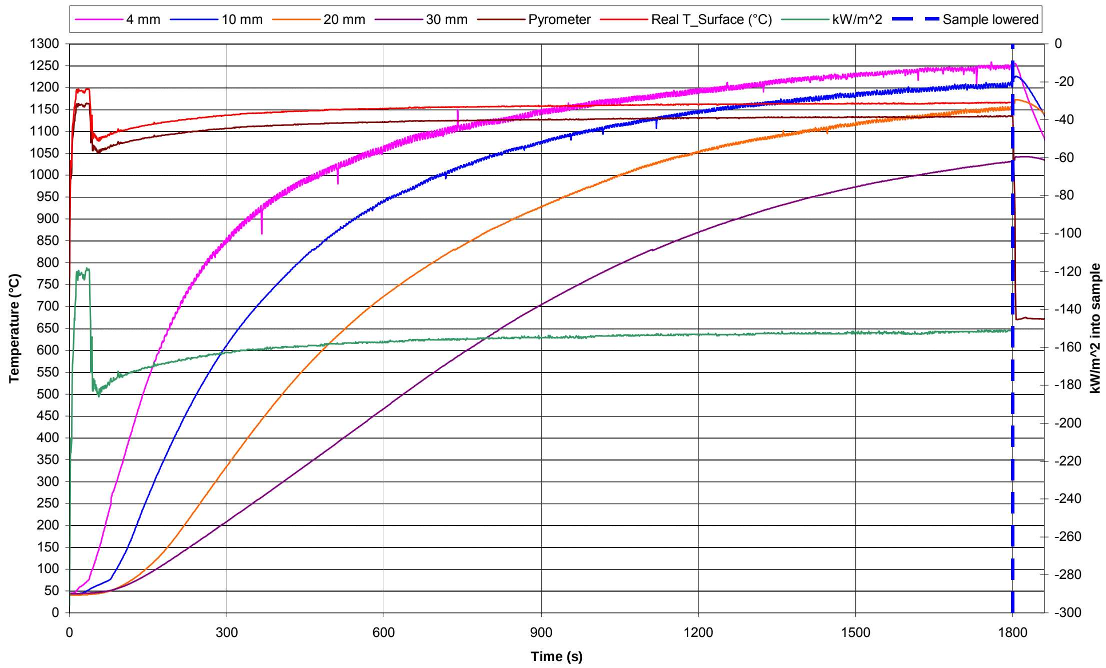
Alumina-Coal; 40 mm layer, 1300°C

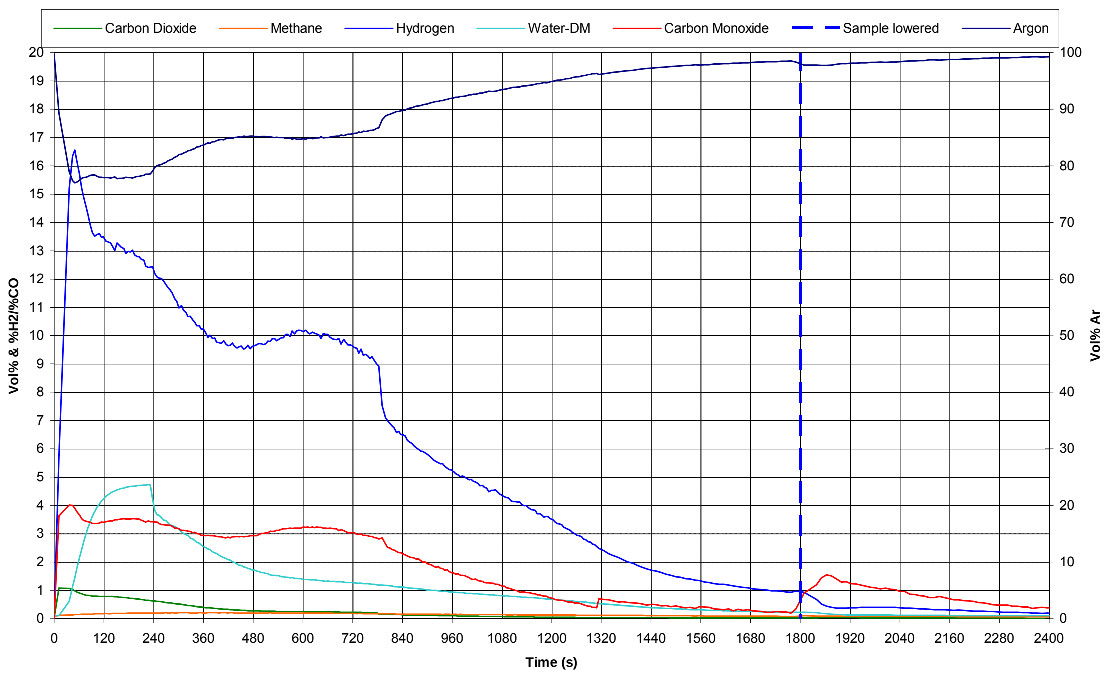


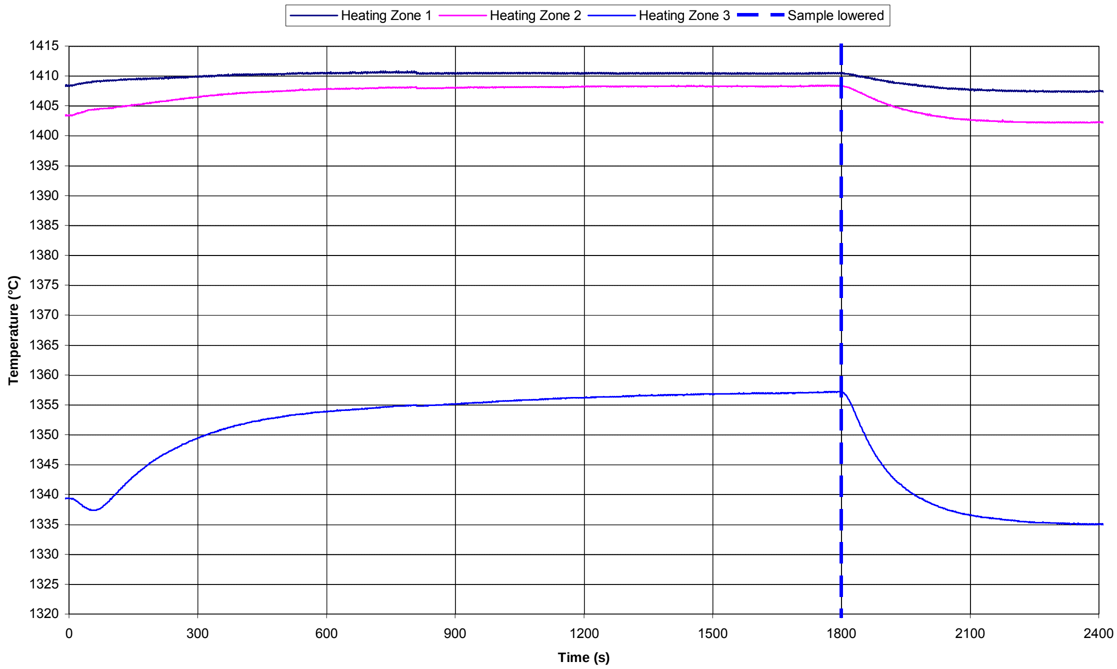

Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
Sample lowered
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
Sample lowered
Temperature (°C)
Time (s)

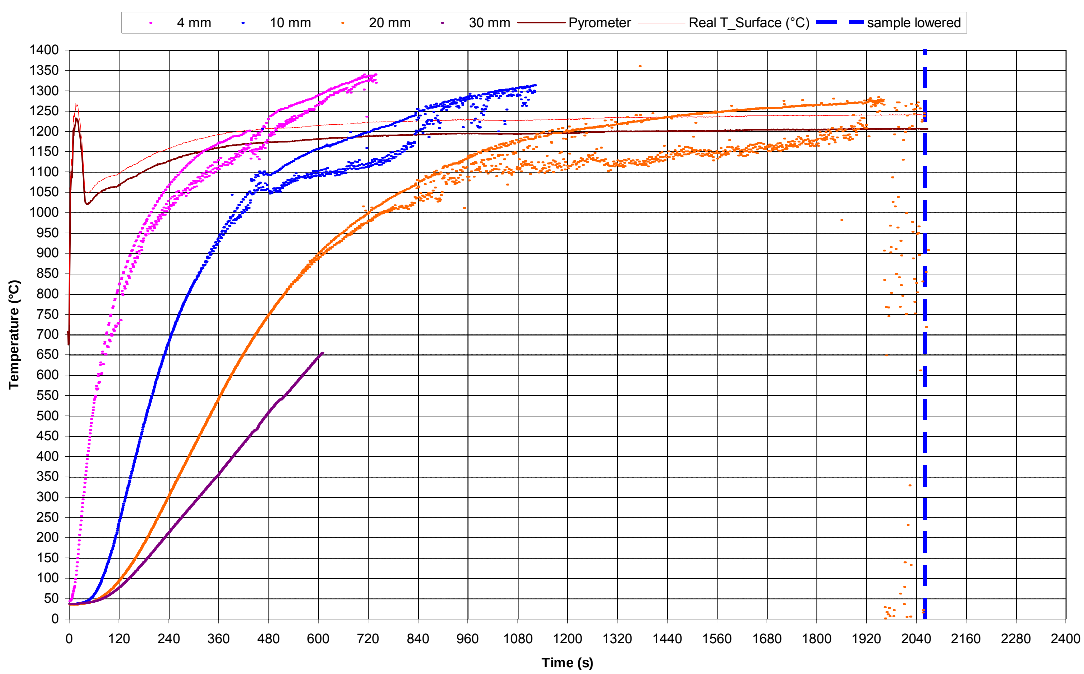
Alumina-Coal; 40 mm layer, 1400°C

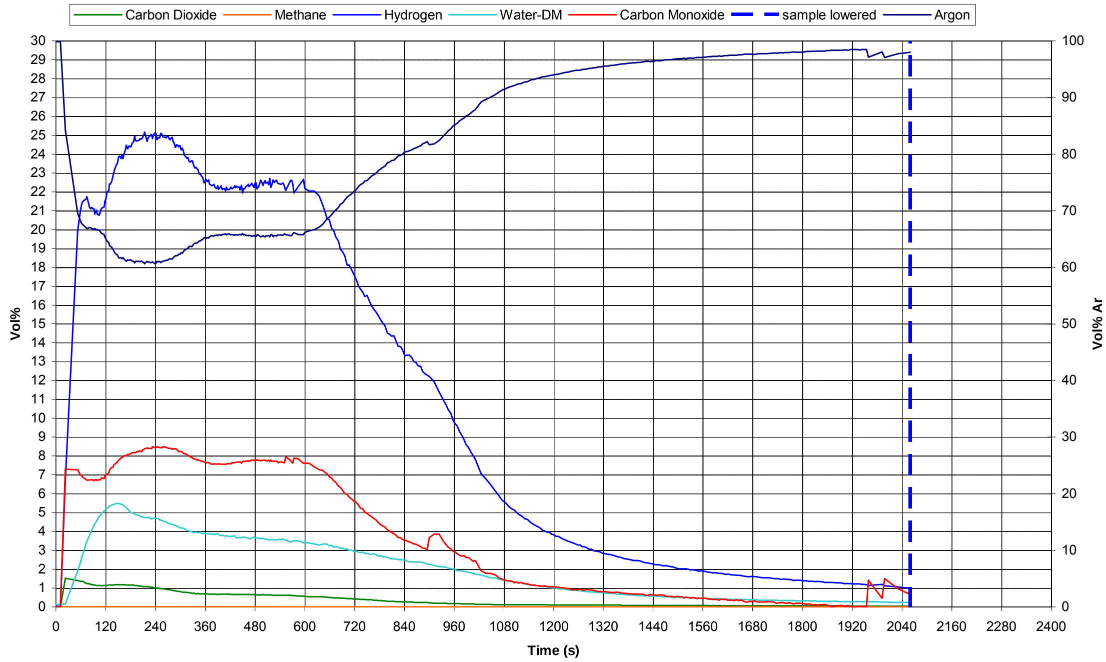


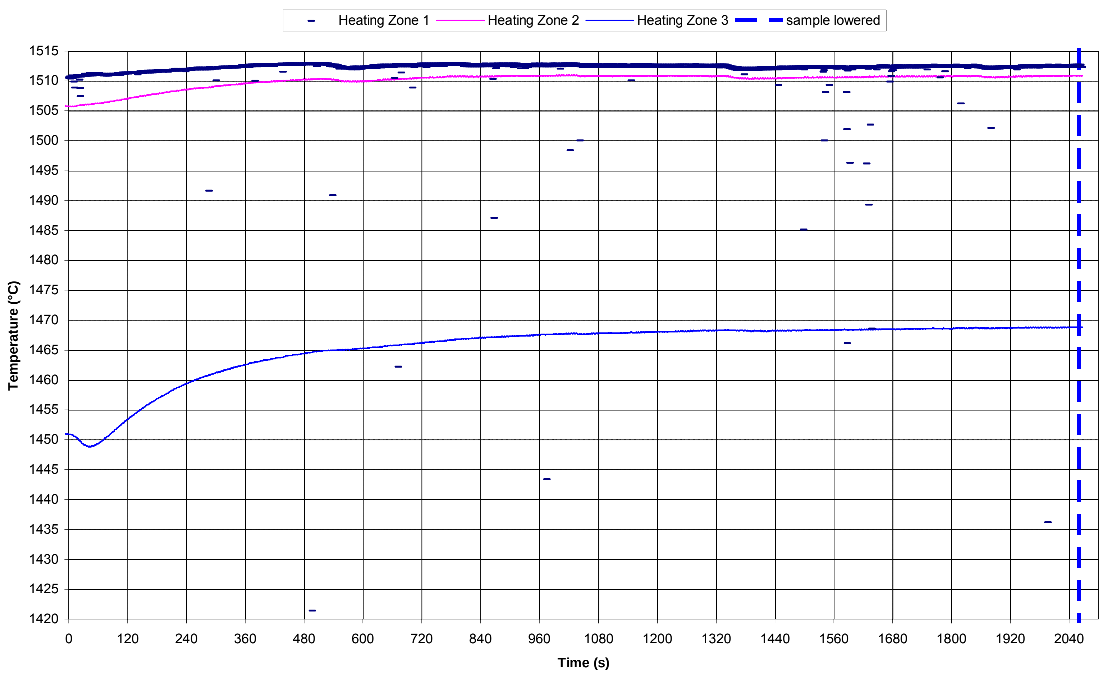




Alumina-Coal; 40 mm layer, 1500°C




Carbon Dioxide
Methane
Hydrogen
Water-DM
Carbon Monoxide
sample lowered
Argon
Vol%
Vol% Ar
Time (s)


Heating Zone 1
Heating Zone 2
Heating Zone 3
sample lowered
Temperature (°C)
Time (s)

Appendix IX

Calculation of %Carbon consumption, %Reduction and Total mass loss

%Carbon consumption

$$m_{total}^{in} = m_{Fe}^{out} \cdot \frac{100}{\%Fe_{ore}^{in}} \cdot \frac{100}{\%Ore}$$

$$m_{C\_total}^{in} = m_{total}^{in} \cdot \frac{\%Coal}{100} \cdot \frac{\%TotalC}{100}$$

$$m_{C}^{top\_in} = X_{top} \cdot m_{C\_total}^{in}$$

$$m_{C}^{top\_out} = m_{total\_corr}^{top\_out} \cdot \frac{\%C_{corr}^{top\_out}}{100}$$

$$\%C_{consumption}^{top} = \frac{(m_{C}^{top\_in} - m_{C}^{top\_out})}{m_{C}^{top\_in}} \cdot 100$$

The %Carbon consumption is calculated similarly for the middle and bottom nodes

%Reduction

$$m_{O}^{top\_in} = m_{total\_corr}^{top\_out} \cdot \frac{\%Fe(total)_{corr}^{top\_out}}{100 \cdot mm_{Fe} \cdot 2} \cdot 3 \cdot mm_{O}$$

$$m_{O}^{top\_out} = m_{total\_corr}^{top\_out} \cdot \left(\frac{\%Fe(+2)_{corr}^{top\_out}}{100 \cdot mm_{Fe}} \cdot mm_{O} + \frac{\%Fe(+3)_{corr}^{top\_out}}{100 \cdot mm_{Fe} \cdot 2} \cdot 3 \cdot mm_{O} \right)$$

$$\%R^{top} = \frac{(m_{O}^{top\_in} - m_{O}^{top\_out})}{m_{O}^{top\_in}} \cdot 100$$

