PROCESS ANALYSIS AND PERFORMANCE EVALUATION OF UPDRAFT COAL GASIFIER

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Introduction

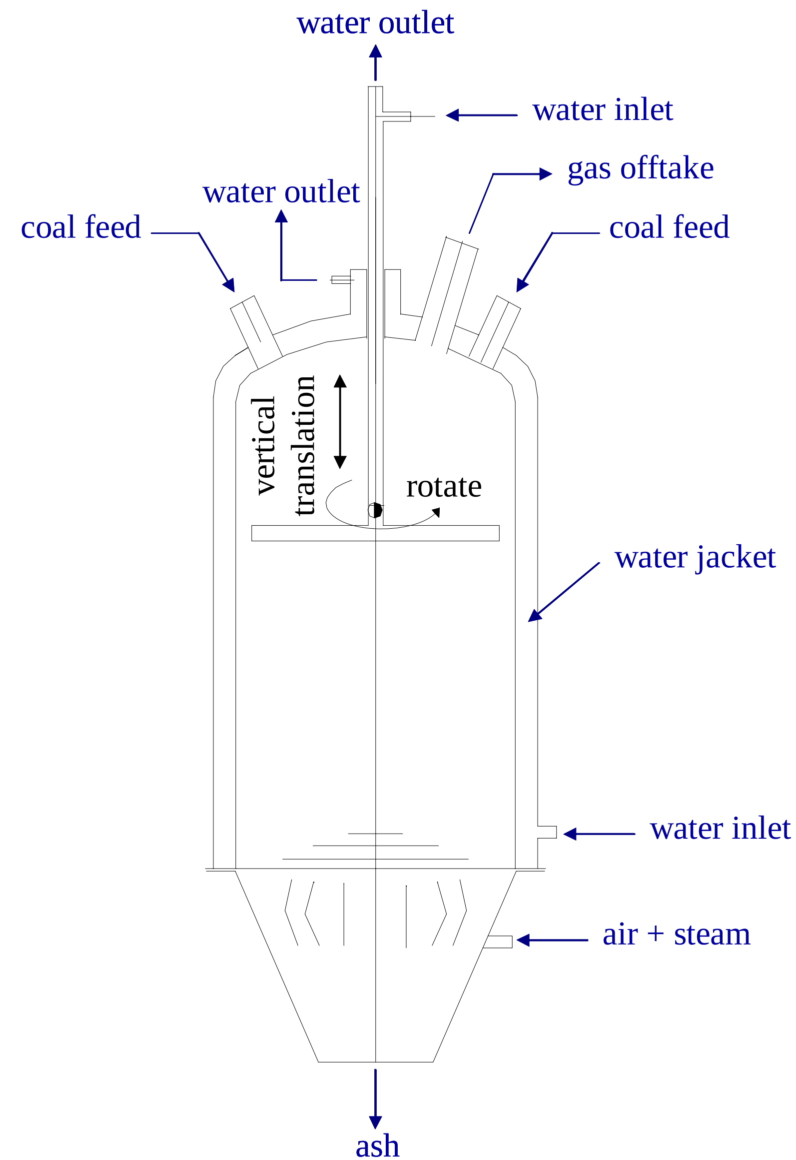
- Coal gasification is increasing its importance for both power generation and for producing hydrogen, methanol, DME and other chemicals and clean fuels.
- IGCC can already achieve efficiency as high as 43-46% with very low emissions.
- Integrated with advanced CC and FC will make it possible to achieve efficiency exceeding 50-55%.
- R&D activities are focussing on reducing the large scale power generation plants (250-500 MW)

Research project

- Department of Mechanical Engineering of the University of Cagliari with project partners: Sotacarbo, Ansaldo Ricerche S.p.A. and ENEA.
- Research project called CO.HY.GEN. for developing integrated gasification processes for the combined production of hydrogen and electricity, in small-to-medium scale commercial plants.
- 2 air blown fixed bed updraft Wellmann Galusha gasifiers: a pilot scale (700 kg/h or 5 MWt) and a laboratory scale (35 kg/h or 0.25 MWt). Fed by low sulphur South African coal and high ash, high sulphur Sulcis coal.
- Under construction at the Sotacarbo Research Centre in Sardinia.

Pilot gasifier

Simplified scheme of the 700 kg/h fixed bed pilot gasifier



Raw gas cleaning section:
- wet scrubber syngas cooling
- dust and tar removal

35 kg/h laboratory scale gasifier:
- no stirrer and water jacket
- overall syngas treatment process

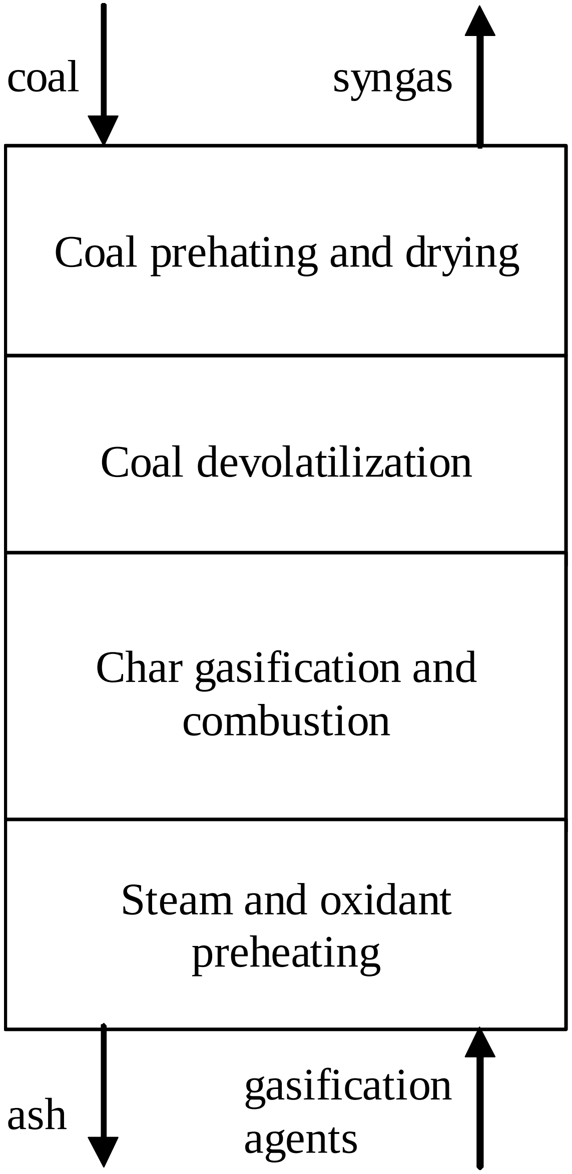
  cold e hot desulphuration, ESP,
  CO shift and CO_2 removal systems
  hydrogen separation unit

Gasification processes

- Gasification processes are very complex, involving: drying, devolatilisation, pyrolysis, gasification and combustion.
- Influenced by kinetics and fluid-dynamical effects.
- Thermodynamic equilibrium only for a known temperature and for reaction time lower than reactants residence time.
- Equilibrium models can predict accurately performance of fluidised-bed and entrained-bed (temperature distribution almost constant).
- In the fixed-bed gasifier drying, devolatilisation, pyrolysis take place at a lower temperature in the heat transfer zone. Moisture and volatiles are generally not involved in the gasification reactions.