The %Reduction is calculated similarly for the middle and bottom nodes

Mass loss calculated from weighed masses and firbre board carry over correction

$$\Delta m_{total}^{weighed} = m_{total}^{in} - m_{total\_corr}^{top\_out} - m_{SiO_2}^{carry-over} - m_{Al_2O_3}^{carry-over}$$

Total mass oxygen in unreacted sample

$$m_{O\_total}^{in} = m_{O}^{top\_in} + m_{O}^{mid\_in} + m_{O}^{bot\_in} + m_{C\_total}^{in} \cdot \left(\frac{\%H_2O\_Coal}{100 \cdot mm_{H_2O}} \cdot mm_{O} + \frac{\%O\_Coal}{100} \right)$$

$\%H_2O\_Coal$ = %Moisture in Proximate analysis of coal

$\%O\_Coal$ = %O in Ultimate analysis of coal

$m_{Al_2O_3}^{carry-over}$ = g. Al_2O_3 carry-over from fibreboard to reacted sample mix in top node

$m_{SiO_2}^{carry-over}$ = g. SiO_2 carry-over from fibreboard to reacted sample mix in top node

m_{total}^{in} = total g. unreacted sample mix in crucible

$\Delta m_{total}^{weighed}$ = sample mass loss calculated from weighed masses and fibre board carry over correction

$m_j^{i\_in}$ = mass of component *j* in node *i* of unreacted sample

$m_j^{i\_out}$ = mass of component *j* in node *i* of reacted sample

$m_{j\_corr}^{i\_out}$ = corrected mass of component *j* in node *i* of reacted sample

m_{total}^{in} = total g. unreacted sample mix in crucible

$\%Y^{i\_in}$ = mass% of component *Y* in node *i* of unreacted sample

$\%Y^{i\_out}$ = mass% of component *Y* in node *i* of reacted sample

$\%Y_{corr}^{i\_out}$ = corrected mass% of component *Y* in node *i* of reacted sample

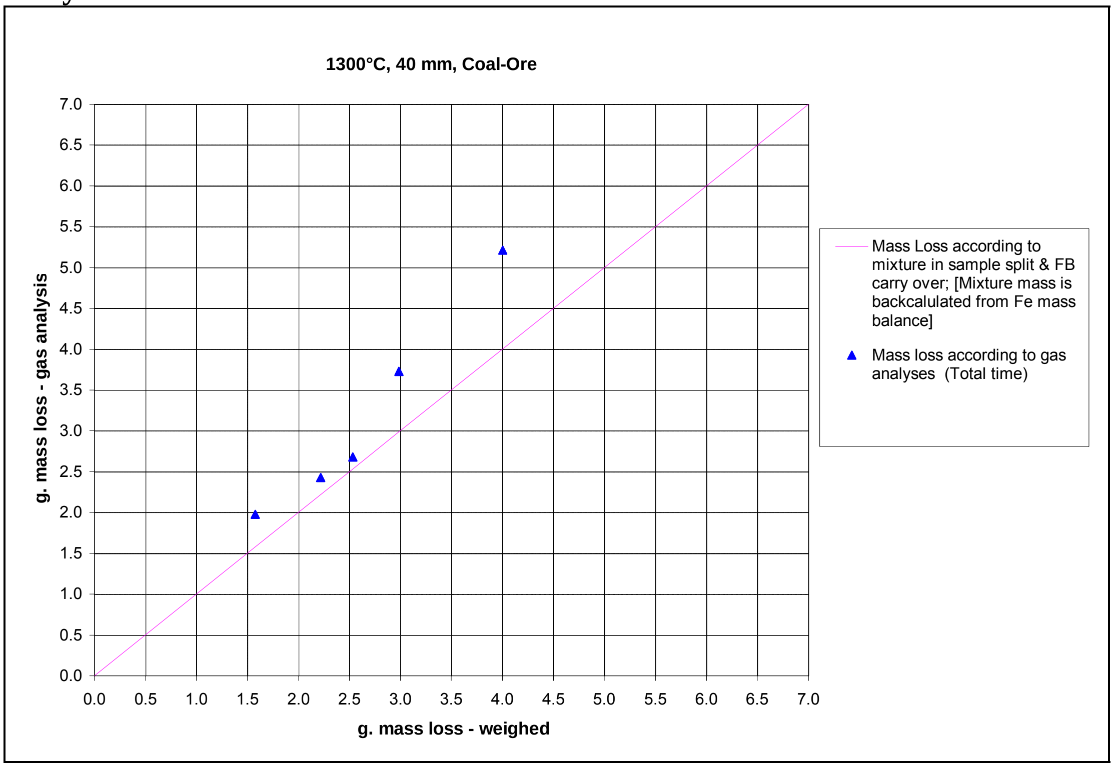
mm_k = molar mass of component *k*

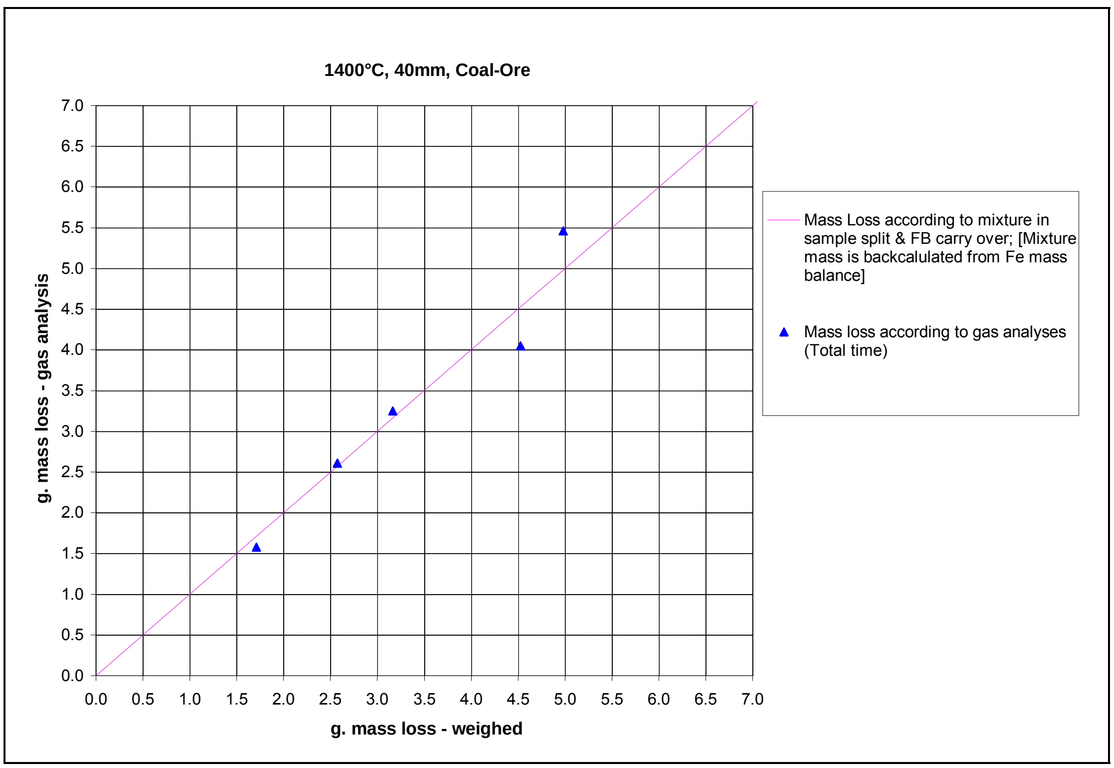
X_i = mass fraction of sample material mix in node *i*, *i* = top, mid, bot for top, middle or bottom node

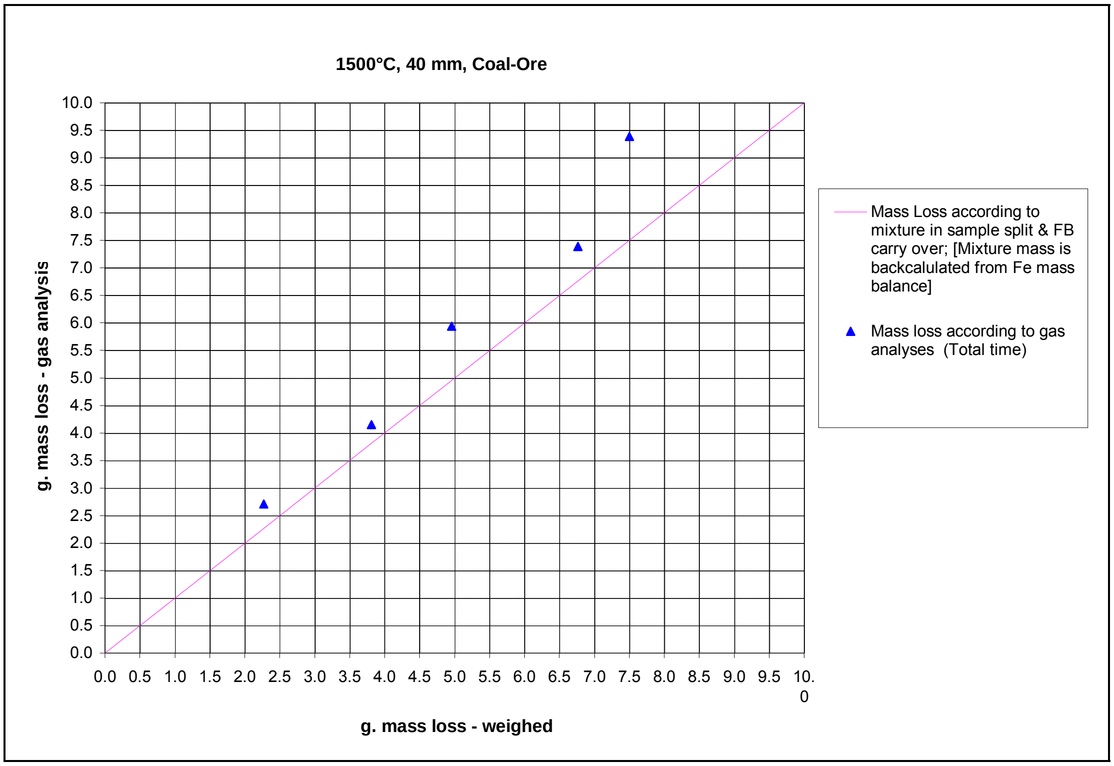
i = top, mid, bot for top, middle or bottom node

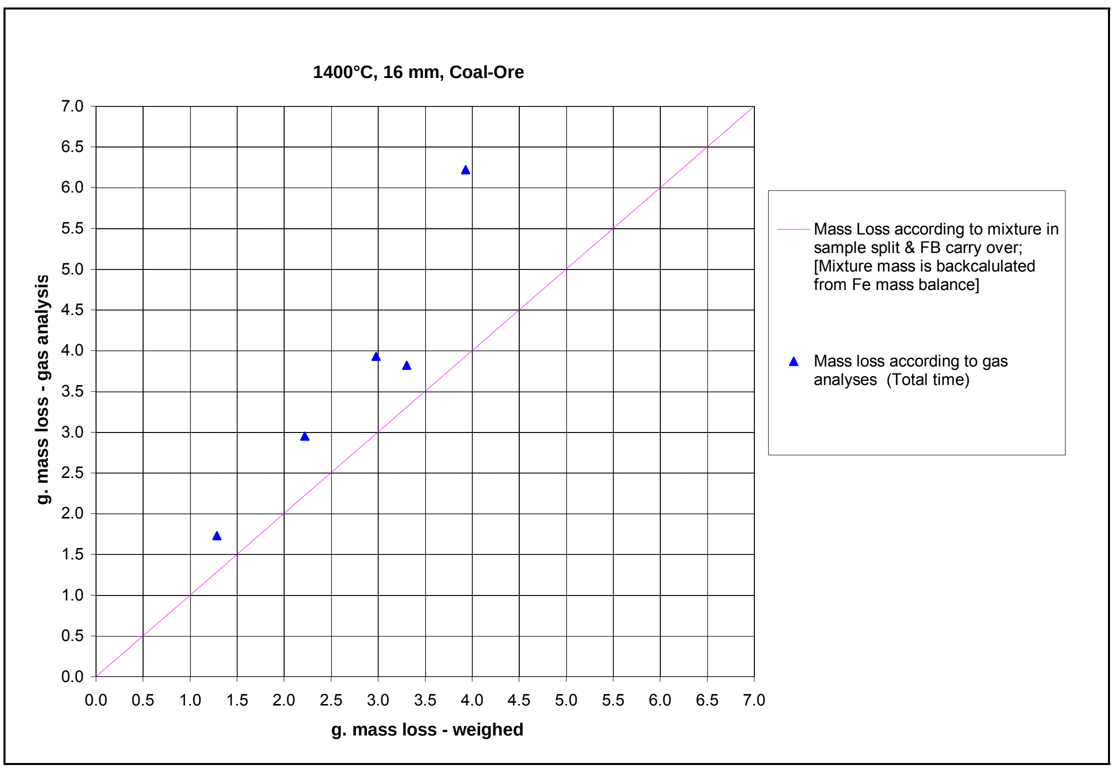
Appendix X

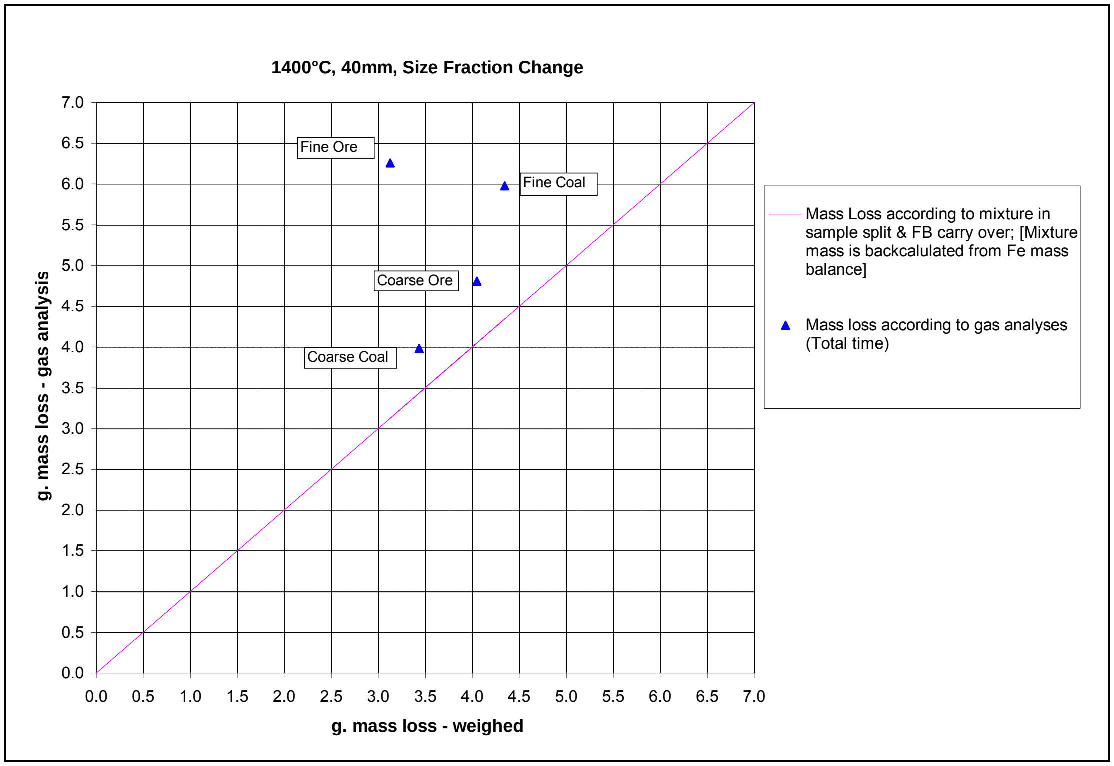
Appendix X (a): Graphs of total sample mass loss calculated from weighed masses and fibreboard (FB) carry over ($\Delta m_{total}^{weighed}$) vs. mass loss according to product gas analyses

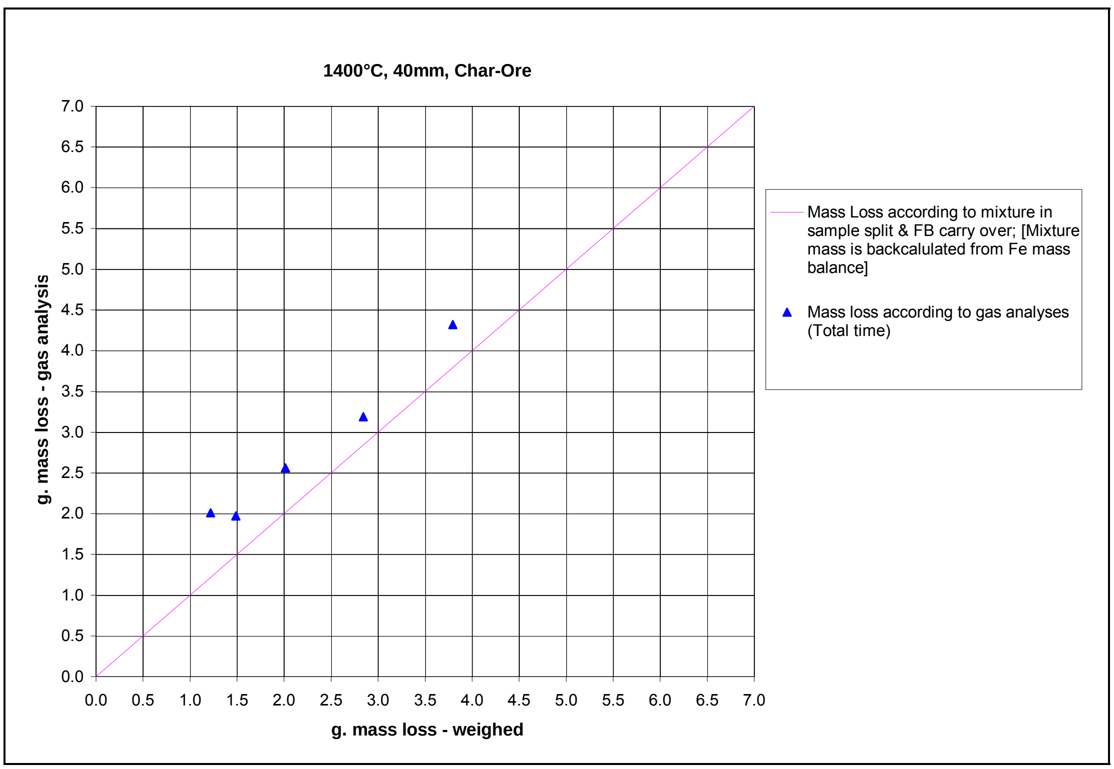




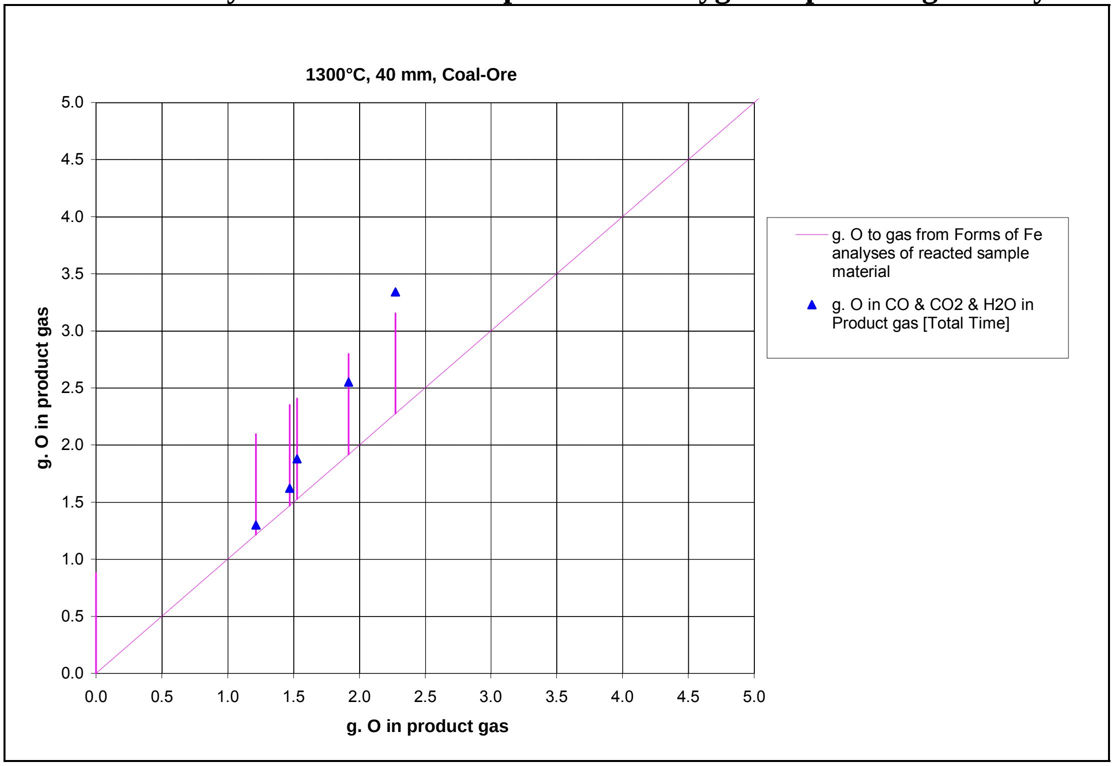

1500°C, 40 mm, Coal-Ore
g. mass loss - gas analysis
g. mass loss - weighed
Mass Loss according to mixture in sample split & FB carry over; [Mixture mass is backcalulated from Fe mass balance]
Mass loss according to gas analyses (Total time)

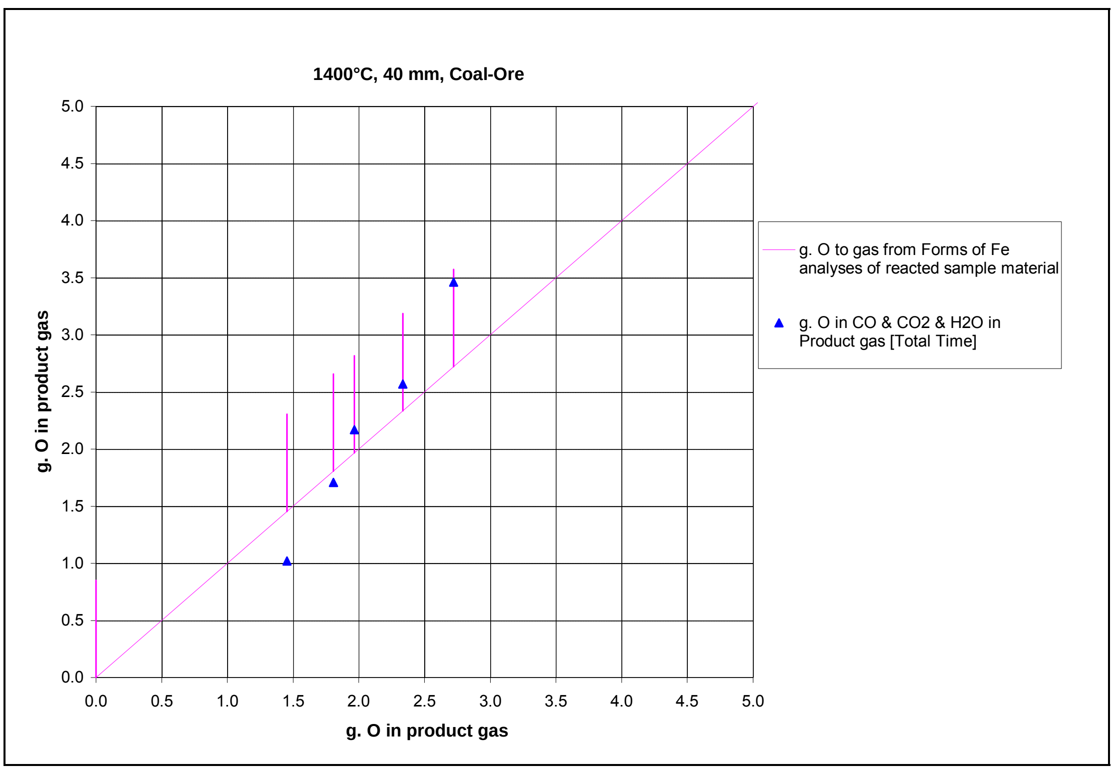

1400°C, 16 mm, Coal-Ore
g. mass loss - gas analysis
g. mass loss - weighed
Mass Loss according to mixture in sample split & FB carry over; [Mixture mass is backcalulated from Fe mass balance]
Mass loss according to gas analyses (Total time)

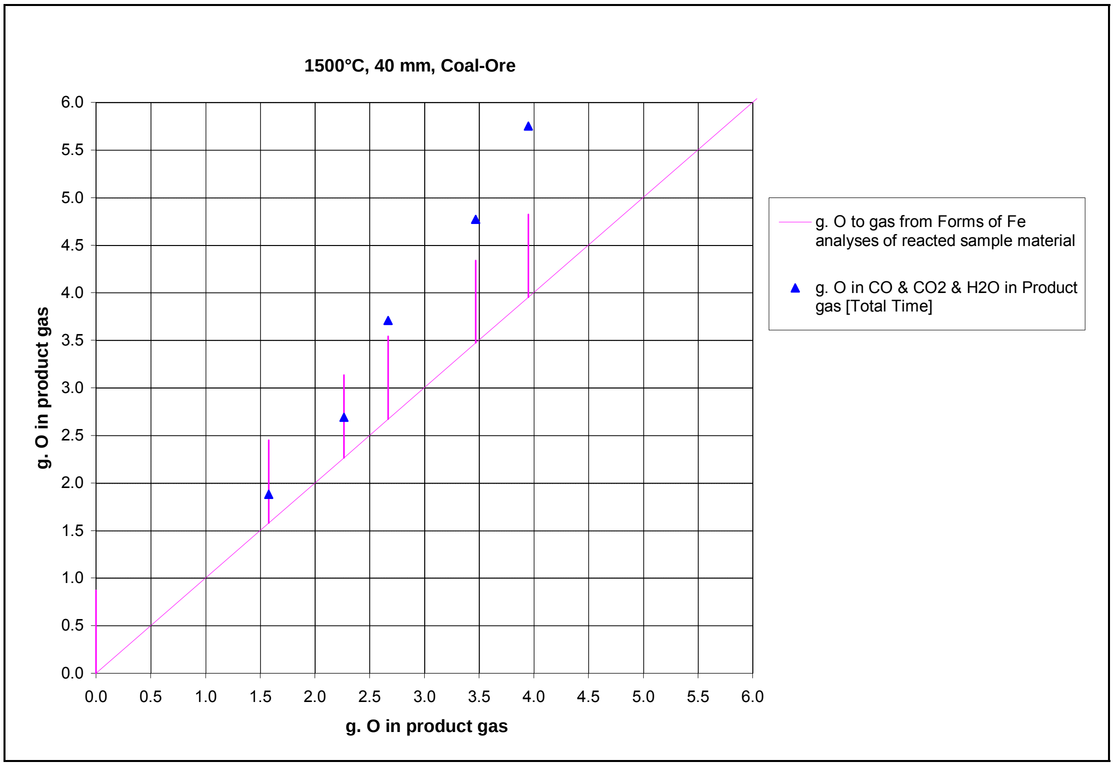

1400°C, 40mm, Size Fraction Change
g. mass loss - gas analysis
g. mass loss - weighed
Fine Ore
Fine Coal
Coarse Ore
Coarse Coal
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Mass Loss according to mixture in sample split & FB carry over; [Mixture mass is backcalulated from Fe mass balance]
Mass loss according to gas analyses (Total time)

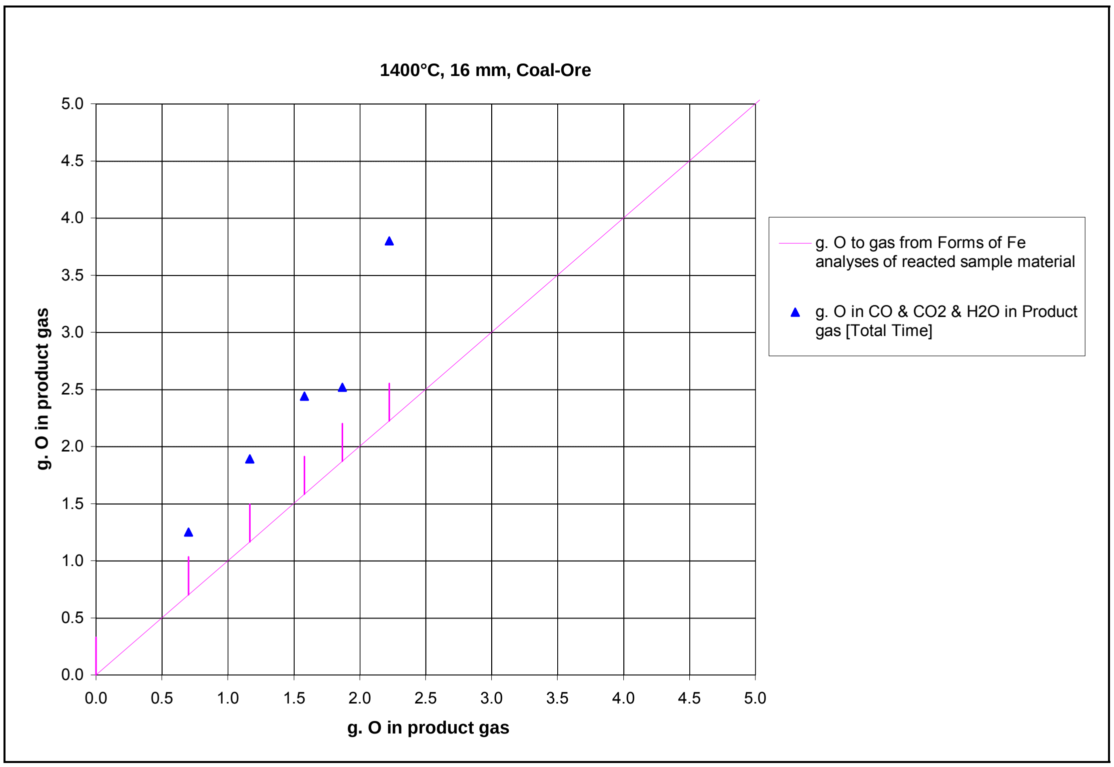

1400°C, 40mm, Char-Ore
g. mass loss - gas analysis
g. mass loss - weighed
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
Mass Loss according to mixture in sample split & FB carry over; [Mixture mass is backcalulated from Fe mass balance]
Mass loss according to gas analyses (Total time)

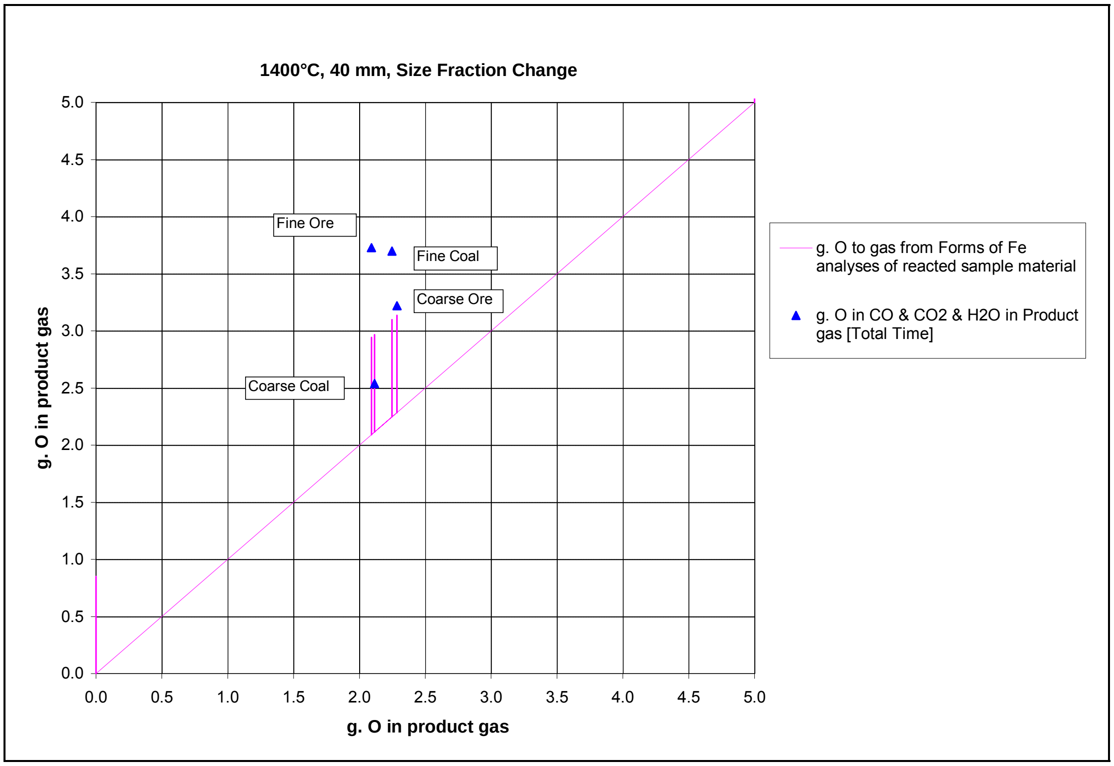
Appendix X (b): Graphs of total oxygen removed from sample as calculated from forms of Fe analyses for reacted sample vs. total oxygen in product gas analyses