Simplified scheme of fixed bed gasification process

Simplified scheme of the fixed bed gasification process

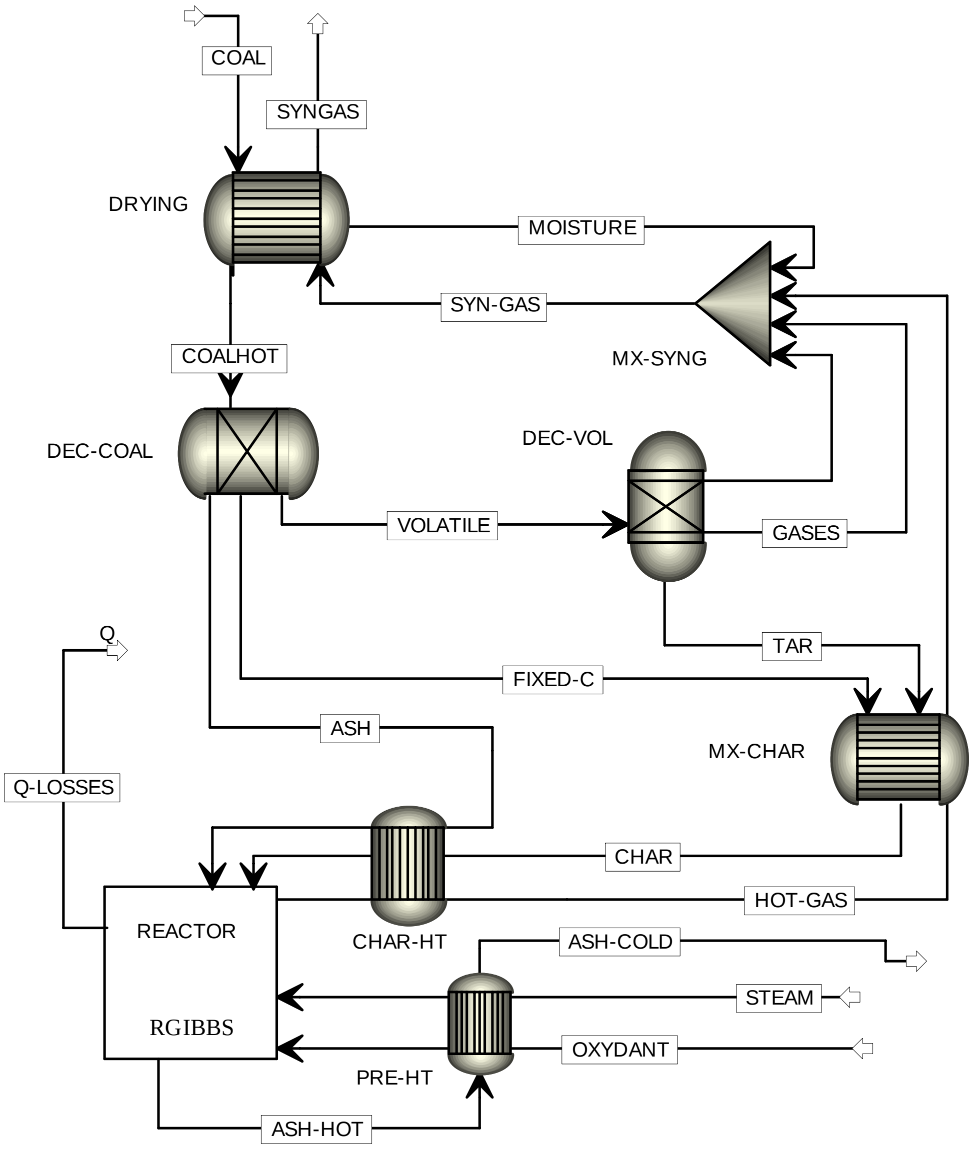


ASPEN simulation model

- New computer simulation model for predicting fixed bed gasifiers performance, developed using **ASPEN Plus**.
- The ASPEN model schematizes the gasifier into several different zones: coal prehating and drying, devolatilisation, gasification and combustion, steam and oxidant preheating.
- The model evaluates the mass and energy balance in each zone and the syngas main characteristics for given coal composition and coal, steam and oxidant mass flows.
- In the gasification and combustion zone the model calculates the syngas composition and the equilibrium temperature minimizing the Gibbs free energy.
- The model calculates the syngas temperature considering the countecurrent heat exchange processes between syngas and coal inside the different sections, imposing a suitable ΔT

ASPEN simplified scheme

Simplified scheme of the Aspen Plus-based gasification model



Input data for the ASPEN model

- Proximate coal analysis (fixed carbon, volatile matter, moisture and ash);
- Ultimate coal analysis (carbon, hydrogen, sulphur, nitrogen, oxygen, moisture and ash);
- Lower Heating Value of the coal;
- Volatile matter and volatile gases composition;
- Oxidant and steam characteristics;
- Thermal energy removed by water jacket and other energy losses;
- Carbon conversion rate.

Proximate and ultimate analysis

Proximate Analysis (%Wt)	Sulcis coal	South African coal
Fixed carbon	32.60	54.00
Volatile matter	38.58	23.00
Ash	17.31	15.00
Moisture	11.51	8.00
Ultimate Analysis (%Wt)		
Carbon	53.17	65.84
Hydrogen	3.89	3.71
Sulphur	5.98	0.55
Nitrogen	1.29	1.50
Oxygen	6.75	5.35
Chlorine	0.10	0.05
Ash	17.31	15.00
Moisture	11.51	8.00
Lower Heating Value (MJ/kg)	20.5-21.5	24.5-25.5

Proximate and ultimate analysis of the coals

VM and VM gases composition and steam and oxidant characteristics

Volatile matter composition (%Wt)	Sulcis coal	South African coal
Water	5.00	15.00
TAR	65.00	50.00
VM gases	30.00	35.00
VM gases composition (%vol)		
CO	33.03	9.73
CO_2	7.01	2.06
H_2	33.07	71.01
CH_4	26.89	17.19

Steam	Sulcis coal	South African coal
Temperature	120 °C	120 °C
Pressure	1.30 bar	1.30 bar
Steam/coal mass ratio	0.26	0.34
Air		
Temperature	20 °C	20 °C
Pressure	1.30 bar	1.30 bar
Oxygen/coal mass ratio	0.414	0.559
Air/coal mass ratio	1.80	2.43

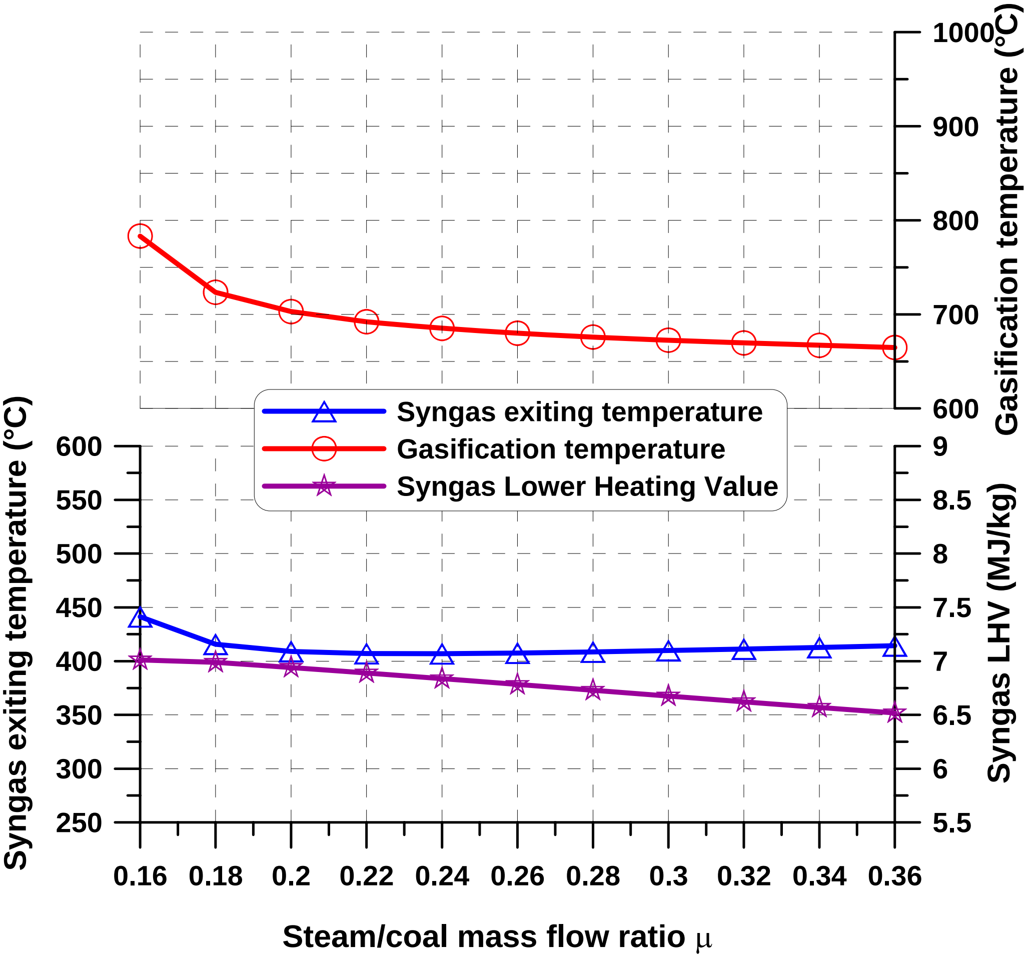
Expected and calculated syngas compositions

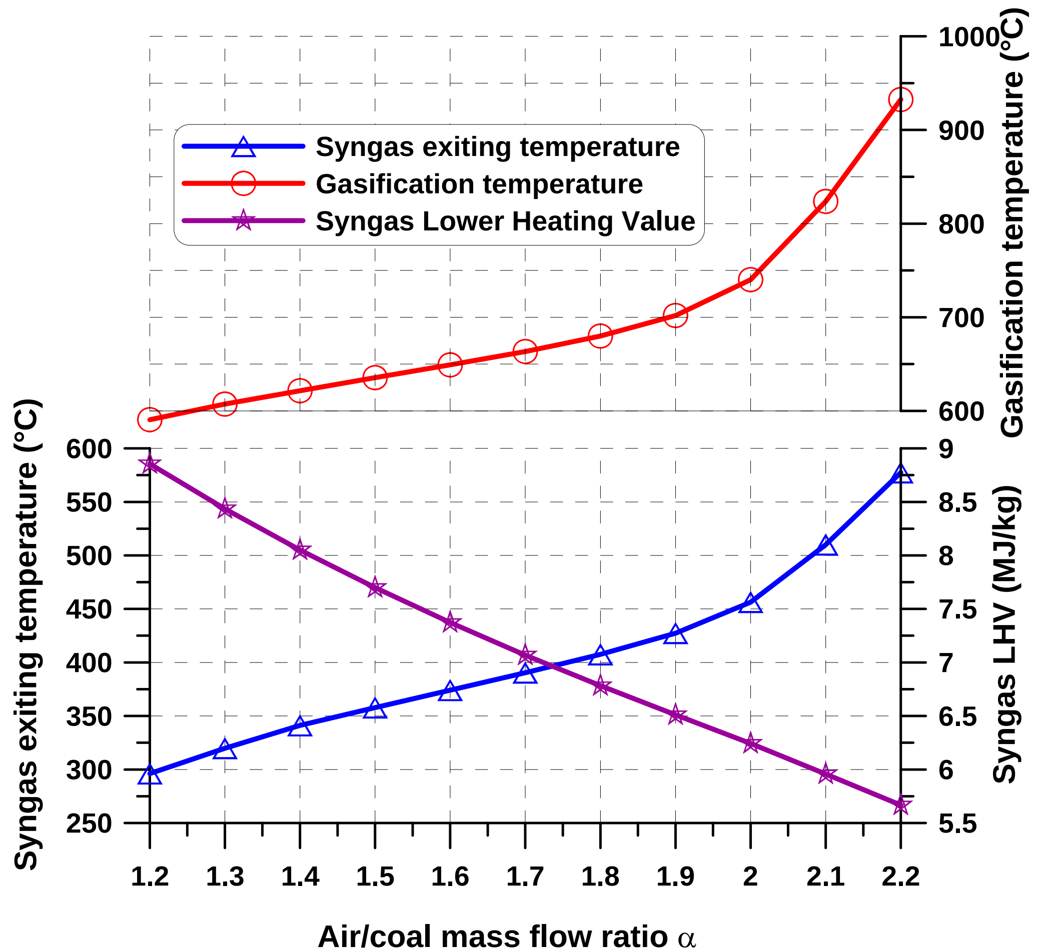
	Sulcis coal			South African coal		
Syngas composition (%vol)	*expected*	*adiabatic*	*5% thermal energy losses*	*expected*	*adiabatic*	*5% thermal energy losses*
CO	31.0	30.05	25.75	28.0	31.33	27.89
CO_2	4.0	3.44	6.70	5.0	2.68	5.32
H_2	18.0	18.73	13.57	18.0	19.83	15.86
N_2	45.5	42.02	44.69	46.5	43.95	46.11
CH_4	1.5	3.66	7.05	2.5	1.58	4.15
Mean gasification temperature (°C)		680	606		736	631
Syngas exit temperature (°C)		407	361		515	446
Syngas LHV (MJ/kg)		6.78	6.49		6.22	5.98
Cold gas efficiency (%)		91.5	87.6		88.5	85.1
Syngas/coal flow ratio (Nm^3/kg)	2.40	2.60	2.44	3.20	3.35	3.19

Expected and calculated syngas composition at reference conditions for the up-draft gasifier

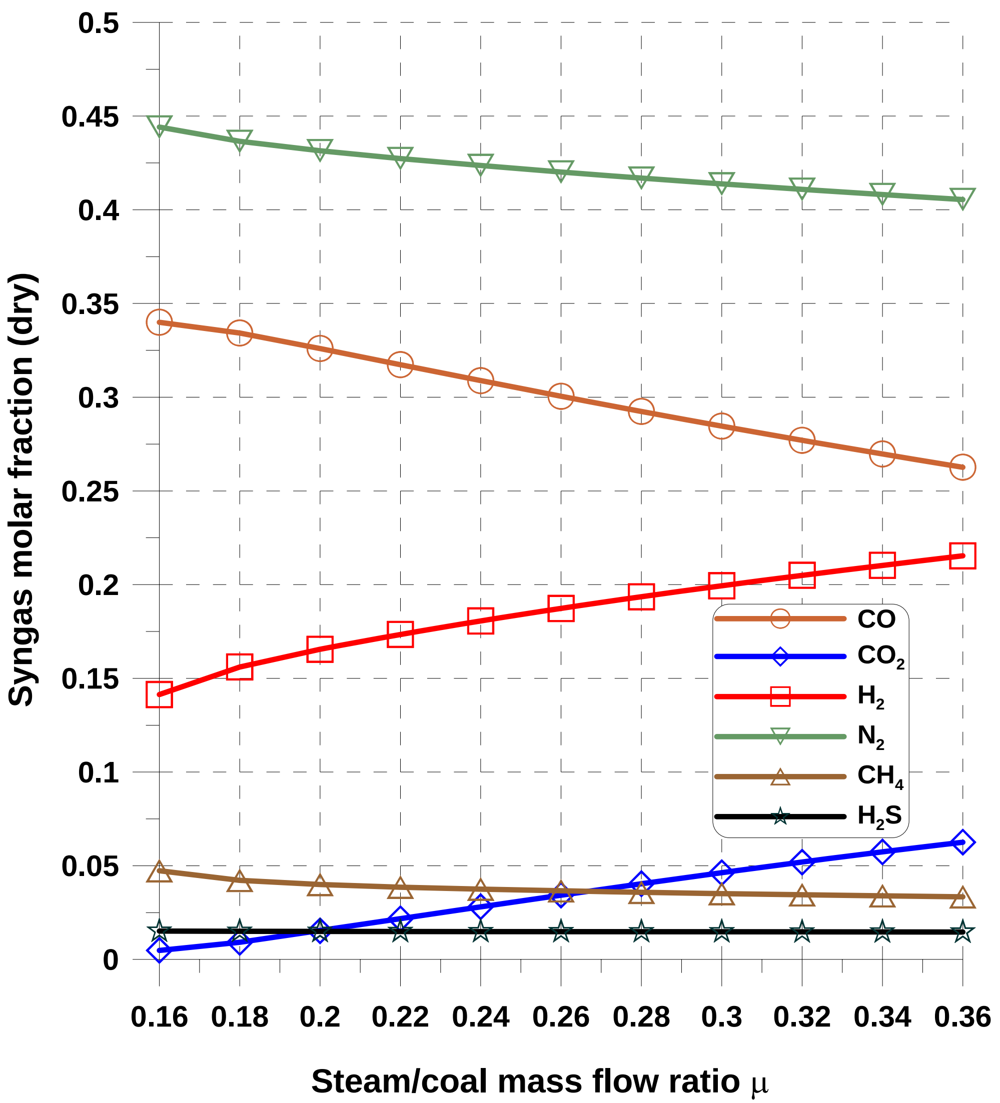
Gasification and syngas temperature and LHV vs steam/coal and air/coal mass ratios