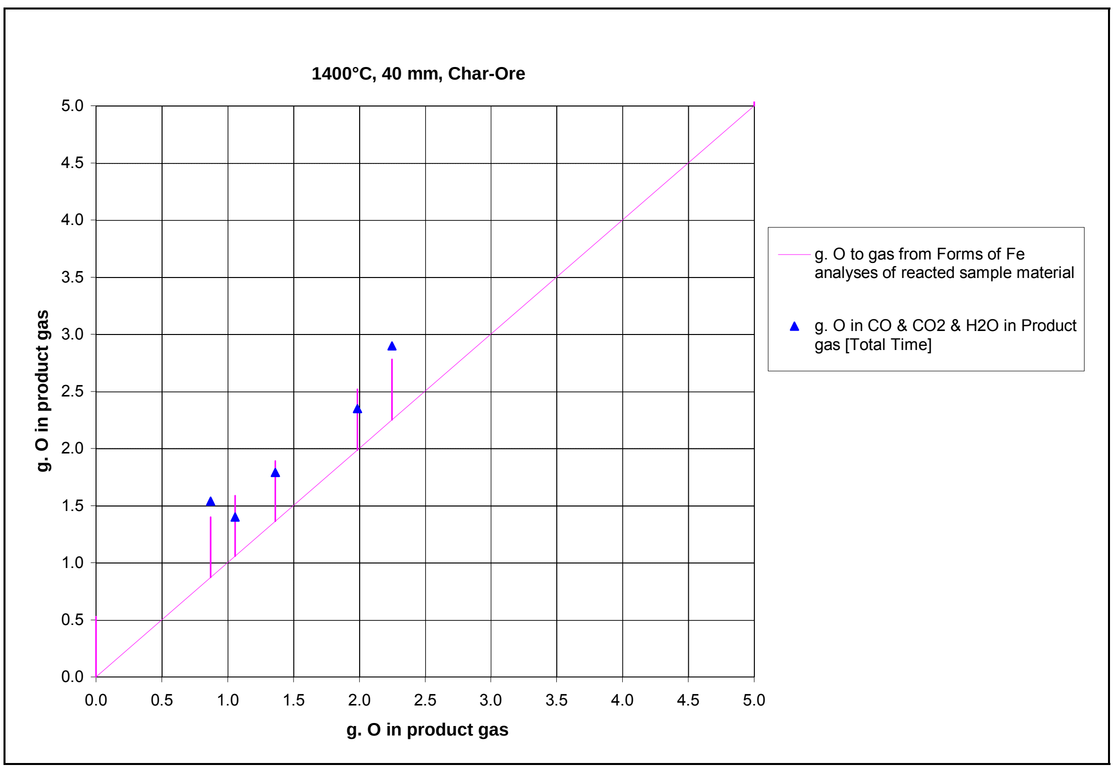




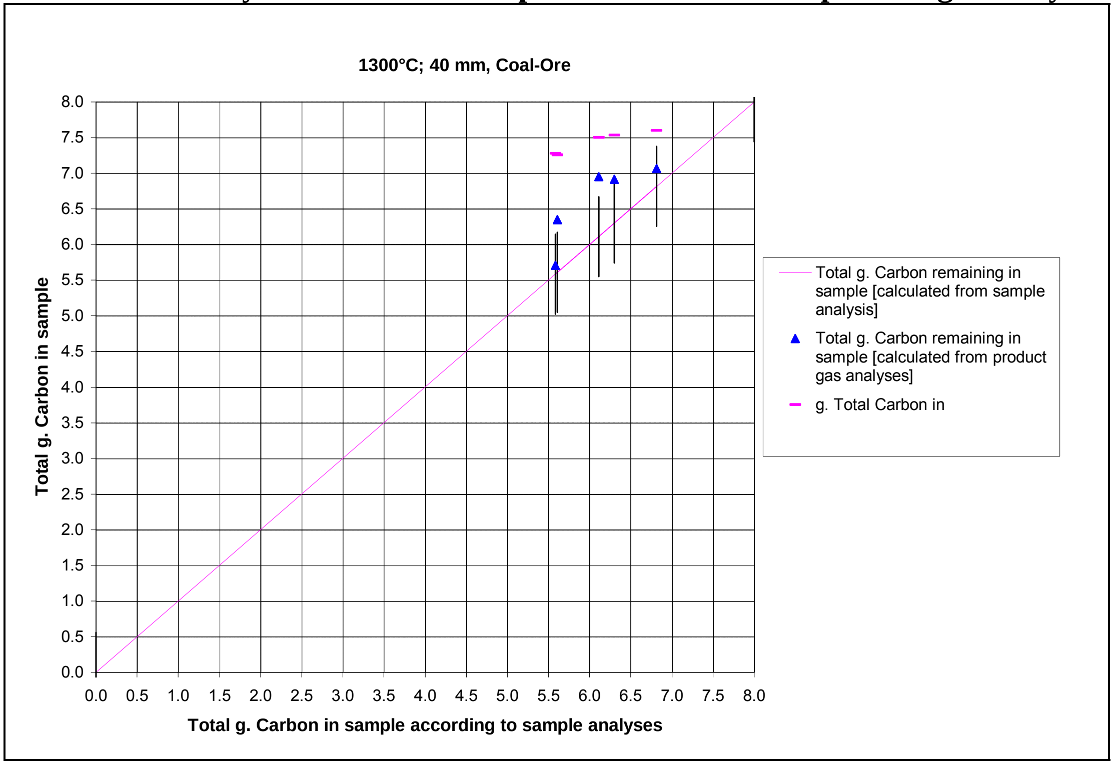

1500°C, 40 mm, Coal-Ore
g. O in product gas
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0
g. O in product gas
g. O to gas from Forms of Fe analyses of reacted sample material
g. O in CO & CO2 & H2O in Product gas [Total Time]

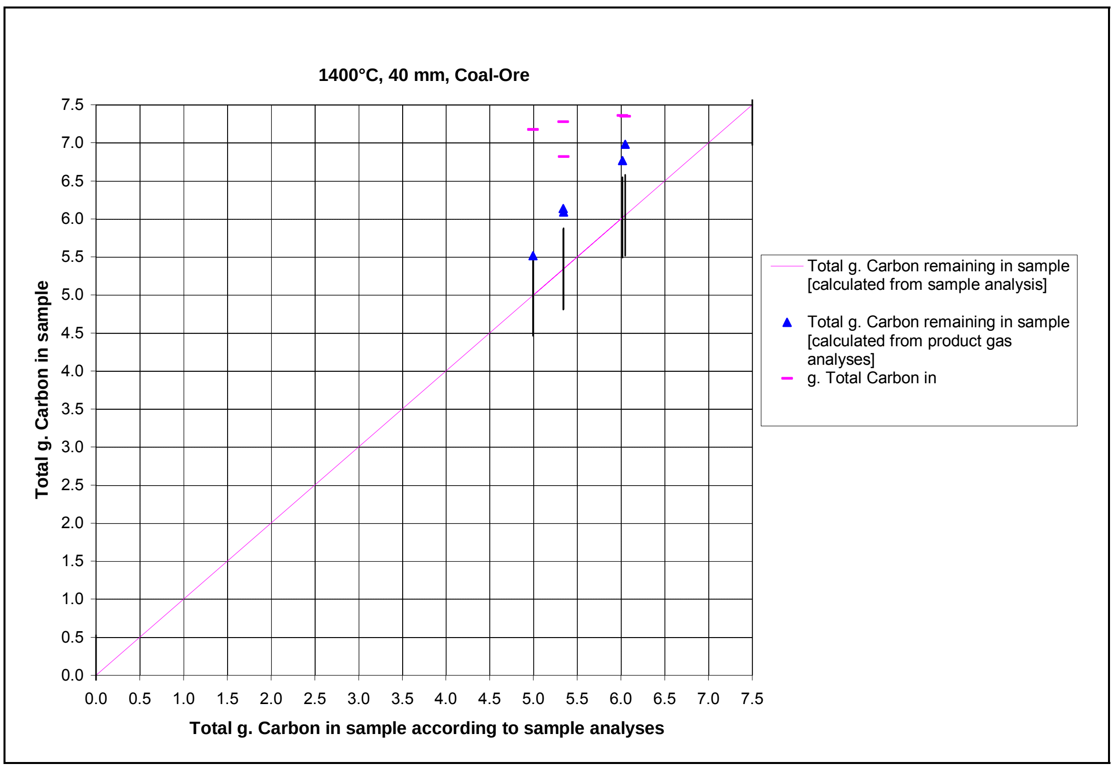

1400°C, 16 mm, Coal-Ore
g. O in product gas
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0
g. O in product gas
g. O to gas from Forms of Fe analyses of reacted sample material
g. O in CO & CO2 & H2O in Product gas [Total Time]

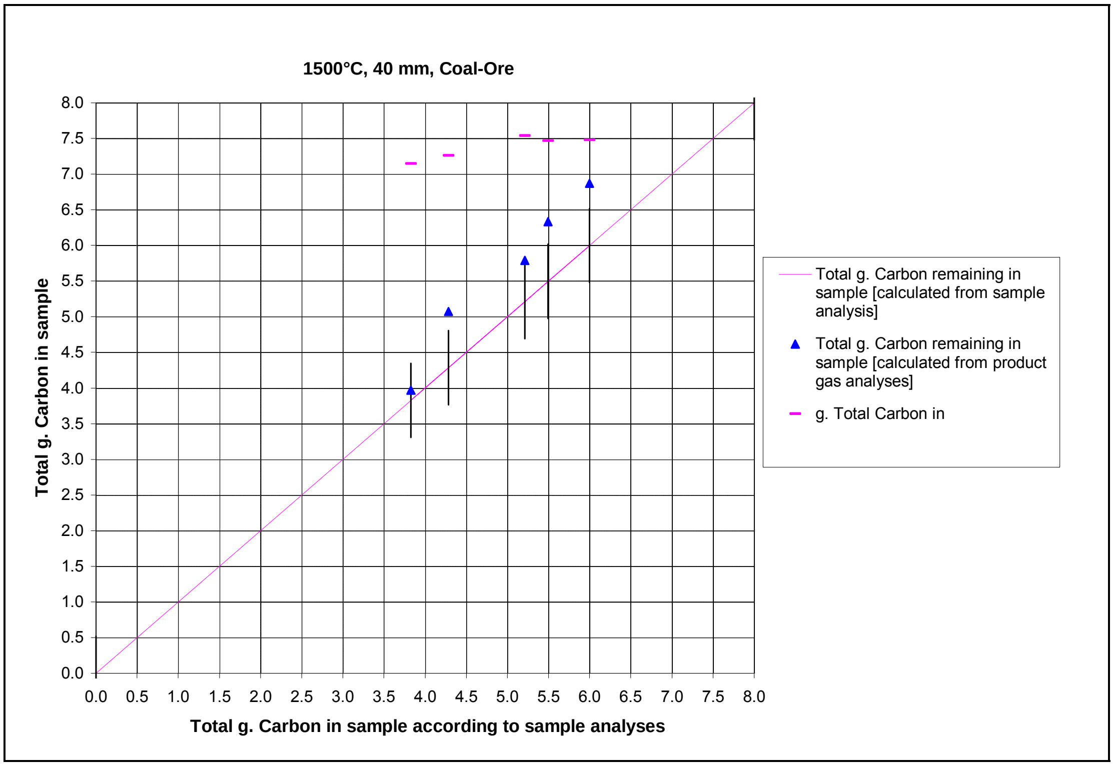

1400°C, 40 mm, Size Fraction Change
Fine Ore
Fine Coal
Coarse Ore
Coarse Coal
g. O in product gas
g. O in product gas
g. O to gas from Forms of Fe analyses of reacted sample material
g. O in CO & CO2 & H2O in Product gas [Total Time]

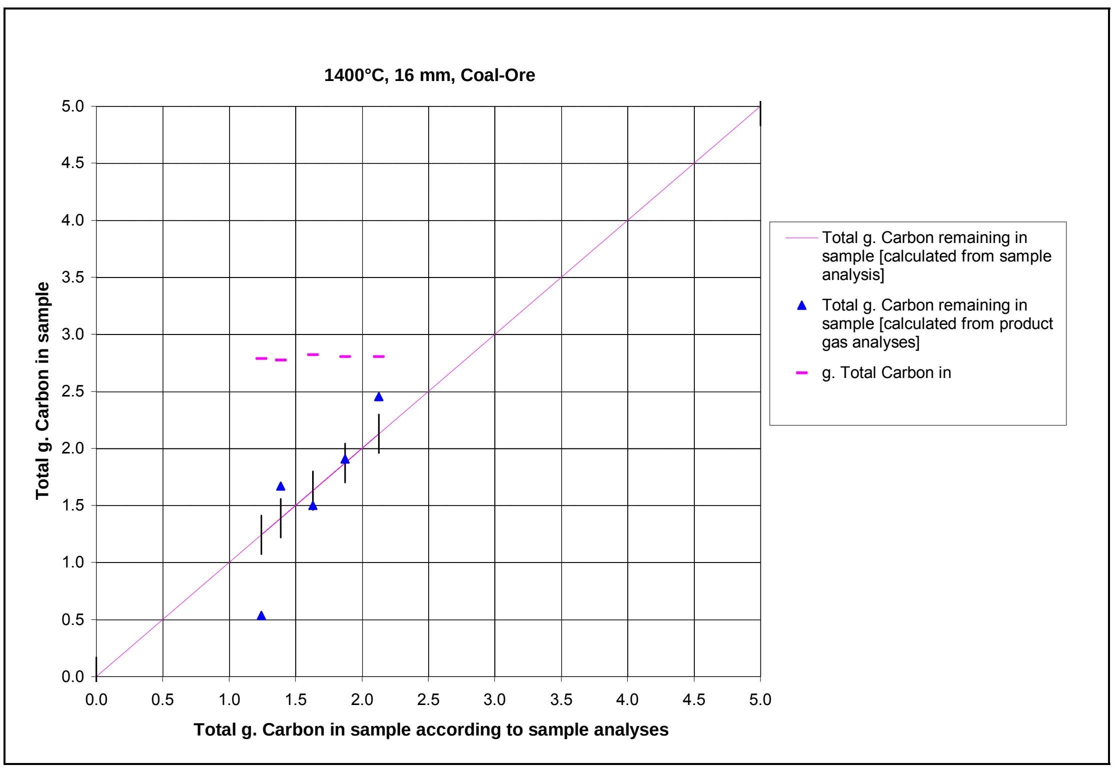

1400°C, 40 mm, Char-Ore
g. O in product gas
g. O in product gas
g. O to gas from Forms of Fe analyses of reacted sample material
g. O in CO & CO2 & H2O in Product gas [Total Time]

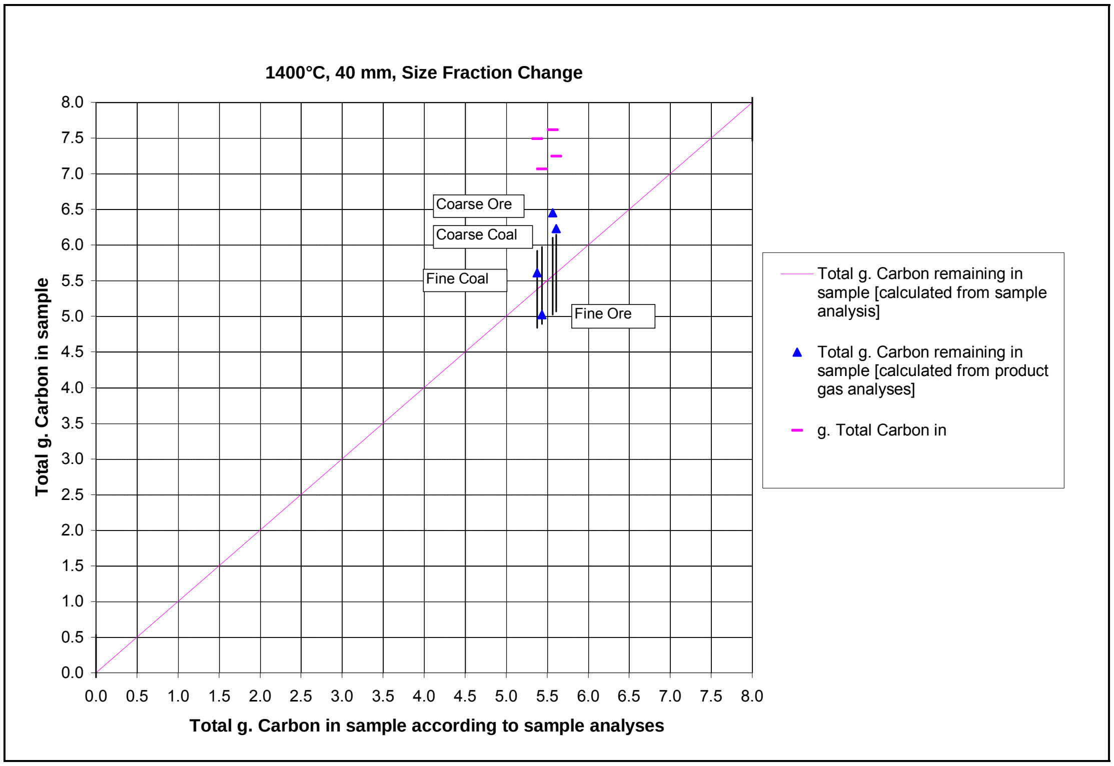
Appendix X (c): Graphs of total carbon remaining in reacted sample as calculated from carbon analyses for reacted sample vs. total carbon in product gas analyses

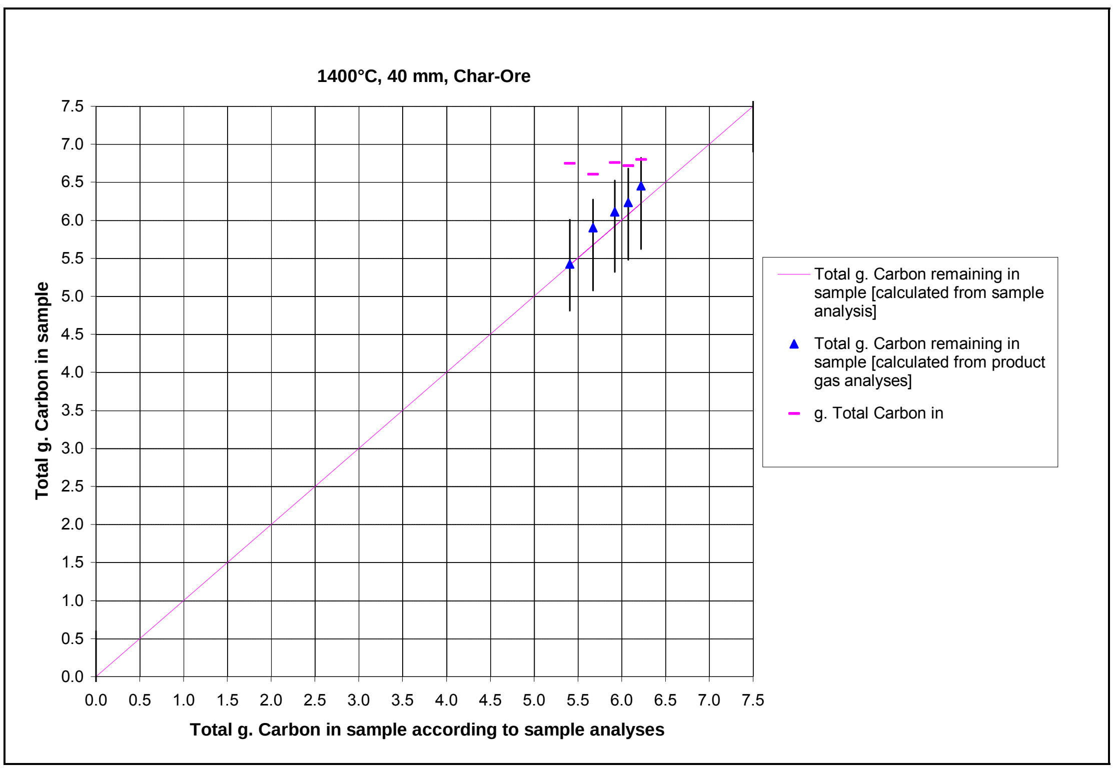





1500°C, 40 mm, Coal-Ore
Total g. Carbon in sample
Total g. Carbon in sample according to sample analyses
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
Total g. Carbon remaining in sample [calculated from sample analysis]
Total g. Carbon remaining in sample [calculated from product gas analyses]
g. Total Carbon in


1400°C, 16 mm, Coal-Ore
Total g. Carbon in sample
Total g. Carbon in sample according to sample analyses
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Total g. Carbon remaining in sample [calculated from sample analysis]
Total g. Carbon remaining in sample [calculated from product gas analyses]
g. Total Carbon in


1400°C, 40 mm, Size Fraction Change
Total g. Carbon in sample
Total g. Carbon in sample according to sample analyses
Coarse Ore
Coarse Coal
Fine Coal
Fine Ore
Total g. Carbon remaining in sample [calculated from sample analysis]
Total g. Carbon remaining in sample [calculated from product gas analyses]
g. Total Carbon in


1400°C, 40 mm, Char-Ore
Total g. Carbon in sample
Total g. Carbon in sample according to sample analyses
Total g. Carbon remaining in sample [calculated from sample analysis]
Total g. Carbon remaining in sample [calculated from product gas analyses]
g. Total Carbon in

Appendix XI: Sample masses and analyses for coal-ore; coal-char and coal-alumina experiments

(*For Coal/Char Size and Ore Size: 1=-2000 +1400 µm; 2 = -850 +425 µm; 3 = -425 +300 µm; * Corrected for Fibreboard carry over)

							Mass% In		Sample Mix Out			Fibreboard			Thermocouples			Totals Out			Mass In		
Sample Number	Furnace Temperature (°C)	Coal/Char	Coal/Char Size*	Ore Size*	Reaction Time [min.]	Sample Layer Thickness [mm]	mass% Ore in	mass% Coal in	g. sample mix - top	g. sample mix - middle	g. sample mix - bottom	g. Fibreboard - top	g. Fibreboard -middle	g. Fibreboard -bottom	g. thermocouple - top	g. thermocouple - middle	g. thermocouple -bottom	Total g. sample mix out	Total g. Fibreboeard out	Total g. Thermocouples out	g. Fibreboard in	g. Mix in	g. Mix in crucible before experiment, according to analyses on reacted sample
1300_3_40	1300	Coal	2	2	3	40	75.3	24.7	13.490	16.210	10.918	5.302	3.888	8.348	0	0	0	40.618	17.538	0	19.591	40.209	40.555
1300_6_40	1300	Coal	2	2	6	40	75.3	24.7	12.843	15.862	10.792	5.480	3.880	8.668	0	0	0	39.497	18.028	0	19.849	40.167	40.197
1300_9_40	1300	Coal	2	2	9	40	75.3	24.7	12.679	16.414	10.049	5.119	3.931	8.719	0	0	0	39.142	17.769	0	19.793	40.236	40.026
1300_12_40	1300	Coal	2	2	12	40	75.3	24.7	15.389	13.901	8.118	10.975	6.266	13.045	0	0	0	37.408	30.286	0	32.529	38.875	38.721
1300_15_40	1300	Coal	2	2	15	40	75.3	24.7	14.145	14.595	7.600	9.733	6.335	12.962	0	0	0	36.340	29.030	0	31.103	38.842	38.825
1400_3_40	1400	Coal	2	2	3	40	75.3	24.7	15.831	15.024	7.378	11.234	6.314	13.137	0	0	0	38.233	30.685	0	31.865	39.092	39.199
1400_6_40	1400	Coal	2	2	6	40	75.3	24.7	14.425	14.775	8.347	10.076	6.491	14.509	0	0	0	37.547	31.076	0	32.460	39.164	39.249
1400_9_40	1400	Coal	2	2	9	40	75.3	24.7	13.755	15.042	5.246	10.804	6.814	12.634	0	0	0	34.043	30.252	0	31.637	39.383	36.382
1400_12_40	1400	Coal	2	2	12	40	75.3	24.7	12.849	14.429	7.717	11.660	6.550	13.540	0	0	0	34.995	31.750	0	32.889	38.473	38.820
1400_15_40	1400	Coal	2	2	15	40	75.3	24.7	11.930	14.693	7.968	9.972	6.138	13.187	0	0	0	34.591	29.297	0	30.991	38.503	38.267
1500_3_40	1500	Coal	2	2	3	40	75.3	24.7	15.622	14.472	8.416	10.112	6.540	13.396	0	0	0	38.510	30.048	0	31.756	39.638	39.909
1500_6_40	1500	Coal	2	2	6	40	75.3	24.7	12.993	14.785	9.013	10.692	6.396	12.863	0	0	0	36.791	29.951	0	31.451	39.523	39.852
1500_9_40	1500	Coal	2	2	9	40	75.3	24.7	13.138	14.922	8.281	10.778	6.751	13.189	0	0	0	36.341	30.718	0	32.562	39.700	40.243
1500_12_40	1500	Coal	2	2	12	40	75.3	24.7	11.468	14.448	7.901	9.697	5.810	12.630	0	0	0	33.817	28.137	0	30.528	38.342	38.734
1500_15_40	1500	Coal	2	2	15	40	75.3	24.7	10.868	13.241	8.373	10.395	5.924	12.276	0	0	0	32.482	28.595	0	31.001	38.432	38.125
1400_3_16	1400	Coal	2	2	3	16	75.3	24.7	13.723	0	0	36.794	0	0	0	0	0	13.723	36.794	0	37.172	14.999	14.946
1400_6_16	1400	Coal	2	2	6	16	75.3	24.7	12.821	0	0	40.621	0	0	0	0	0	12.821	40.621	0	40.887	15.007	14.953
1400_9_16	1400	Coal	2	2	9	16	75.3	24.7	12.159	0	0	37.403	0	0	0	0	0	12.159	37.403	0	37.730	14.997	15.063
1400_12_16	1400	Coal	2	2	12	16	75.3	24.7	11.668	0	0	39.304	0	0	0	0	0	11.668	39.304	0	39.668	14.976	14.799
1400_15_16	1400	Coal	2	2	15	16	75.3	24.7	11.188	0	0	39.941	0	0	0	0	0	11.188	39.941	0	40.357	14.980	14.855
Coarse ore_I	1400	Coal	2	1	9	40	75.3	24.7	14.777	16.677	6.439	5.333	3.941	9.672	0	0	0	37.893	18.946	0	21.139	40.222	40.646
Coarse coal_II	1400	Coal	1	2	9	40	75.3	24.7	16.635	14.001	5.650	6.559	3.798	8.538	0	0	0	36.286	18.895	0	20.495	39.340	38.605
Fine coal_A	1400	Coal	3	2	9	40	75.3	24.7	11.779	15.669	9.383	5.652	3.875	9.075	0	0	0	36.831	18.602	0	20.440	40.241	39.901
Fine ore_B	1400	Coal	2	3	9	40	75.3	24.7	9.598	16.092	10.185	5.231	3.917	9.316	0	0	0	35.875	18.464	0	20.514	39.089	37.698
1400_3_40_char	1400	Char	2	2	3	40	79.7	20.3	14.929	17.208	10.078	5.445	4.132	9.093	0	0	0	42.215	18.67	0	20.606	42.074	42.522
1400_6_40_char	1400	Char	2	2	6	40	79.8	20.2	15.509	16.130	9.916	5.408	3.908	9.115	0	0	0	41.555	18.431	0	20.082	42.003	42.041
1400_9_40_char	1400	Char	2	2	9	40	79.8	20.2	15.333	16.019	9.813	10.124	5.815	14.334	0	0	0	41.165	30.273	0	32.236	41.992	42.288
1400_12_40_char	1400	Char	2	2	12	40	79.8	20.2	15.974	15.371	8.380	6.053	3.896	9.277	0	0	0	39.725	19.226	0	21.024	41.427	41.368
1400_15_40_char	1400	Char	2	2	15	40.0	79.7	20.3	15.118	14.743	9.377	5.751	3.881	8.984	0	0	0	39.238	18.616	0	21.278	41.792	42.038