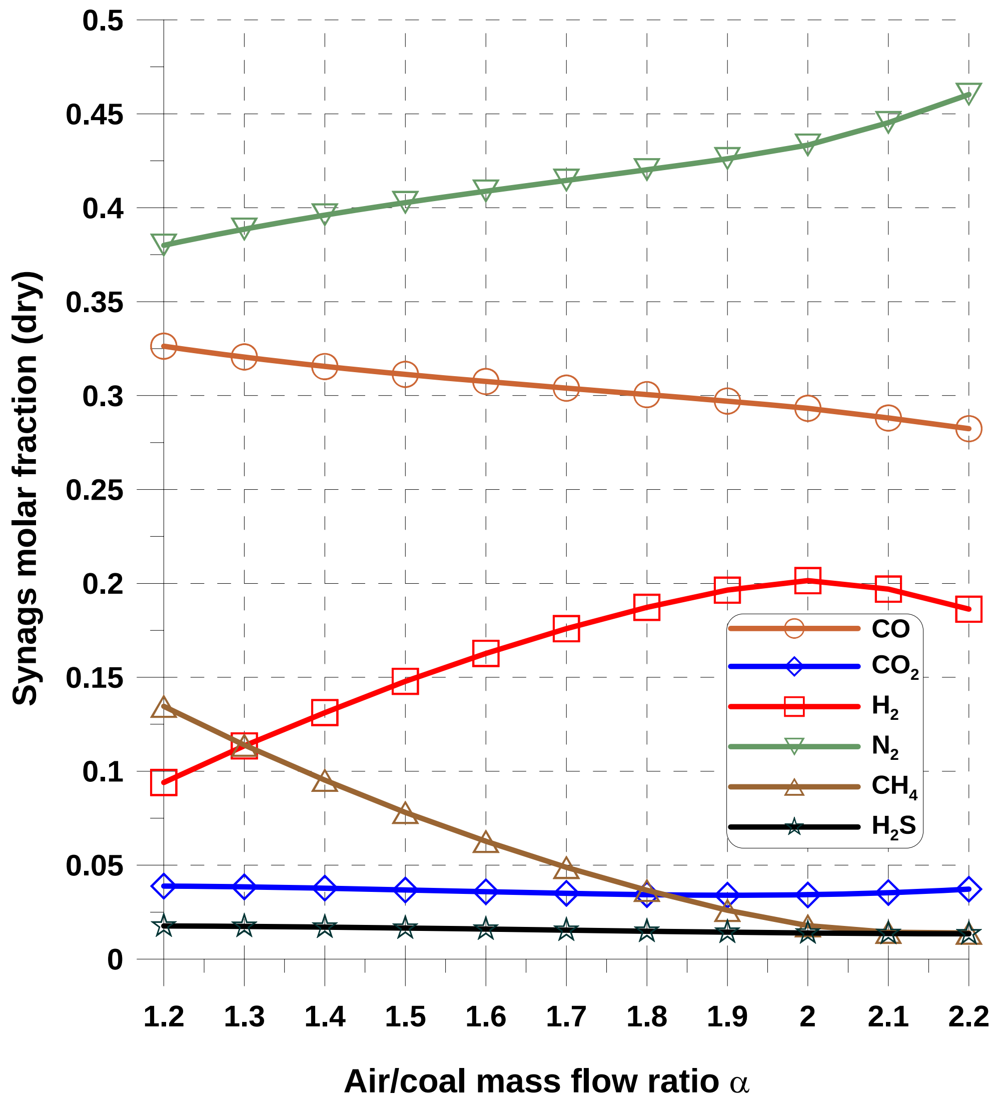
SULCIS COAL



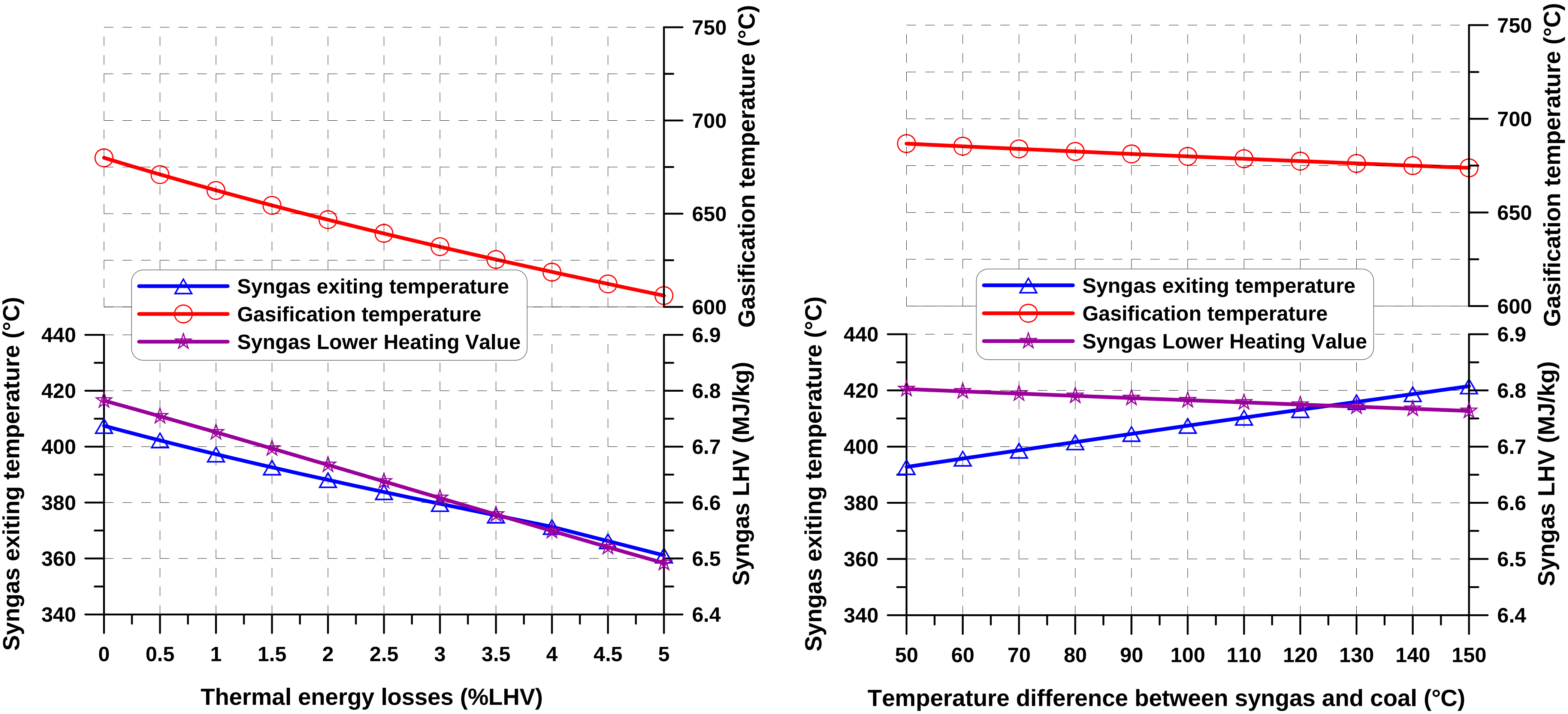


Syngas molar fraction vs steam/coal and air/coal mass ratios



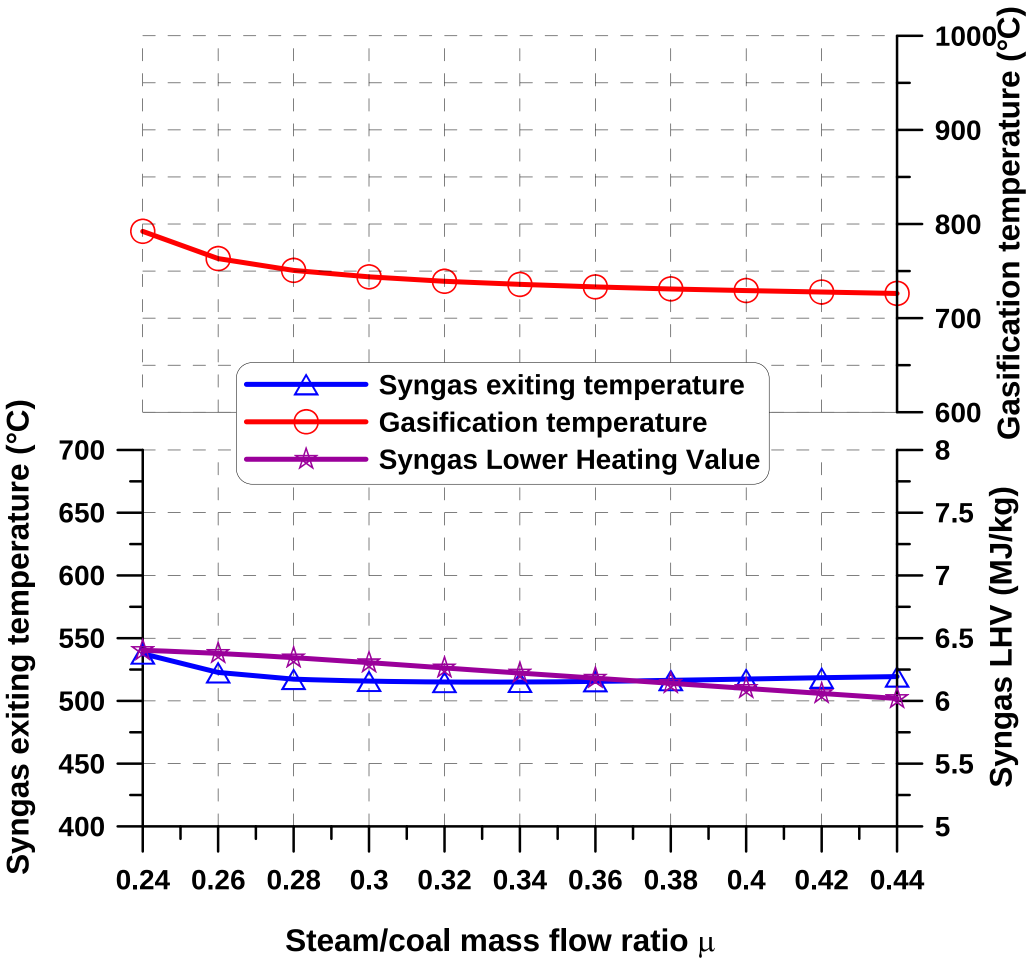


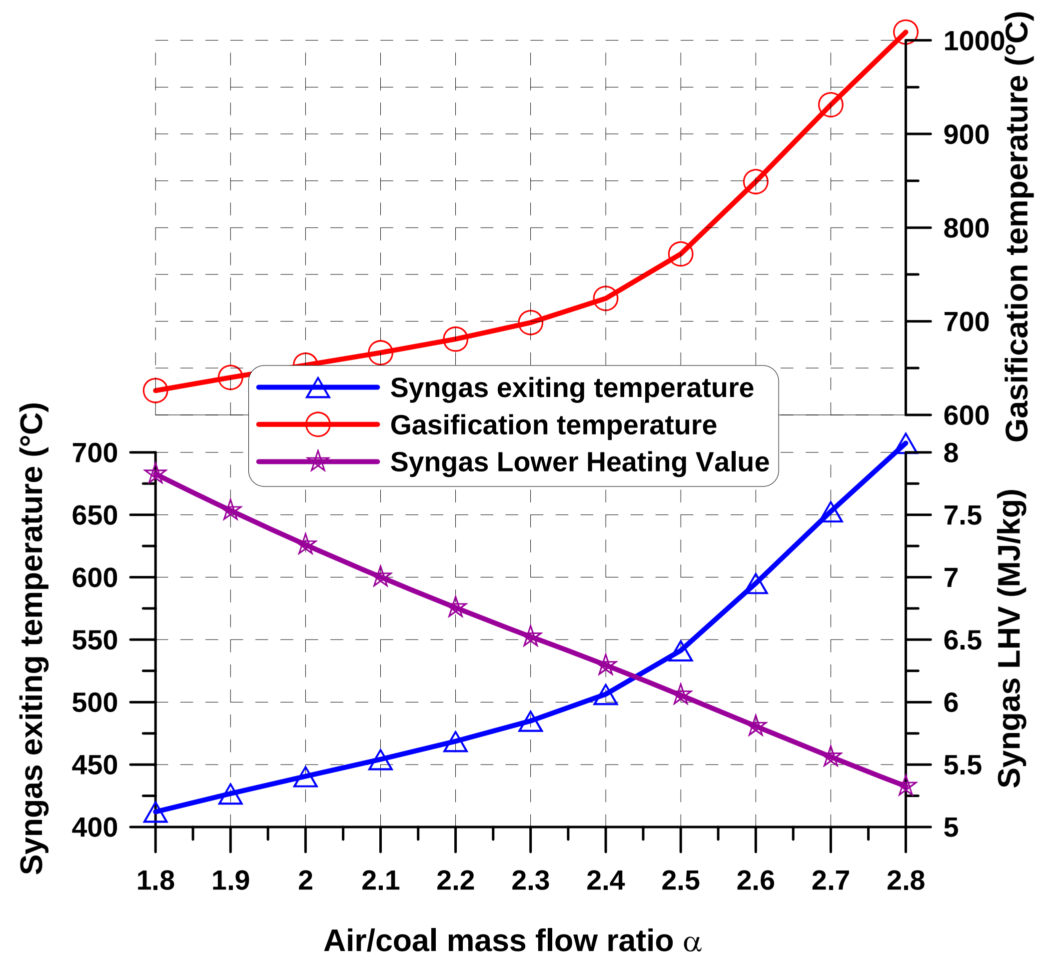
Gasification and syngas temperature and LHV vs thermal energy losses and ΔT



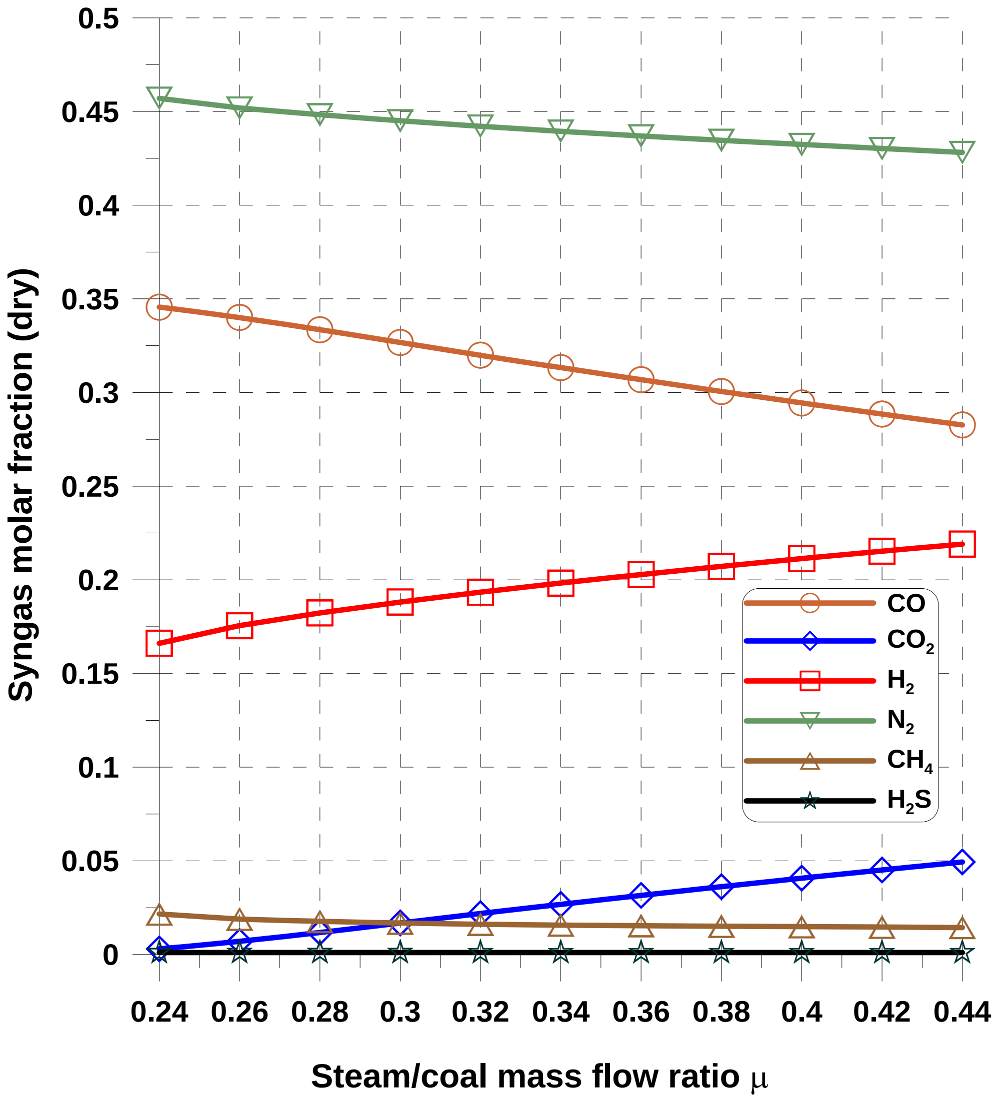
Gasification and syngas temperature and LHV vs steam/coal and air/coal mass ratios