	Product Gas					Product gas analysed					Sample out Fe analyses									Sample out Fe analyses - Corrected*																		
Sample Number	Mass loss according to Product gas analysis [Total Time]	Mass loss according to Product gas analysis [Experimental Time only]	g. O in CO & CO_2 in Product gas [Total Time]	g. O in CO & CO_2 in Product gas [Experimental time only]	g. O in CO & CO_2 & H_2O in Product gas [Total Time]	Total g. CO_2 in Product Gas	Total g. CH_4 in Product Gas	Total g. CO in Product Gas	Total g. H_2 in Product Gas	Total g. H_2O in Product Gas	%Fe(met) - Top	%Fe(met) - Middle	%Fe(met) - Bottom	%FeO - Top	%FeO - Middle	%FeO - Bottom	%Fe_2O_3 -Top	%Fe_2O_3 - Middle	%Fe_2O_3 - Bottom	%Fe(met) - Top (Corrected)*	%Fe(met) - Middle (Corrected)*	%Fe(met) - Bottom (Corrected)*	%FeO - Top (Corrected)*	%FeO - Middle (Corrected)*	%FeO - Bottom (Corrected)*	%Fe_2O_3 - Top (Corrected)*	%Fe_2O_3 - Middle (Corrected)*	%Fe_2O_3 - Bottom (Corrected)*	%Fe(+2) - Top (Corrected)*	%Fe(+2) - Middle (Corrected*)	%Fe(+2) - Bottom (Corrected)*	%Fe(+3) - Top (Corrected*)	%Fe(+3) - Middle (Corrected*)	%Fe(+3) - Bottom (Corrected*)	%Fe(total) - Top (Corrected)*	%Fe(total) - Middle (Corrected)*	%Fe(total) - Bottom (Corrected)*	g. Fe in/ g. Fe out
1300_3_40	1.98	0.76	0.82	0.33	1.30	0.30	0.01	1.05	0.09	0.54	0.3	0.4	0.2	11.3	2.8	3.3	56.8	67.8	63.4	0.3	0.4	0.2	11.4	2.9	3.4	57.3	71.9	65.7	8.9	2.3	2.6	40.1	50.3	45.9	49.3	52.9	48.8	0.99
1300_6_40	2.43	1.52	1.02	0.66	1.62	0.55	0.01	1.09	0.11	0.67	1.4	0.2	0.2	26.9	3.6	3.0	41.7	65.0	67.5	1.4	0.2	0.2	26.9	3.9	3.1	41.7	69.6	69.1	20.9	3.0	2.4	29.2	48.7	48.3	51.4	51.9	50.9	1.00
1300_9_40	2.68	2.10	1.04	0.93	1.88	0.83	0.01	0.76	0.13	0.94	3.0	0.2	0.2	26.4	3.4	2.1	38.9	67.5	67.6	3.0	0.2	0.2	26.6	3.7	2.1	39.2	72.4	69.0	20.7	2.9	1.6	27.4	50.7	48.3	51.1	53.7	50.1	1.01
1300_12_40	3.73	2.98	1.58	1.35	2.55	1.02	0.01	1.47	0.13	1.10	4.9	0.4	0.4	33.9	7.4	0.4	34.5	59.8	65.0	5.1	0.4	0.4	34.9	7.9	0.4	35.5	63.9	66.1	27.1	6.1	0.3	24.8	44.7	46.2	57.0	51.2	46.9	1.00
1300_15_40	5.21	3.97	2.43	1.83	3.34	0.92	0.00	3.08	0.18	1.02	10.6	0.3	0.5	35.0	8.9	4.9	26.1	62.3	62.4	10.9	0.3	0.5	35.8	9.5	4.9	26.7	66.5	62.8	27.8	7.4	3.8	18.7	46.5	44.0	57.4	54.2	48.3	1.00
1400_3_40	1.58	0.93	0.62	0.44	1.02	0.39	0.05	0.60	0.10	0.45	3.6	0.2	0.3	14.4	2.7	2.8	48.6	72.0	65.1	3.6	0.2	0.3	14.6	2.8	2.8	49.3	74.0	64.1	11.4	2.2	2.2	34.5	51.8	44.8	49.5	54.2	47.2	1.00
1400_6_40	2.61	1.82	1.06	0.86	1.71	0.75	0.10	0.90	0.12	0.74	5.7	1.3	0.3	26.1	3.2	2.6	37.3	67.8	67.5	5.7	1.3	0.3	26.4	3.3	2.5	37.8	70.3	67.1	20.5	2.5	2.0	26.4	49.2	46.9	52.7	53.0	49.2	1.00
1400_9_40	3.25	2.53	1.35	1.20	2.17	1.04	0.13	1.03	0.13	0.92	9.9	0.3	0.4	29.5	4.7	3.7	33.3	66.7	62.8	10.0	0.3	0.3	29.9	4.9	3.5	33.7	70.1	59.5	23.2	3.8	2.7	23.6	49.1	41.6	56.8	53.2	44.6	1.08
1400_12_40	4.05	3.61	1.87	1.71	2.57	0.96	0.08	2.04	0.17	0.79	15.2	0.2	0.2	32.4	7.4	3.8	25.4	67.0	67.5	15.3	0.2	0.2	32.5	7.7	3.7	25.5	69.4	66.9	25.3	6.0	2.9	17.8	48.6	46.8	58.4	54.8	49.9	0.99
1400_15_40	5.46	4.74	2.62	2.31	3.46	1.16	0.04	3.12	0.20	0.94	21.9	0.3	0.3	35.2	11.8	7.0	13.9	60.5	64.8	22.3	0.3	0.3	35.9	12.5	7.0	14.2	64.2	64.8	27.9	9.7	5.5	9.9	44.9	45.3	60.1	55.0	51.1	1.01
1500_3_40	2.71	1.51	1.12	0.80	1.88	0.86	0.00	0.87	0.13	0.85	4.5	0.4	0.4	16.7	2.2	3.3	51.3	67.5	64.6	4.6	0.4	0.4	16.8	2.3	3.3	51.6	70.0	64.8	13.1	1.8	2.5	36.1	48.9	45.3	53.7	51.1	48.2	0.99
1500_6_40	4.15	3.30	1.95	1.67	2.69	1.20	0.00	1.89	0.24	0.83	14.0	0.4	0.4	32.0	4.3	2.7	26.9	66.7	68.6	13.9	0.4	0.4	31.9	4.5	2.7	26.8	69.7	68.2	24.7	3.5	2.1	18.7	48.7	47.7	57.4	52.6	50.2	0.99
1500_9_40	5.94	5.07	2.77	2.46	3.71	1.20	0.00	3.32	0.36	1.06	20.0	0.3	0.4	28.8	9.5	4.4	22.8	63.8	67.4	20.2	0.3	0.4	29.1	10.0	4.3	23.0	67.2	66.9	22.6	7.8	3.4	16.1	47.0	46.8	58.9	55.1	50.6	0.99
1500_12_40	7.39	6.30	3.55	3.11	4.77	1.72	0.00	4.01	0.27	1.38	37.8	0.4	0.3	28.4	17.4	8.0	6.8	53.8	64.4	39.3	0.5	0.3	29.5	18.8	8.2	7.1	58.1	65.4	22.9	14.6	6.3	5.0	40.6	45.7	67.2	55.7	52.4	0.99
1500_15_40	9.39	7.93	4.81	4.04	5.75	1.58	0.00	6.40	0.35	1.07	47.8	1.1	0.4	17.7	31.5	13.2	10.4	37.3	58.7	49.7	1.2	0.4	18.4	34.1	13.5	10.8	40.4	60.2	14.3	26.5	10.5	7.6	28.3	42.1	71.5	55.9	53.0	1.01
1400_3_16	1.73	0.94	0.68	0.48	1.25	0.58	0.00	0.45	0.05	0.65	0.9	0.0	0.0	20.7	0.0	0.0	51.8	0.0	0.0	1.0	0.0	0.0	21.7	0.0	0.0	54.3	0.0	0.0	16.8	0.0	0.0	38.0	0.0	0.0	55.8	0.0	0.0	1.00
1400_6_16	2.95	2.14	1.42	1.05	1.89	0.60	0.00	1.71	0.10	0.53	5.6	0.0	0.0	37.0	0.0	0.0	32.5	0.0	0.0	5.9	0.0	0.0	39.0	0.0	0.0	34.3	0.0	0.0	30.3	0.0	0.0	24.0	0.0	0.0	60.1	0.0	0.0	1.00
1400_9_16	3.93	2.93	2.00	1.46	2.44	0.66	0.00	2.66	0.12	0.49	11.7	0.0	0.0	47.1	0.0	0.0	17.6	0.0	0.0	12.3	0.0	0.0	49.7	0.0	0.0	18.6	0.0	0.0	38.6	0.0	0.0	13.0	0.0	0.0	64.0	0.0	0.0	1.00
1400_12_16	3.82	3.27	1.89	1.61	2.52	1.13	0.02	1.85	0.10	0.71	18.9	0.0	0.0	45.8	0.0	0.0	10.8	0.0	0.0	20.2	0.0	0.0	48.9	0.0	0.0	11.5	0.0	0.0	38.0	0.0	0.0	8.1	0.0	0.0	66.2	0.0	0.0	1.01
1400_15_16	6.22	4.13	3.31	2.16	3.80	0.88	0.00	4.68	0.12	0.55	29.5	0.0	0.0	38.3	0.0	0.0	8.1	0.0	0.0	31.9	0.0	0.0	41.4	0.0	0.0	8.8	0.0	0.0	32.1	0.0	0.0	6.1	0.0	0.0	70.1	0.0	0.0	1.01
Coarse ore_I	4.81	3.98	2.06	1.85	3.22	1.38	0.00	1.84	0.28	1.31	10.5	0.5	0.4	32.9	6.1	3.2	31.0	65.5	65.8	10.6	0.5	0.4	33.1	6.4	3.2	31.2	69.3	66.4	25.7	5.0	2.5	21.8	48.5	46.5	58.1	54.0	49.3	0.99
Coarse coal_II	3.98	3.41	1.7	1.53	2.54	0.95	0.00	1.77	0.31	0.95	3.2	0.5	0.8	44.9	10.2	4.9	30.0	54.3	58.2	3.2	0.5	0.8	45.3	10.8	4.8	30.3	57.5	57.9	35.2	8.4	3.7	21.2	40.2	40.5	59.6	49.1	45.0	1.02
Fine coal_A	5.98	4.99	2.93	2.49	3.70	1.19	0.00	3.62	0.31	0.86	14.8	0.3	0.4	33.0	8.6	3.8	26.0	62.3	66.8	14.8	0.3	0.4	33.0	9.1	3.9	26.0	66.1	68.0	25.6	7.0	3.0	18.2	46.2	47.5	58.6	53.6	50.9	1.01
Fine ore_B	6.26	5.18	3.03	2.53	3.73	0.87	0.00	4.21	0.40	0.78	14.7	0.6	0.4	34.2	9.8	4.4	17.5	61.6	69.2	14.4	0.7	0.4	33.5	10.6	4.5	17.2	66.1	70.5	26.1	8.2	3.5	12.0	46.2	49.3	52.5	55.1	53.2	1.04
1400_3_40_char	2.01	1.19	0.85	0.69	1.54	1.06	0.00	0.13	0.04	0.78	0.5	0.1	0.0	15.3	1.6	0.9	57.9	71.4	74.1	0.5	0.1	0.0	15.1	1.6	0.9	57.3	75.0	74.0	11.8	1.3	0.7	40.1	52.5	51.8	52.4	53.8	52.5	0.99
1400_6_40_char	1.97	1.63	1.02	0.87	1.4	1.03	0.00	0.47	0.04	0.43	2.1	0.2	0.3	19.9	0.9	0.7	52.8	70.6	74.1	2.1	0.2	0.3	19.8	1.0	0.7	52.6	73.9	74.6	15.4	0.8	0.5	36.8	51.7	52.2	54.3	52.6	53.0	1.00
1400_9_40_char	2.56	2.28	1.3	1.2	1.79	1.21	0.00	0.73	0.07	0.55	5.3	0.1	0.1	25.6	1.5	0.8	41.6	73.5	73.9	5.2	0.1	0.1	25.6	1.5	0.8	41.6	76.5	74.0	19.9	1.2	0.7	29.1	53.5	51.8	54.2	54.8	52.5	1.00
1400_12_40_char	3.19	2.88	1.74	1.6	2.35	2.20	0.02	0.24	0.04	0.69	8.4	0.2	0.2	43.8	4.7	1.4	24.0	66.5	70.3	8.4	0.2	0.2	44.2	5.0	1.4	24.2	70.0	70.6	34.3	3.9	1.1	16.9	49.0	49.4	59.7	53.1	50.7	1.00
1400_15_40_char	4.32	3.98	2.5	2.31	2.9	2.03	0.00	1.79	0.05	0.46	10.8	0.2	0.0	48.8	9.4	3.0	18.6	62.3	71.2	10.9	0.2	0.0	49.1	9.8	3.0	18.7	65.0	71.5	38.1	7.6	2.3	13.1	45.5	50.0	62.0	53.3	52.3	1.00

*Corrected for Fibreboard carry over

							g. Al2O3 pick-up			g. SiO2 pick-up			%Al2O3 - Out			%SiO2 - Out			Corrected masses out			Correced Fibreboard masses		
Sample Number	g. Al2O3 In	g. Al2O3 out	g. SiO2 In	g. SiO2 out	Total g. Al2O3 pick-up	Total g. SiO2 pick-up	g. Al2O3 pick-up - top	g. Al2O3 pick-up - middle	g. Al2O3 pick-up - bottom	g. SiO2 pick-up - top	g. SiO2 pick-up - middle	g. SiO2 pick-up - bottom	%Al2O3 Analysed -Top	%Al2O3 Analysed -Middle	%Al2O3 Analysed -Bottom	%SiO2 Analysed -Top	%SiO2 Analysed -Middle	%SiO2 Analysed -Bottom	g. sample mix out - Top (Corrected)*	g. sample mix out - Middle (Corrected)*	g. sample mix out - Bottom (Corrected)*	g. Fibreboard out - Top (Corrected)*	g. Fibreboard out - Middle (Corrected)*	g. Fibreboard out - Bottom (Corrected)*
1300_3_40	0.97	2.05	1.84	2.40	1.07	0.57	0.17	0.56	0.35	-0.04	0.36	0.03	4.56	5.42	5.07	5.94	5.94	5.85	13.37	15.30	10.54	5.43	4.80	8.73
1300_6_40	0.97	1.98	1.83	2.35	1.01	0.51	0.08	0.65	0.27	-0.08	0.40	-0.02	4.12	6.12	4.44	5.95	6.31	5.39	12.84	14.82	10.54	5.48	4.93	8.92
1300_9_40	0.97	2.08	1.84	2.38	1.10	0.55	0.15	0.69	0.26	-0.05	0.43	-0.05	4.72	6.16	4.65	6.29	6.30	5.50	12.58	15.30	9.84	5.22	5.05	8.93
1300_12_40	0.94	1.97	1.78	2.42	1.03	0.64	0.27	0.54	0.21	0.17	0.34	-0.08	4.59	6.14	5.04	6.42	6.67	6.22	14.94	13.02	7.99	11.42	7.15	13.18
1300_15_40	0.94	1.87	1.77	2.36	0.93	0.59	0.22	0.55	0.16	0.11	0.37	-0.11	4.63	5.87	4.70	6.56	6.55	6.31	13.81	13.68	7.55	10.07	7.25	13.02
1400_3_40	0.95	1.41	1.79	2.06	0.47	0.28	0.16	0.23	0.07	0.07	0.18	-0.19	3.78	3.64	3.62	5.65	5.12	5.42	15.59	14.61	7.50	11.47	6.73	13.02
1400_6_40	0.95	1.52	1.79	2.09	0.57	0.30	0.15	0.32	0.10	0.03	0.20	-0.15	4.06	4.29	3.58	5.91	5.36	5.31	14.25	14.25	8.39	10.26	7.01	14.46
1400_9_40	0.95	1.52	1.80	2.06	0.57	0.26	0.12	0.44	0.01	0.04	0.30	-0.30	4.08	5.00	3.95	6.30	5.94	5.63	13.59	14.30	5.54	10.97	7.55	12.34
1400_12_40	0.93	1.41	1.76	1.98	0.48	0.22	0.08	0.31	0.09	-0.03	0.20	-0.16	3.94	4.25	3.74	6.09	5.40	5.44	12.80	13.92	7.78	11.71	7.06	13.47
1400_15_40	0.93	1.77	1.76	2.23	0.83	0.47	0.19	0.51	0.13	0.04	0.35	-0.13	5.19	5.57	4.12	7.14	6.30	5.67	11.70	13.84	7.96	10.21	6.99	13.19
1500_3_40	0.96	1.53	1.81	2.09	0.57	0.28	0.10	0.32	0.14	0.00	0.19	-0.12	3.49	4.39	4.11	5.30	5.43	5.70	15.52	13.96	8.39	10.21	7.05	13.42
1500_6_40	0.96	1.45	1.80	2.05	0.49	0.24	0.02	0.38	0.09	-0.08	0.25	-0.15	3.53	4.73	3.22	5.81	5.70	4.97	13.05	14.15	9.07	10.64	7.03	12.80
1500_9_40	0.96	1.62	1.81	2.19	0.65	0.38	0.10	0.46	0.09	0.03	0.29	-0.15	4.12	5.23	3.55	6.54	5.97	5.36	13.01	14.17	8.34	10.90	7.51	13.13
1500_12_40	0.93	2.04	1.75	2.47	1.11	0.71	0.30	0.63	0.19	0.13	0.44	-0.07	6.32	6.46	4.86	8.20	7.05	6.41	11.04	13.38	7.78	10.13	6.88	12.75
1500_15_40	0.93	2.07	1.75	2.45	1.14	0.70	0.30	0.61	0.23	0.11	0.40	-0.03	6.67	6.93	5.11	8.45	7.42	6.60	10.46	12.23	8.17	10.80	6.94	12.48
1400_3_16	0.36	0.39	0.68	0.72	0.03	0.03	0.23	0.00	0.00	0.40	0.00	0.00	2.87	0.00	0.00	5.22	0.00	0.00	13.09	0.00	0.00	37.42	0.00	0.00
1400_6_16	0.36	0.42	0.69	0.72	0.06	0.03	0.26	0.00	0.00	0.40	0.00	0.00	3.30	0.00	0.00	5.58	0.00	0.00	12.16	0.00	0.00	41.28	0.00	0.00
1400_9_16	0.36	0.41	0.68	0.71	0.05	0.02	0.25	0.00	0.00	0.39	0.00	0.00	3.41	0.00	0.00	5.81	0.00	0.00	11.52	0.00	0.00	38.04	0.00	0.00
1400_12_16	0.36	0.49	0.68	0.73	0.13	0.05	0.32	0.00	0.00	0.42	0.00	0.00	4.21	0.00	0.00	6.26	0.00	0.00	10.93	0.00	0.00	40.04	0.00	0.00
1400_15_16	0.36	0.52	0.68	0.79	0.16	0.10	0.36	0.00	0.00	0.47	0.00	0.00	4.68	0.00	0.00	7.04	0.00	0.00	10.36	0.00	0.00	40.77	0.00	0.00
Coarse ore_I	0.97	2.05	1.84	2.06	1.07	0.22	0.17	0.64	0.27	-0.07	0.28	-0.21	4.15	5.76	7.33	5.25	5.30	6.22	14.68	15.76	6.38	5.43	4.86	9.73
Coarse coal_II	0.96	1.80	1.78	2.06	0.84	0.28	0.13	0.51	0.19	0.02	0.26	-0.22	3.46	5.93	6.95	5.04	6.07	6.50	16.48	13.22	5.68	6.71	4.57	8.51
Fine coal_A	0.98	1.92	1.82	2.15	0.94	0.33	0.11	0.58	0.26	-0.11	0.32	-0.09	4.73	5.77	4.93	6.15	5.89	5.40	11.79	14.77	9.22	5.65	4.78	9.24
Fine ore_B	0.95	2.00	1.78	2.04	1.06	0.25	0.06	0.73	0.27	-0.24	0.37	-0.09	5.12	6.45	4.64	6.03	5.97	4.87	9.78	14.99	10.00	5.04	5.01	9.50
1400_3_40_char	1.03	1.92	2.16	2.18	0.89	0.02	0.09	0.59	0.21	-0.25	0.24	-0.22	3.77	5.39	4.25	4.98	5.52	4.84	15.09	16.38	10.09	5.28	4.96	9.08
1400_6_40_char	1.03	1.84	2.15	2.35	0.81	0.19	0.09	0.48	0.24	-0.14	0.24	-0.17	3.61	5.08	4.60	5.49	5.91	5.47	15.56	15.41	9.84	5.36	4.63	9.19
1400_9_40_char	1.03	1.87	2.15	2.20	0.84	0.05	0.14	0.49	0.22	-0.14	0.14	-0.20	3.99	5.16	4.43	5.52	5.28	5.15	15.34	15.40	9.80	10.12	6.44	14.35
1400_12_40_char	1.01	1.93	2.12	2.40	0.92	0.28	0.17	0.52	0.23	-0.04	0.25	-0.19	3.97	5.57	5.28	5.89	6.20	6.09	15.84	14.60	8.34	6.18	4.67	9.32
1400_15_40_char	1.02	1.83	2.14	2.33	0.81	0.19	0.15	0.44	0.21	-0.07	0.18	-0.18	4.14	5.27	4.58	6.04	6.02	5.64	15.04	14.12	9.34	5.83	4.50	9.02