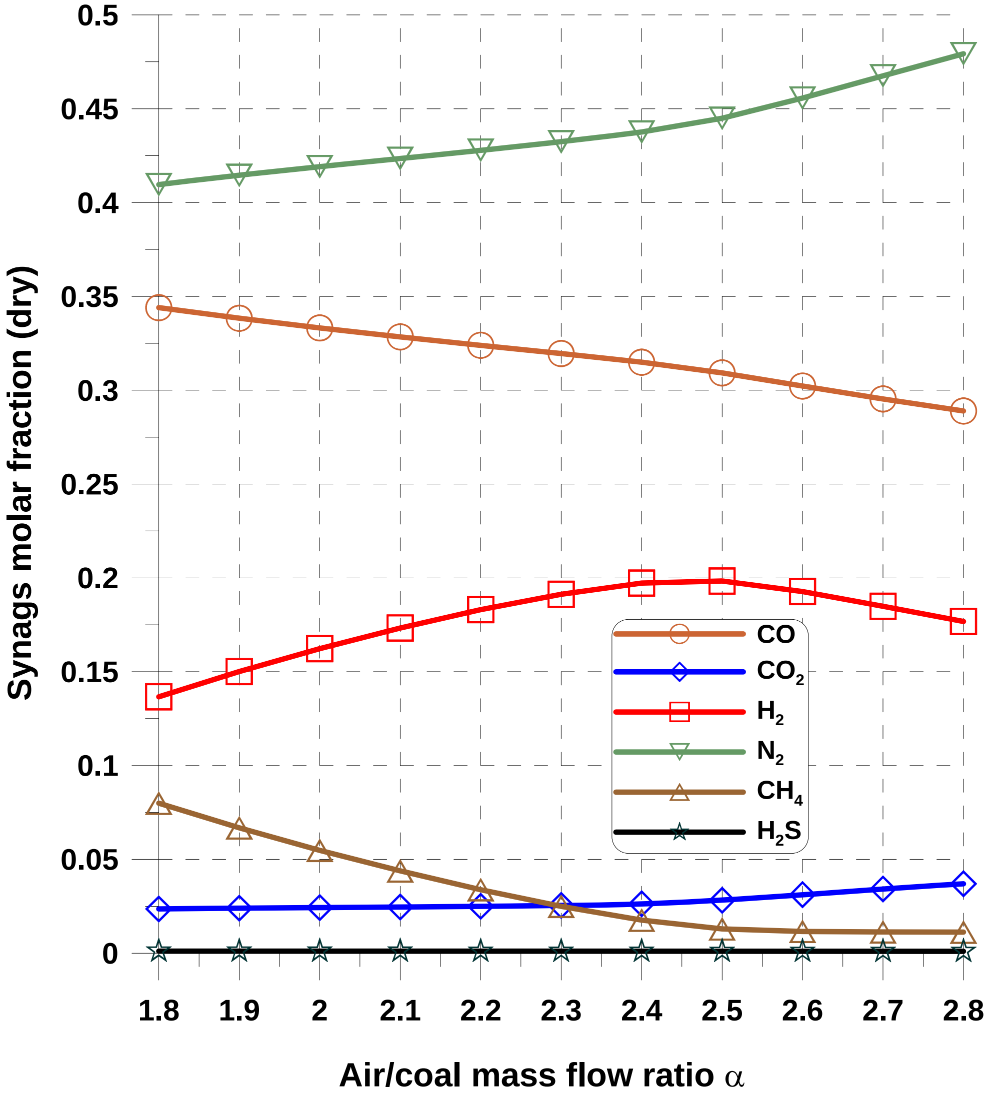
SOUTH AFRICAN COAL



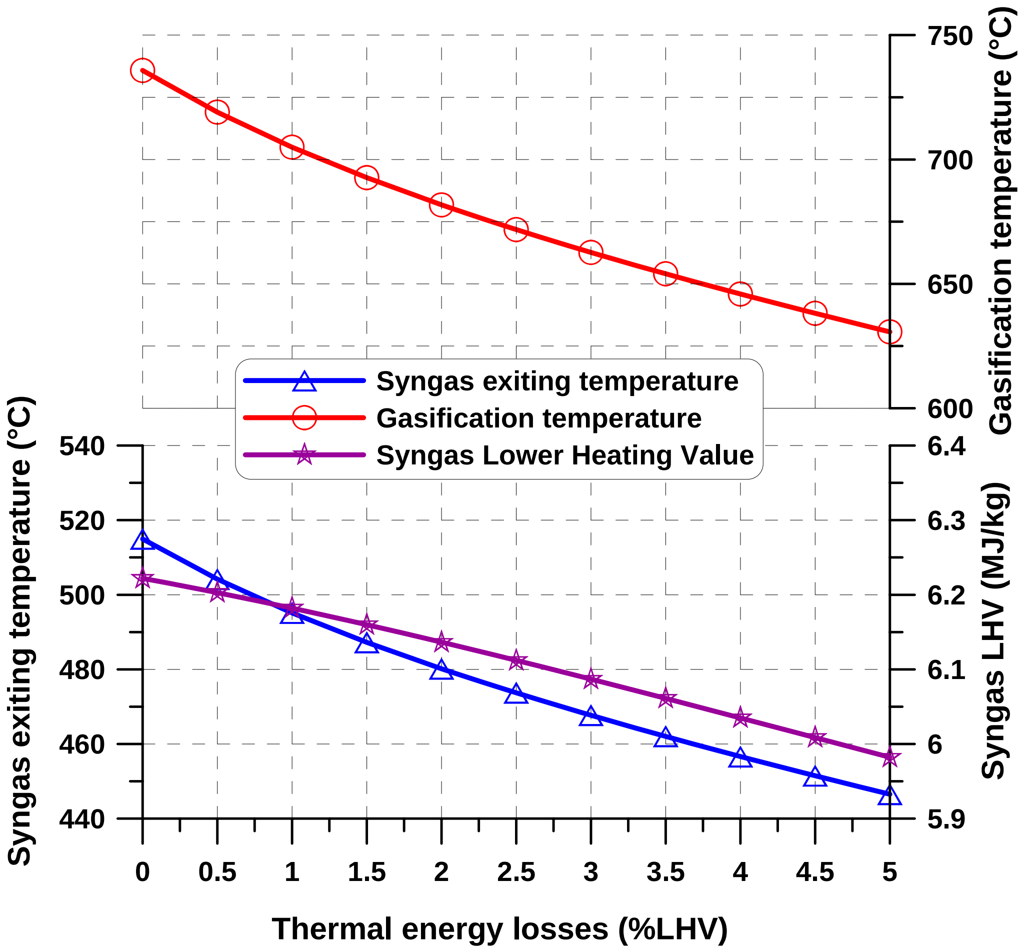


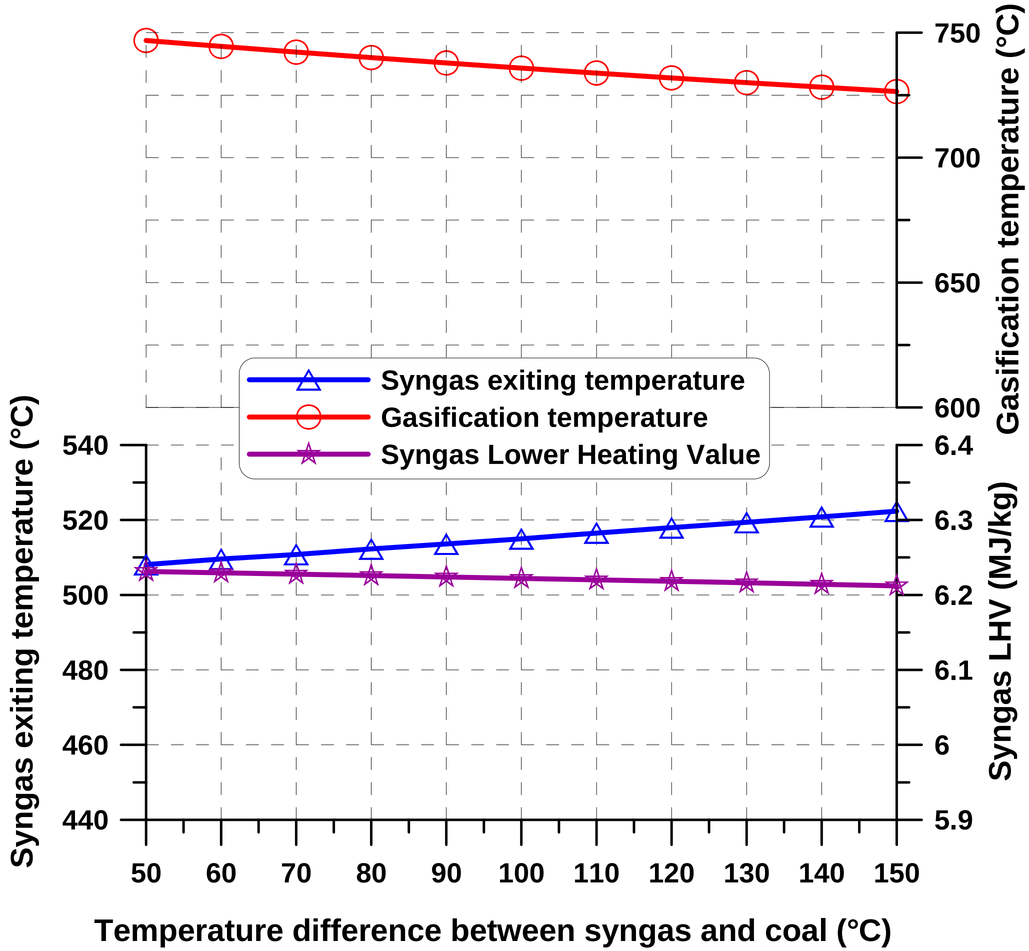
Syngas molar fraction vs steam/coal and air/coal mass ratios





Gasification and syngas temperature and LHV vs thermal energy losses and ΔT





Conclusions

- The computational model developed using ASPEN Plus simulates fixed bed gasifier performance accurately.
- Fairly good agreement between gasifier performance calculated and expected performance indicated by the manufacturer.
- The influence of the main process parameters has been also evaluated. The study shows that gasifier performance is extremely sensitive to air/coal and steam/coal mass ratios and to thermal energy losses and minimum ΔT between syngas and coal.
- Accuracy of performance prediction could be improved optimising adjustable parameters as internal minimum ΔT between syngas and coal, amount and distribution of thermal energy losses and carbon conversion rate.

Acknowledgments

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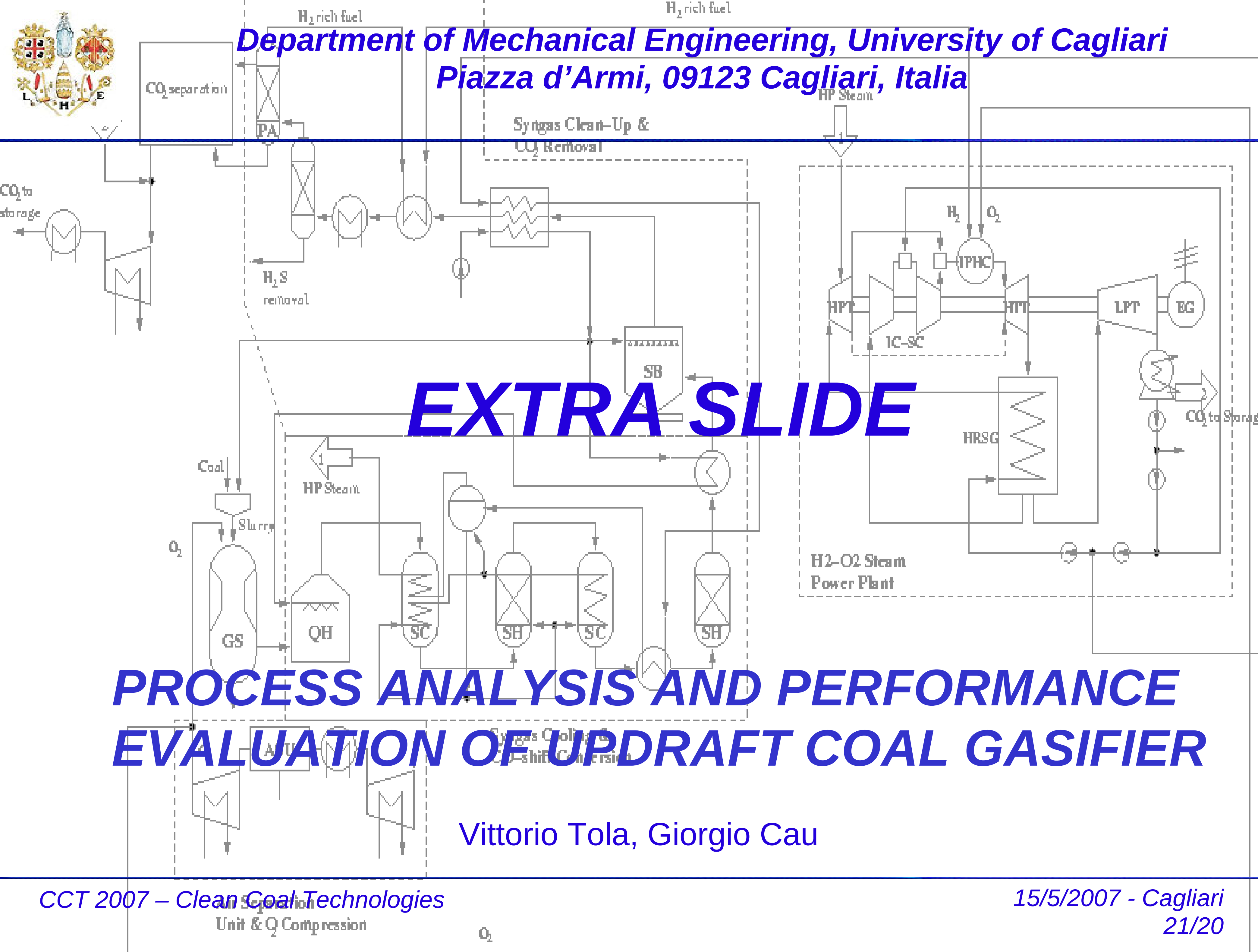

EXTRA SLIDE

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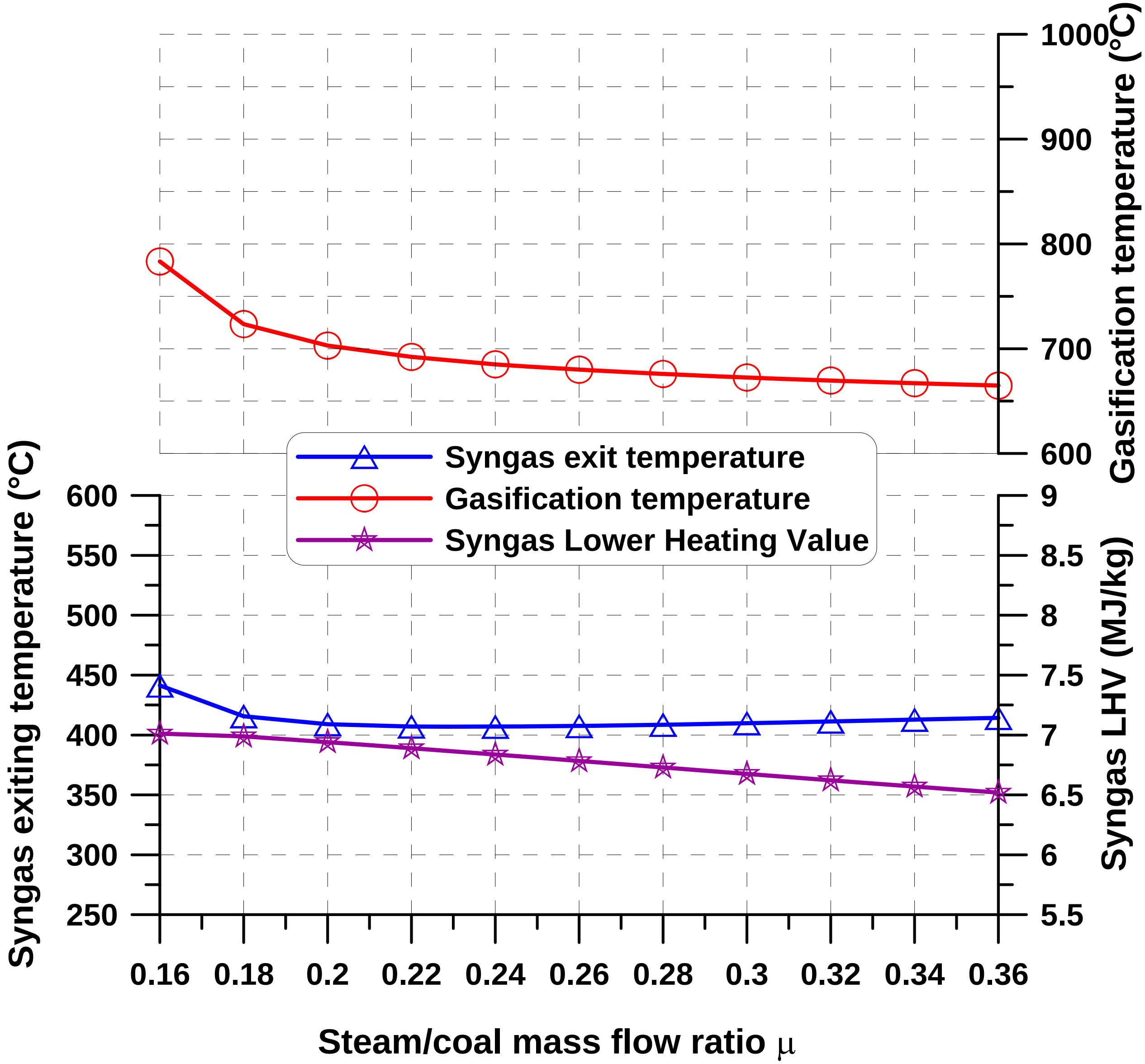
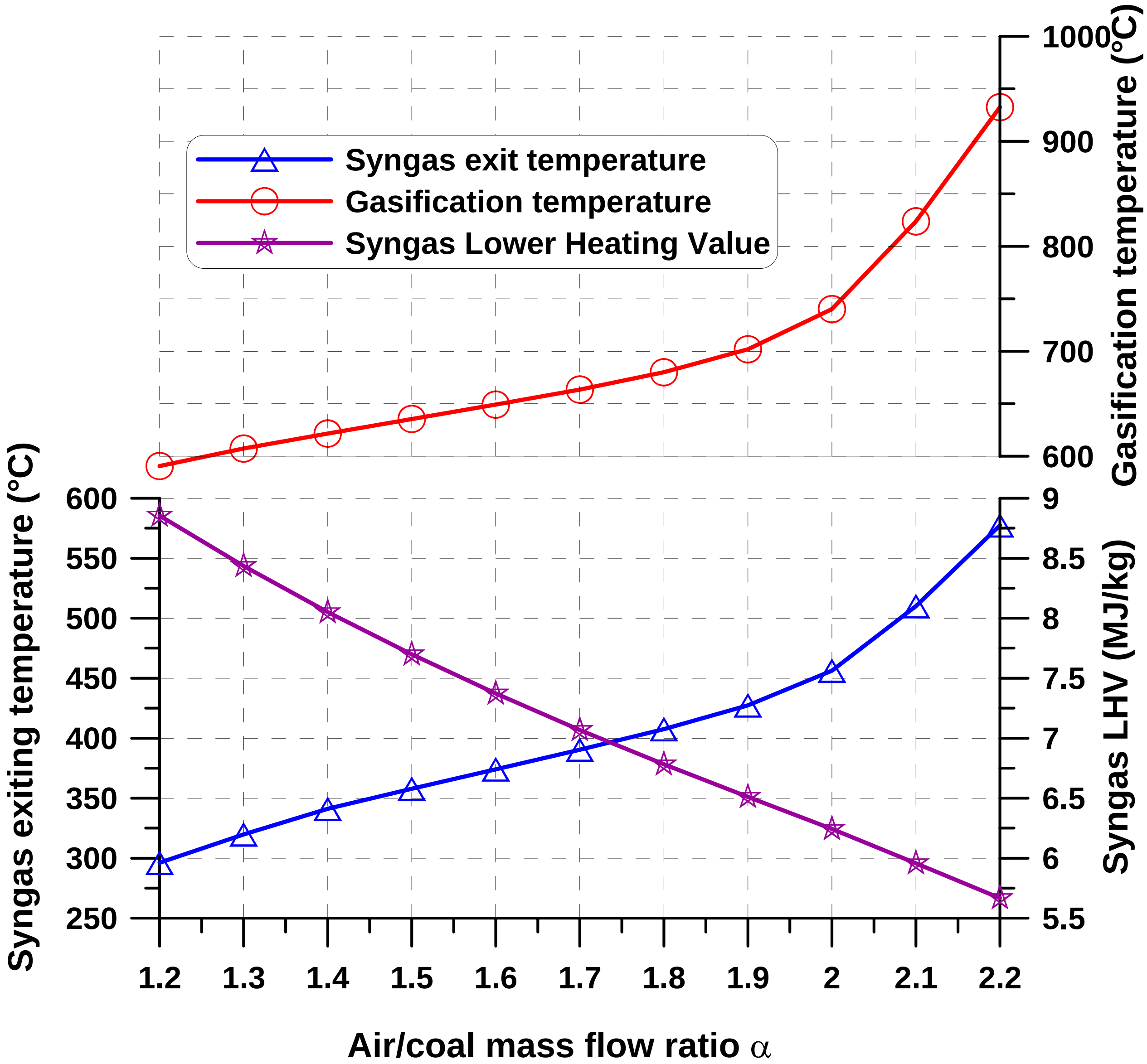
Gasification and syngas temperature and LHV vs steam/coal mass ratio

Sulcis coal



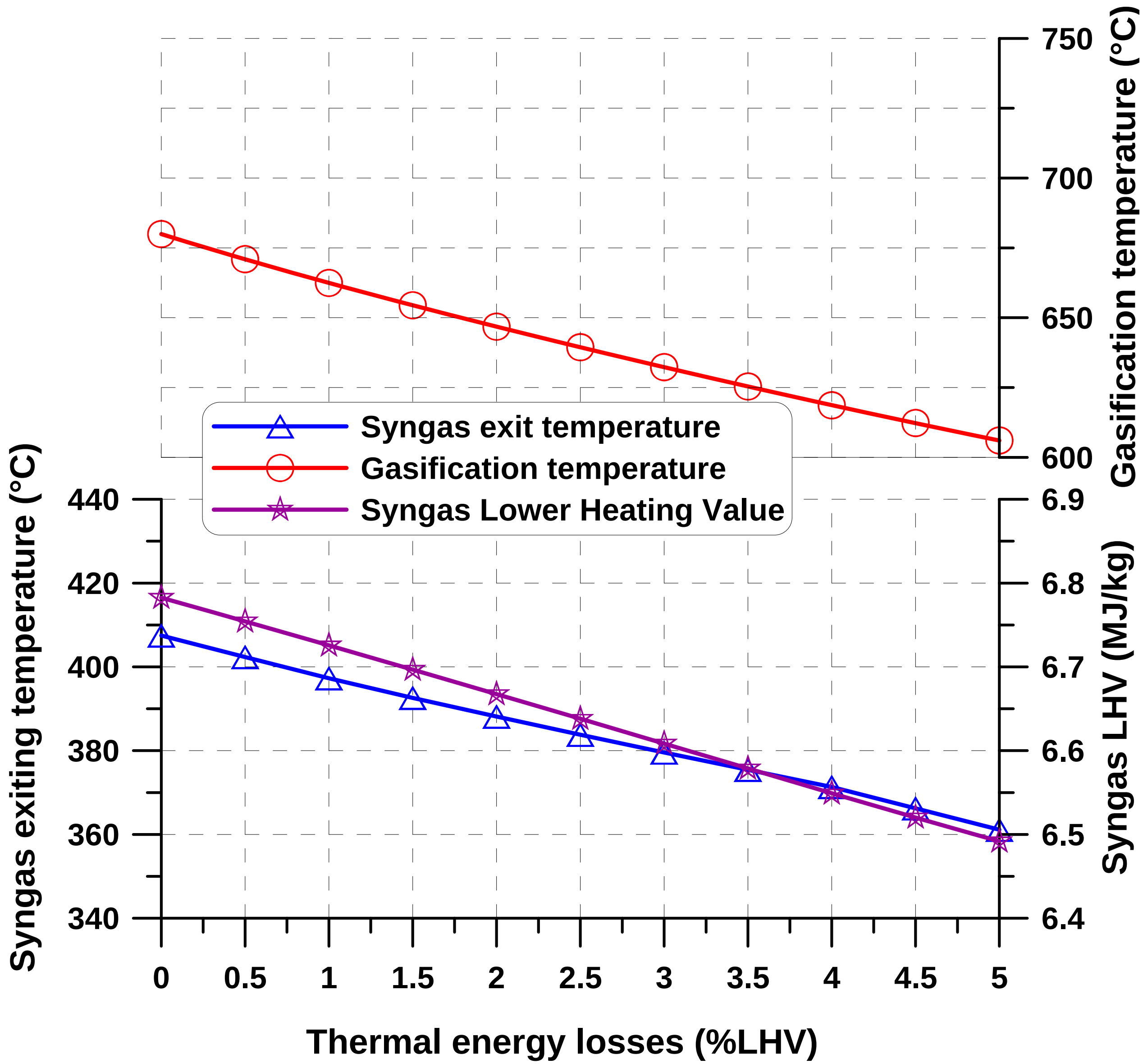
Gasification and syngas temperature and LHV vs air/coal mass ratio