*Corrected for Fibreboard carry over

	%Reduction			%Carbon out									Mass Carbon In								%Carbon consumption			
Sample Number	%Reduction - Top	%Reduction - Middle	%Reduction - Bottom	%C analysed - Top	%C analysed - Middle	%C analysed - Bottom	%C out analysed - top (Corrected)*	%C out analysed - middle (Corrected)*	%C out analysed - bottom (Corrected)*	Composite %Carbon	%Fixed Carbon in start mixture	%Total Carbon in start mixture	g. Total Carbon in	g. Total C in - top	g. Total C in - middle	g. Total C in - bottom	g. Total FC in - top	g. Total FC in - middle	g. Total FC in - bottom	%C consumption - top	%C consumption - middle	%C consumption - bottom	Composite %C consumption
1300_3_40	6.7	2.2	2.3	18.7	15.3	16.6	18.9	16.2	17.2	17.6	15.4	18.7	7.60	3.50	2.51	1.60	2.87	2.06	1.31	27.8	1.1	-13.5	10.3
1300_6_40	16.2	2.4	1.9	17.7	15.1	15.1	17.7	16.2	15.5	16.7	15.4	18.7	7.53	3.47	2.49	1.58	2.84	2.04	1.30	34.4	3.7	-3.0	16.4
1300_9_40	19.4	2.1	1.5	19.2	12.6	16.0	19.4	13.5	16.3	16.8	15.4	18.7	7.50	3.45	2.48	1.58	2.83	2.03	1.29	29.5	16.5	-2.1	18.6
1300_12_40	24.8	4.8	1.1	14.1	15.8	15.3	14.5	16.9	15.6	15.5	15.4	18.7	7.26	3.34	2.39	1.52	2.74	1.96	1.25	35.0	8.3	18.5	22.7
1300_15_40	35.1	5.1	3.7	13.3	17.4	15.3	13.6	18.6	15.4	15.6	15.4	18.7	7.28	3.35	2.40	1.53	2.74	1.97	1.25	43.8	-5.7	23.9	23.3
1400_3_40	15.0	1.7	2.1	18.7	12.3	16.8	19.0	12.6	16.5	16.4	15.4	18.7	7.35	3.38	2.42	1.54	2.77	1.99	1.26	12.4	23.8	19.7	17.7
1400_6_40	23.9	4.1	1.9	18.2	13.3	17.1	18.4	13.8	17.0	16.6	15.4	18.7	7.36	3.38	2.43	1.54	2.77	1.99	1.27	22.4	19.0	7.6	18.2
1400_9_40	31.2	3.0	2.8	15.9	14.4	18.9	16.1	15.1	17.9	16.2	15.4	18.7	6.82	3.14	2.25	1.43	2.57	1.84	1.17	30.3	3.7	30.8	21.6
1400_12_40	40.6	4.1	2.4	16.7	14.1	15.0	16.8	14.6	14.9	15.7	15.4	18.7	7.28	3.35	2.40	1.53	2.74	1.97	1.25	35.9	15.3	24.2	26.6
1400_15_40	52.6	6.5	4.1	15.5	13.1	15.3	15.8	13.9	15.3	15.1	15.4	18.7	7.17	3.30	2.37	1.51	2.70	1.94	1.23	44.0	18.7	19.1	30.4
1500_3_40	16.6	1.9	2.5	16.0	14.0	17.5	16.1	14.5	17.6	15.9	15.4	18.7	7.48	3.44	2.47	1.57	2.82	2.02	1.29	27.4	17.9	6.2	19.8
1500_6_40	38.6	3.0	2.2	16.0	13.9	15.1	15.9	14.5	15.0	15.3	15.4	18.7	7.47	3.44	2.47	1.57	2.82	2.02	1.29	39.5	16.6	13.2	26.4
1500_9_40	47.1	5.2	3.0	16.3	12.3	14.9	16.5	13.0	14.8	15.0	15.4	18.7	7.54	3.47	2.49	1.58	2.84	2.04	1.30	38.3	26.2	22.1	30.9
1500_12_40	69.9	9.6	4.6	10.4	13.7	14.1	10.8	14.8	14.3	12.9	15.4	18.7	7.26	3.34	2.40	1.52	2.74	1.96	1.25	64.3	17.4	26.9	41.0
1500_15_40	76.1	17.9	7.3	6.1	14.7	14.6	6.3	15.9	15.0	11.3	15.4	18.7	7.15	3.29	2.36	1.50	2.69	1.93	1.23	80.0	17.5	18.5	46.4
1400_3_16	11.8	0.0	0.0	15.5	0.0	0.0	16.2	0.0	0.0	7.5	15.4	18.8	2.80	2.80	0.00	0.00	1.06	0.76	0.48	24.1	0.0	0.0	24.1
1400_6_16	26.5	0.0	0.0	14.6	0.0	0.0	15.4	0.0	0.0	7.1	15.4	18.7	2.80	2.80	0.00	0.00	1.06	0.76	0.48	33.2	0.0	0.0	33.2
1400_9_16	39.4	0.0	0.0	13.4	0.0	0.0	14.1	0.0	0.0	6.5	15.4	18.7	2.82	2.82	0.00	0.00	1.06	0.76	0.49	42.3	0.0	0.0	42.3
1400_12_16	49.6	0.0	0.0	11.9	0.0	0.0	12.7	0.0	0.0	5.8	15.4	18.7	2.77	2.77	0.00	0.00	1.05	0.75	0.48	49.9	0.0	0.0	49.9
1400_15_16	60.7	0.0	0.0	11.1	0.0	0.0	12.0	0.0	0.0	5.5	15.4	18.8	2.79	2.79	0.00	0.00	1.05	0.75	0.48	55.4	0.0	0.0	55.4
Coarse ore_I	32.9	4.0	2.4	15.1	14.9	13.2	15.2	15.8	13.3	15.0	15.4	18.7	7.62	3.50	2.51	1.60	2.87	2.06	1.31	36.3	1.1	46.9	26.9
Coarse coal_II	25.1	6.8	4.5	11.8	18.7	18.2	11.9	19.8	18.1	15.8	15.3	18.8	7.25	3.33	2.39	1.52	2.72	1.95	1.24	41.1	-9.5	32.4	22.6
Fine coal_A	39.8	5.0	2.7	13.8	14.8	15.3	13.8	15.7	15.6	14.8	15.3	18.8	7.49	3.44	2.47	1.57	2.81	2.02	1.28	52.8	6.1	8.7	28.1
Fine ore_B	44.0	6.2	3.0	20.6	13.0	13.4	20.2	14.0	13.6	16.8	15.4	18.7	7.06	3.25	2.33	1.48	2.66	1.91	1.22	39.2	10.3	8.0	23.1
1400_3_40_char	8.5	1.0	0.5	15.8	14.2	14.1	15.6	14.9	14.1	15.1	15.7	16.0	6.80	3.13	2.24	1.43	3.07	2.20	1.40	24.6	-8.9	0.5	8.4
1400_6_40_char	13.2	0.8	0.9	13.2	15.4	15.6	13.2	16.1	15.7	14.7	15.7	16.0	6.72	3.09	2.22	1.41	3.03	2.18	1.39	33.7	-12.1	-9.7	9.5
1400_9_40_char	21.9	1.0	0.6	16.6	12.8	13.5	16.6	13.3	13.5	14.9	15.7	16.0	6.75	3.11	2.23	1.42	3.05	2.19	1.39	18.1	8.0	6.6	12.3
1400_12_40_char	33.3	2.9	1.1	12.5	15.7	15.1	12.6	16.5	15.2	14.4	15.7	16.0	6.60	3.04	2.18	1.39	2.98	2.14	1.36	34.3	-10.7	8.8	14.1
1400_15_40_char	38.0	5.1	1.5	11.1	15.9	14.8	11.2	16.6	14.9	13.7	15.8	16.0	6.74	3.10	2.23	1.42	3.05	2.19	1.39	45.9	-5.3	2.0	19.8

*Corrected for Fibreboard carry over

	Mass Carbon remaining				Mass loss				Mass oxygen					Energy Input	
Sample Number	Total g. Carbon remaining in sample [calculated from product gas analyses]	Total g. Carbon remaining in sample [calculated from sample analysis]	g. C Difference: (Total g. Carbon remaining in sample [calculated from product gas analyses]) - (Total g. Carbon remaining in sample [calculated from sample analysis])	g. Difference as % of analysed C remaining in reacted sample	Mass loss according to gas analyses (Total time)	Mass Loss according to mixture in sample split & FB carry over; [Mixture mass is backcalculated from Fe mass balance]	g. Mass loss difference: (Mass loss according to gas analyses (Total time)) - (Mass Loss according to mixture in sample split & FB carry over; [Mixture mass is backcalulated from Fe mass balance])	g. Difference as % of weighed mass loss	g. O in	g. O remaining in sample	g. O to gas from Forms of Fe analyses	g. O Difference: (g. O in CO & CO2 & H2O in Product gas [Total Time]) - (g. O to gas from Forms of Fe analyses of reacted sample material)	g. Difference as % of g. O to gas from forms of Fe analysis	Average kW/m^2 into sample - Radiation Network	Total radiation heat input to sample (MJ/m^2)
1300_3_40	7.07	6.82	0.25	4	1.98	1.6	0.4	26	9.42	8.21	1.21	0.09	7	-120	21
1300_6_40	6.92	6.30	0.62	10	2.43	2.2	0.2	10	9.34	7.87	1.47	0.15	10	-127	46
1300_9_40	6.95	6.11	0.84	14	2.68	2.5	0.1	6	9.30	7.77	1.53	0.35	23	-125	67
1300_12_40	6.35	5.61	0.74	13	3.73	3.0	0.7	25	8.99	7.08	1.92	0.63	33	-109	79
1300_15_40	5.71	5.58	0.12	2	5.21	4.0	1.2	30	9.02	6.74	2.28	1.06	47	-108	97
1400_3_40	6.98	6.05	0.93	15	1.58	1.7	-0.1	-8	9.11	7.65	1.45	-0.43	-30	-181	33
1400_6_40	6.77	6.02	0.75	12	2.61	2.6	0.0	1	9.12	7.31	1.81	-0.10	-5	-180	65
1400_9_40	6.09	5.34	0.75	14	3.25	3.2	0.1	3	8.45	6.48	1.97	0.20	10	-178	96
1400_12_40	6.14	5.34	0.80	15	4.05	4.5	-0.5	-11	9.02	6.68	2.34	0.23	10	-175	126
1400_15_40	5.52	4.99	0.52	10	5.46	5.0	0.5	10	8.89	6.17	2.72	0.74	27	-169	152
1500_3_40	6.87	6.00	0.87	15	2.71	2.2	0.5	20	9.27	7.69	1.58	0.30	19	-259	47
1500_6_40	6.33	5.49	0.84	15	4.15	3.8	0.4	9	9.26	6.99	2.26	0.43	19	-250	89
1500_9_40	5.79	5.21	0.58	11	5.94	4.9	1.0	20	9.35	6.68	2.67	1.04	39	-254	137
1500_12_40	5.07	4.29	0.78	18	7.39	6.7	0.6	10	9.00	5.53	3.47	1.30	37	-211	151
1500_15_40	3.97	3.83	0.14	4	9.39	7.5	1.9	26	8.86	4.90	3.95	1.80	45	-208	186
1400_3_16	2.45	2.13	0.33	15	1.73	1.3	0.4	35	3.47	2.77	0.70	0.55	78	-165	29
1400_6_16	1.91	1.87	0.03	2	2.95	2.2	0.7	33	3.47	2.31	1.17	0.72	62	-158	56
1400_9_16	1.50	1.63	-0.13	-8	3.93	3.0	1.0	32	3.50	1.92	1.58	0.86	54	-157	85
1400_12_16	1.67	1.39	0.28	20	3.82	3.3	0.5	16	3.44	1.57	1.87	0.65	35	-157	113
1400_15_16	0.54	1.24	-0.70	-57	6.22	3.9	2.3	58	3.45	1.23	2.22	1.58	71	-153	138
Coarse ore_I	6.45	5.57	0.88	16	4.81	4.0	0.8	19	9.57	7.29	2.29	0.93	41	-152	82
Coarse coal_II	6.23	5.61	0.62	11	3.98	3.4	0.5	16	8.93	6.81	2.11	0.43	20	-146	79
Fine coal_A	5.61	5.38	0.23	4	5.98	4.3	1.6	38	9.23	6.98	2.25	1.45	65	-153	82
Fine ore_B	5.02	5.43	-0.41	-8	6.26	3.1	3.1	100	8.88	6.79	2.09	1.64	78	-153	82
1400_3_40_char	6.45	6.22	0.23	4	2.01	1.2	0.8	65	10.00	9.12	0.87	0.67	77	-175	33
1400_6_40_char	6.23	6.08	0.16	3	1.97	1.5	0.5	33	9.88	8.83	1.06	0.34	33	-168	60
1400_9_40_char	6.11	5.92	0.19	3	2.56	2.0	0.5	27	9.94	8.58	1.36	0.43	31	-163	88
1400_12_40_char	5.90	5.68	0.23	4	3.19	2.8	0.3	12	9.73	7.74	1.99	0.36	18	-155	112
1400_15_40_char	5.42	5.41	0.01	0	4.32	3.8	0.5	14	9.88	7.63	2.25	0.65	29	-151	136

Sample masses and analyses for coal-alumina experiments

							Mass% In		Sample Mix Out			Fibreboard			Thermocouples			Totals Out			Mass In	
Sample Number	Furnace Temperature (°C)	Coal/Char	Coal/Char Size*	Ore Size*	Reaction Time [min.]	Sample Layer Thickness [mm]	mass% Alumina in	mass% Coal in	g. sample mix - top	g. sample mix - middle	g. sample mix - bottom	g. Fibreboard - top	g. Fibreboard -middle	g. Fibreboard -bottom	g. thermocouple - top	g. thermocouple - middle	g. thermocouple -bottom	Total g. sample mix out	Total g. Fibreboeard out	Total g. Thermocouples out	g. Fibreboard in	g. Mix in
1300_Devol	1300	Coal	2	2	2337	40.0	75.3	24.7	9.716	15.024	9.417	5.102	3.954	8.716	0	0	0	34.157	17.772	0	19.738	35.172
1400_Devol	1400	Coal	2	2	1800	40.0	75.3	24.7	10.528	14.895	8.511	10.559	6.083	12.530	0	0	0	33.934	29.172	0	31.127	34.859
1500_Devol	1500	Coal	2	2	2060	40.0	75.3	24.7	11.509	14.390	8.666	11.215	6.172	12.742	0	0	0	34.565	30.129	0	32.707	35.166

	Product Gas					Product gas analysed						H2O - out				H In vs. H in Product Gas			O In vs. O in Product Gas		
Sample Number	Mass loss according to Product gas analysis [Total Time]	Mass loss according to Product gas analysis [Experimental Time only]	g. O in CO & CO2 in Product gas [Total Time]	g. O in CO & CO2 in Product gas [Experimental time only]	g. O in CO & CO2 & H2O in Product gas [Total Time]	Total g. CO2 in Product Gas	Total g. CH4 in Product Gas	Total g. CO in Product Gas	Total g. H2 in Product Gas	Total g. H2O in Product Gas	g. H2O in - Proximate analysis	g. H2O in - (Proximate analysis) + (All %O from Ultimate Analysis as H2O)	%H2O - Proximate Analysis	%H2O in - (Proximate analysis) + (All %O from Ultimate Analysis as H2O)	%H2O in - Product Gas Analysis	Total g. H in	Total g. H out - (From Product Gas Analysis)	g. H in/g. H out	g. O in	Total g. O out - (From Product Gas Analysis)	g. O in/g. O out
1300_Devol	1.28	1.28	0.14	0.14	0.79	0.19	0.02	0.00	0.33	0.73	0.29	0.90	3.3	10.1	8.2	0.35	0.8	0.5	0.8	0.79	1.0
1400_Devol	2.91	2.6	1.08	0.95	1.68	0.29	0.08	1.52	0.34	0.68	0.30	0.91	3.3	10.1	7.5	0.35	0.8	0.5	0.8	1.68	0.5
1500_Devol	5.79	5.79	2.29	2.29	3.35	0.55	0.00	3.32	0.73	1.19	0.30	0.92	3.3	10.1	13.1	0.36	1.6	0.2	0.8	3.35	0.2

	Total C Balance											%Fixed carbon back-calculated			%Volatile Matter Content - back-calculated						Mass loss			
Sample Number	g. Total Carbon in	Total g. Carbon to gas [calculated from product gas analyses]	Total g. Carbon remaining in sample [calculated from product gas analyses]	Total g. Carbon remaining in sample [calculated from sample analysis]	g. C deposited if all H_2 off as CH_4	g. C Difference: (Total g. Carbon remaining in sample [calculated from product gas analyses]) - (Total g. Carbon remaining in sample [calculated from sample analysis])	g. Difference as % of analysed C remaining in reacted sample	g. Total C out according to Product Gas analysis & %C analysed in reacted sample	g. C in/g. C out	%Total Carbon in Coal	% Total C in Coal calculated from Product Gas Analysis & %C analysed in reacted sample	%Fixed Carbon in coal - Proximate analysis	%Fixed Carbon in coal from Carbon remaining in reacted sample [calculated from product gas analyses]	%Fixed Carbon in coal from Carbon remaining in reacted sample [calculated from sample analysis]	%Volatile Matter Content - Proximate Analysis	g. Volatile Matter Content - Proximate Analysis	%Volatile Matter Content - Calculated from Product Gas Analysis	g. Volatile Matter Content - Calculated from Product Gas Analysis	%Volatile Matter Content - Calculated from Sample mass loss wieghed	g. Volatile Matter Content - Calculated from Sample mass loss wieghed	Mass loss according to gas analyses (Total time)	Mass Loss according to mixture in sample split & FB carry over; [Mixture mass is backcalulated from Fe mass balance]	g. Mass loss difference: (Mass loss according to gas analyses (Total time)) - (Mass Loss according to mixture in sample split & FB carry over; [Mixture mass is backcalulated from Fe mass balance])	g. Difference as % of weighed mass loss
1300_Devol	6.75	0.07	6.69	5.34	0.98	1.4	25	5.40	1.2	75.9	61	62.2	75	60	22.5	2.00	14	1.28	24	2.10	1.28	2.10	-0.8	-39
1400_Devol	6.85	0.79	6.06	5.01	1.01	1.0	21	5.80	1.2	75.9	64	62.2	67	56	22.5	2.03	32	2.91	31	2.75	2.91	2.75	0.2	6
1500_Devol	6.92	1.57	5.34	5.07	2.17	0.3	5	6.64	1.0	75.9	73	62.2	59	56	22.5	2.05	64	5.79	28	2.54	5.79	2.54	3.3	128

							g. Al_2O_3 pick-up			g. SiO_2 pick-up			%Al_2O_3 - Out			%SiO_2 - Out			Corrected masses out			Correced Fibreboard masses			
Sample Number	g. Al_2O_3 In	g. Al_2O_3 out	g. SiO_2 In	g. SiO_2 out	Total g. Al_2O_3 pick-up	Total g. SiO_2 pick-up	g. Al_2O_3 pick-up - top	g. Al_2O_3 pick-up - middle	g. Al_2O_3 pick-up - bottom	g. SiO_2 pick-up - top	g. SiO_2 pick-up - middle	g. SiO_2 pick-up - bottom	%Al_2O_3 Analysed -Top	%Al_2O_3 Analysed -Middle	%Al_2O_3 Analysed -Bottom	%SiO_2 Analysed -Top	%SiO_2 Analysed -Middle	%SiO_2 Analysed -Bottom	g. sample mix out - Top (Corrected)*	g. sample mix out - Middle (Corrected)*	g. sample mix out - Bottom (Corrected)*	g. Fibreboard out - Top (Corrected)*	g. Fibreboard out - Middle (Corrected)*	g. Fibreboard out - Bottom (Corrected)*	g. Al_2O_3 in/ g.Al_2O_3e out
1300_Devol	26.53	27.29	0.62	1.09	0.13	0.07	0.00	0.13	0.00	0.00	0.07	0.00	76.70	80.00	83.00	2.78	3.78	2.63	9.72	14.83	9.42	5.10	4.15	8.72	0.98
1400_Devol	26.30	27.53	0.62	1.00	0.09	0.05	0.00	0.09	0.00	0.00	0.05	0.00	79.00	82.60	81.20	2.57	3.42	2.63	10.53	14.76	8.51	10.56	6.22	12.53	0.96
1500_Devol	26.53	27.81	0.62	1.22	0.12	0.06	0.09	0.02	0.00	0.05	0.01	0.00	79.30	82.10	79.30	2.93	3.98	3.58	11.36	14.36	8.67	11.36	6.20	12.74	0.96

*Corrected for Fibreboard carry over

			%Carbon out							Mass Carbon In						%Carbon consumption			
Sample Number	g. Coal in	g. Coal In back-calculated from Alumina mass balance	%C analysed - Top	%C analysed - Middle	%C analysed - Bottom	%C out analysed - top (Corrected)*	%C out analysed - middle (Corrected)*	%C out analysed - bottom (Corrected)*	Composite %Carbon	g. Total C in - top	g. Total C in - middle	g. Total C in - bottom	g. Total FC in - top	g. Total FC in - middle	g. Total FC in - bottom	%C consumption - top	%C consumption - middle	%C consumption - bottom	Composite %C consumption
1300_Devol	8.7	8.9	18.9	14.9	13.4	18.9	15.1	13.4	16.5	3.11	2.23	1.42	2.55	1.83	1.16	40.9	-0.4	11.0	21.0
1400_Devol	8.6	9.0	17.0	13.0	15.1	17.0	13.1	15.1	15.3	3.15	2.26	1.44	2.58	1.85	1.18	43.2	14.3	10.6	26.8
1500_Devol	8.7	9.1	16.2	12.7	15.9	16.41	12.7	15.9	15.1	3.18	2.28	1.45	2.61	1.87	1.19	41.4	19.9	5.1	26.7

*Corrected for Fibreboard carry over

Appendix XII: Calculation of equilibrium %CO in CO-CO_2 gas

The heat capacity values and standard enthalpy and entropy values used are those from Kubashewski *et al.* (1993). The values used are summarised in the table below.

Enthalpy equation:

$$C_p(T) = A + BT + C/T^2 + DT^2 \text{ [J/mol K]}$$

$$\Delta H = \int_{T_1}^{T_2} C_p dT + \Delta H_{T_1} = A \cdot (T_2 - T_1) + B/2 \cdot (T_2^2 - T_1^2) - C/(T_2 - T_1) + D/3 \cdot (T_2^3 - T_1^3)$$

The $C_p(T)$ equations were obtained from Kubashewski *et al.* (1993).

Entropy equation:

$$\Delta S = \int_{T_1}^{T_2} \frac{C_p}{T} dT + \Delta S_{T_1} = A \cdot \ln(\frac{T_2}{T_1}) + B \cdot (T_2 - T_1) - \frac{C}{2}(\frac{1}{T_2^2} - \frac{1}{T_1^2}) + D/2 \cdot (T_2^2 - T_1^2)$$

$$\Delta G = \Delta H - T\Delta S$$

$$\Delta G = -RT \ln K$$

T = temperature (K)

$C_p(T)$ = heat capacity of component at constant pressure (J/mol K)

ΔH = change in enthalpy of component material when heated from T_1 to T_2 (J)

ΔS = change in entropy of component material when heated from T_1 to T_2 (J)

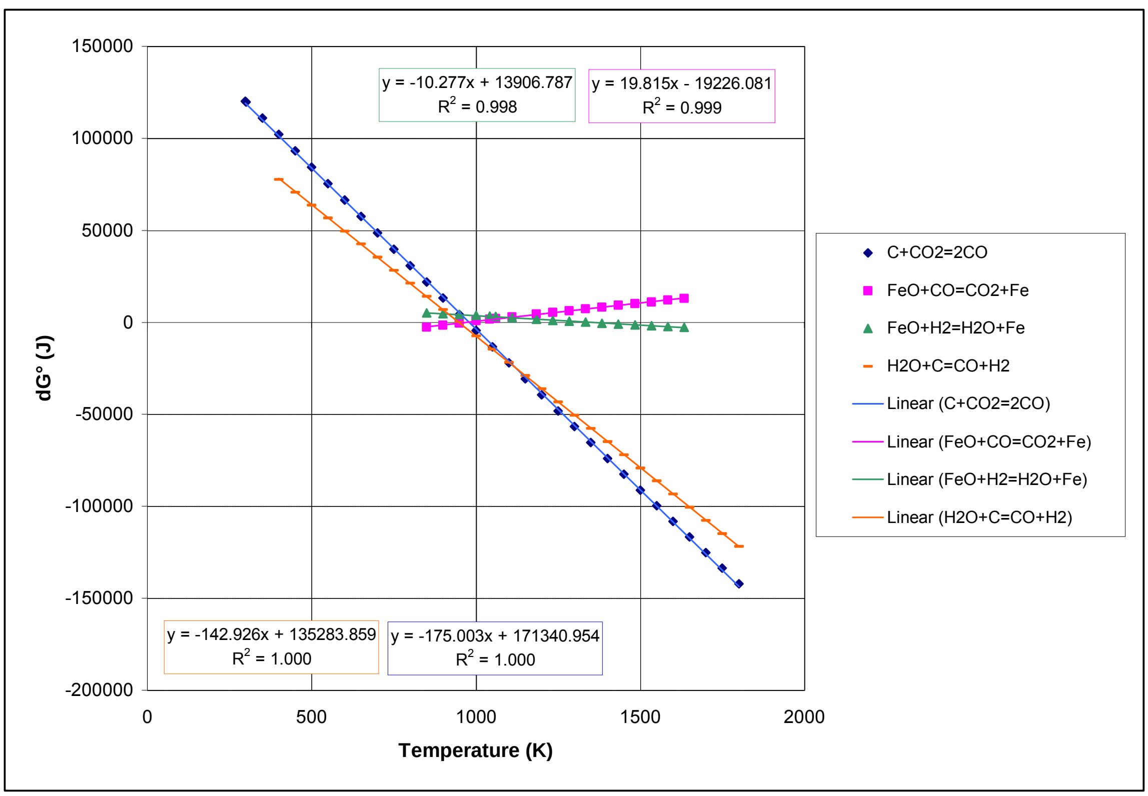
ΔG = Gibbs free energy change for reaction between T_1 to T_2 (J)

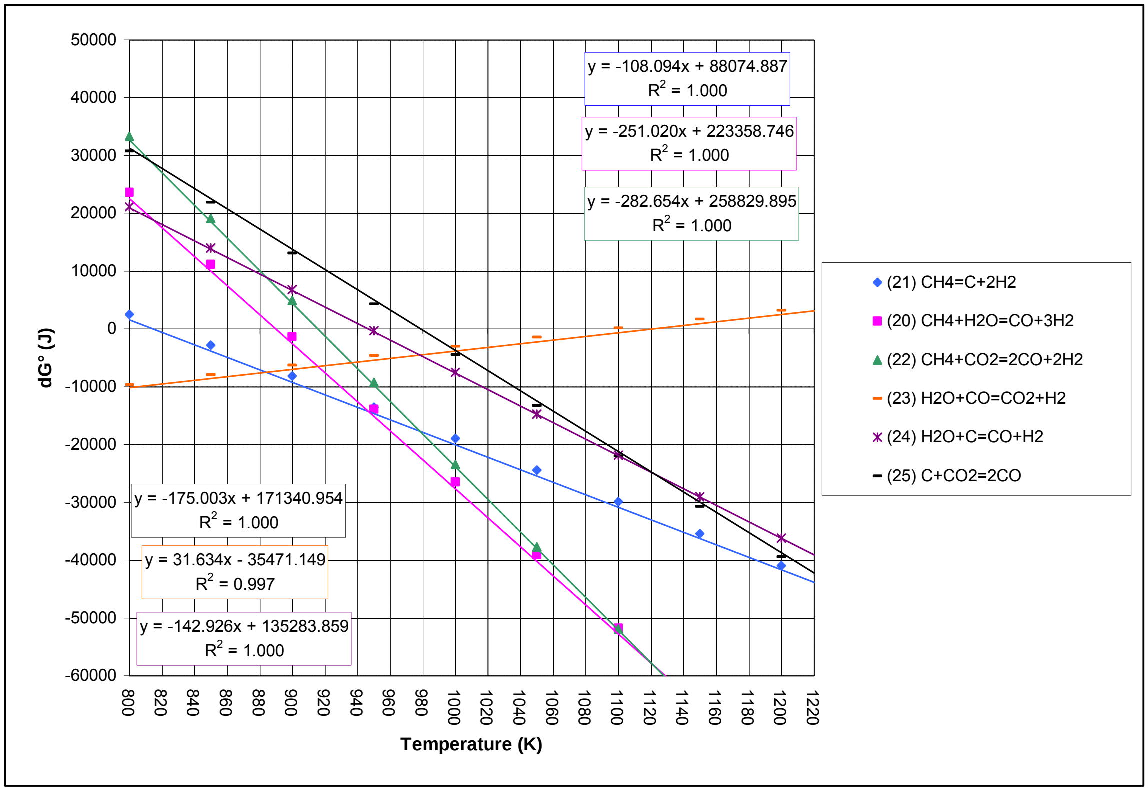
K= equilibrium constant

The enthalpy and entropy equation parameters used are shown below:

Component	$\Delta H_{T_1}[J/mol]$	ΔS_{T_1} $[J/\deg mol]$	H_t [kJ/mol]	$T_1[K]$	$T_2[K]$	[J/deg mol]			
						A	$B\cdot 10^3$	$C\cdot 10^{-5}$	$D\cdot 10^6$
$Fe_{0.945}O$	-263000	60.10	---	>=298		48.79	8.37	-2.8	---
Fe	0	27.3	---	298	800	28.18	-7.32	-2.9	---
	15571	56.95	---	800	1000	-263.45	255.81	619.23	---
	24408	66.74	---	1000	1042	-641.91	696.34	---	---
	27308	69.58	---	1042	1060	1946.25	-1787.5	---	---
	28525	70.73	---	1060	1184	-561.95	334.13	2912.11	---
	35002	76.54	0.9	1184	1665	23.99	8.36	---	---
	53069	89.22	0.8	1665	1809	24.64	9.9	---	---
	72893	100.32	13.8	1809	2000	46.02	---	---	---
CO	-110500	197.50	---	>=298		28.41	4.1	-0.46	---
CO_2	-393500	213.7	---	>=298		44.14	9.04	-8.54	---
C(graphite)	0	5.7	---	298	1100	0.11	38.94	-1.48	---
	13998	26.56	---	>=1100		24.43	0.44	-31.63	---
H_2	0	130.6	---	298		27.37	3.33	---	---
H_2O (liquid)	-285800	69.9	---	>=298		75.44	---	---	---
H_2O (gas)	-241800	188.7	---	>=298		30	10.71	0.33	---
CH_4	-74800	186.3	---	>=298		12.45	76.69	1.45	-17.99
O_2	0	205.1	---	>=298		29.96	4.18	-1.67	---

The linear plots for ΔG^o:




y = -108.094x + 88074.887
R2 = 1.000
y = -251.020x + 223358.746
R2 = 1.000
y = -282.654x + 258829.895
R2 = 1.000
y = -175.003x + 171340.954
R2 = 1.000
y = 31.634x - 35471.149
R2 = 0.997
y = -142.926x + 135283.859
R2 = 1.000
dG° (J)
Temperature (K)
(21) CH4=C+2H2
(20) CH4+H2O=CO+3H2
(22) CH4+CO2=2CO+2H2
(23) H2O+CO=CO2+H2
(24) H2O+C=CO+H2
(25) C+CO2=2CO