Sulcis coal



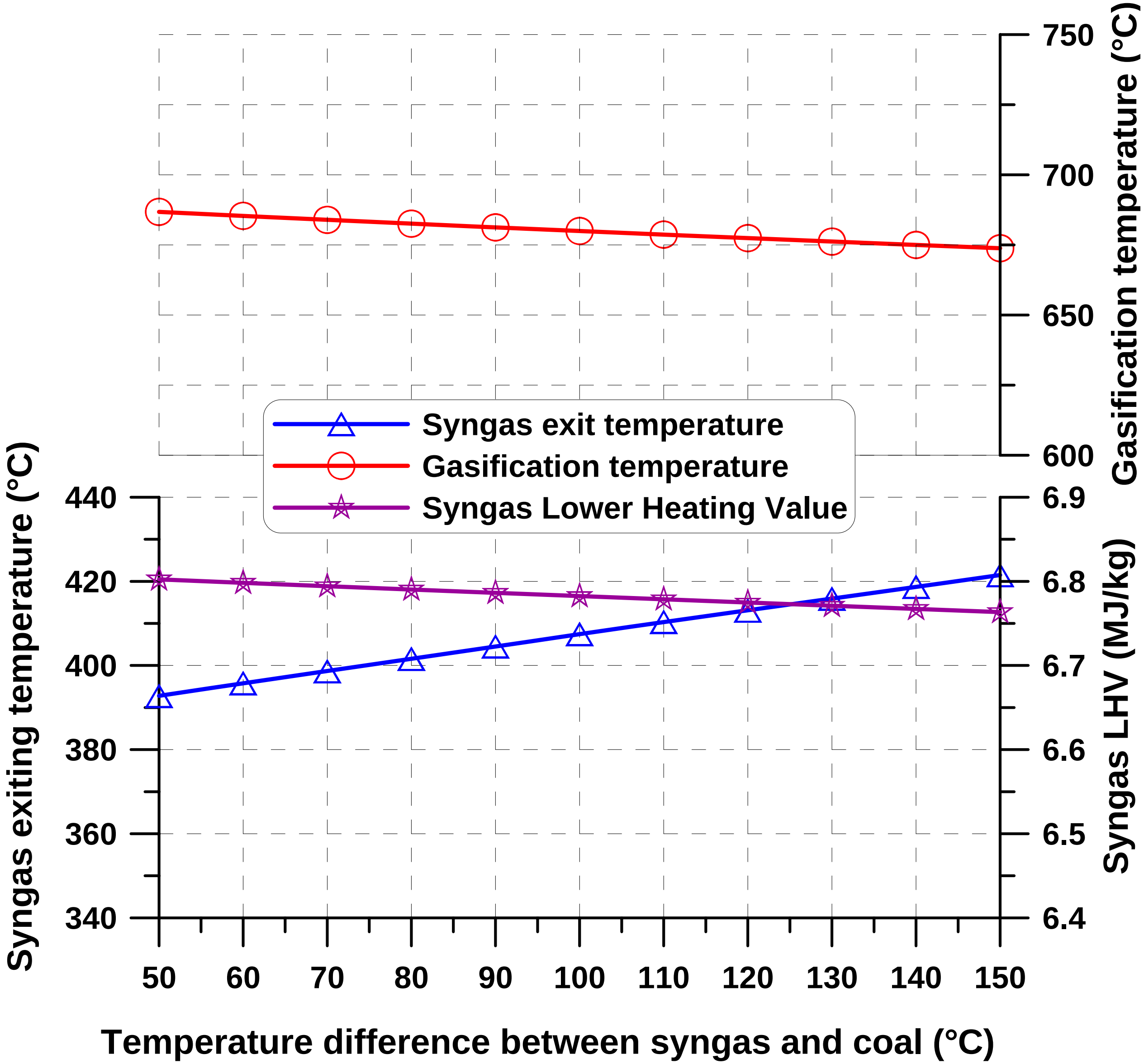
Gasification and syngas temperature and LHV vs thermal energy losses

Sulcis coal



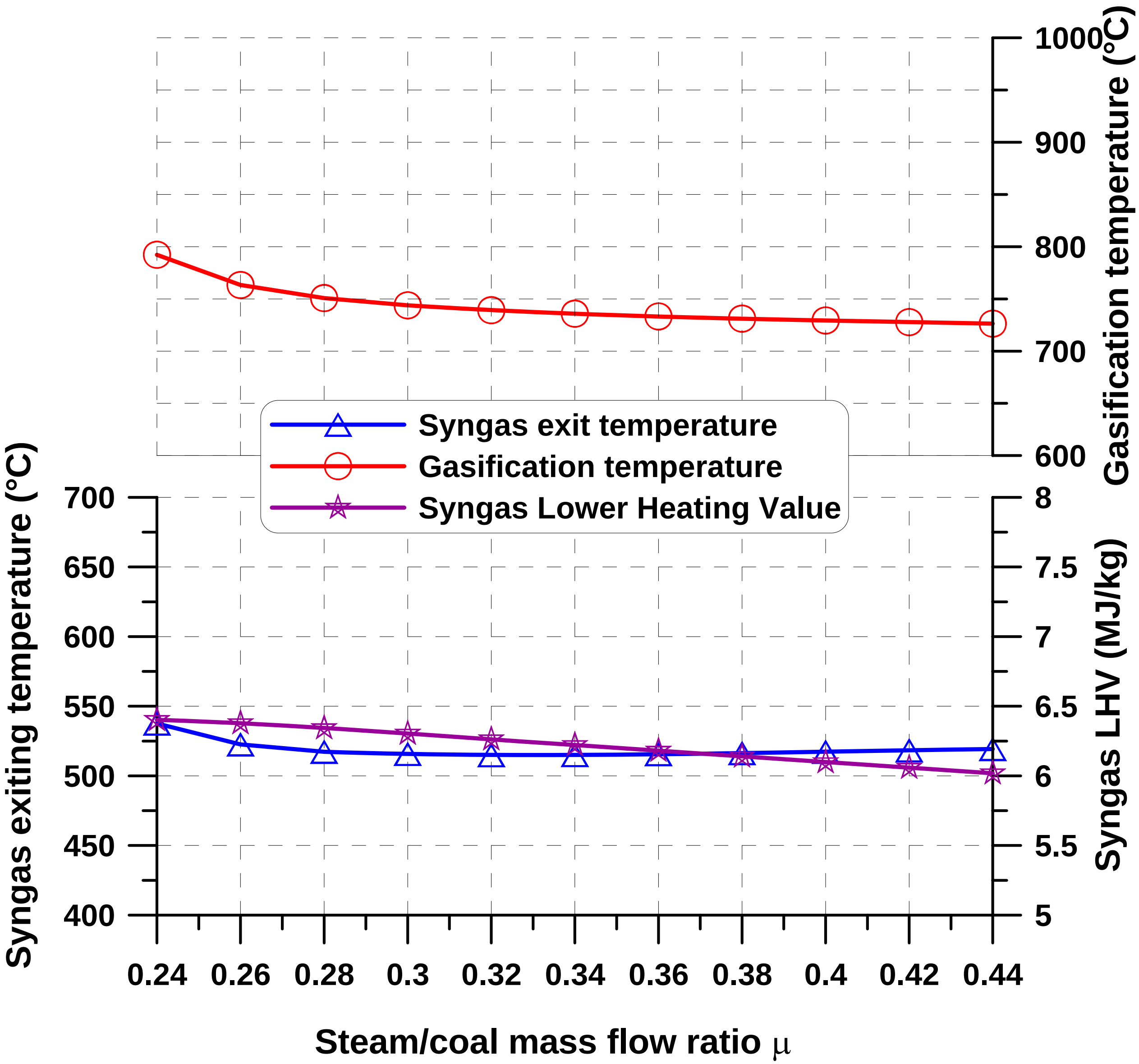
Gasification and syngas temperature and LHV vs temperature difference

Sulcis coal



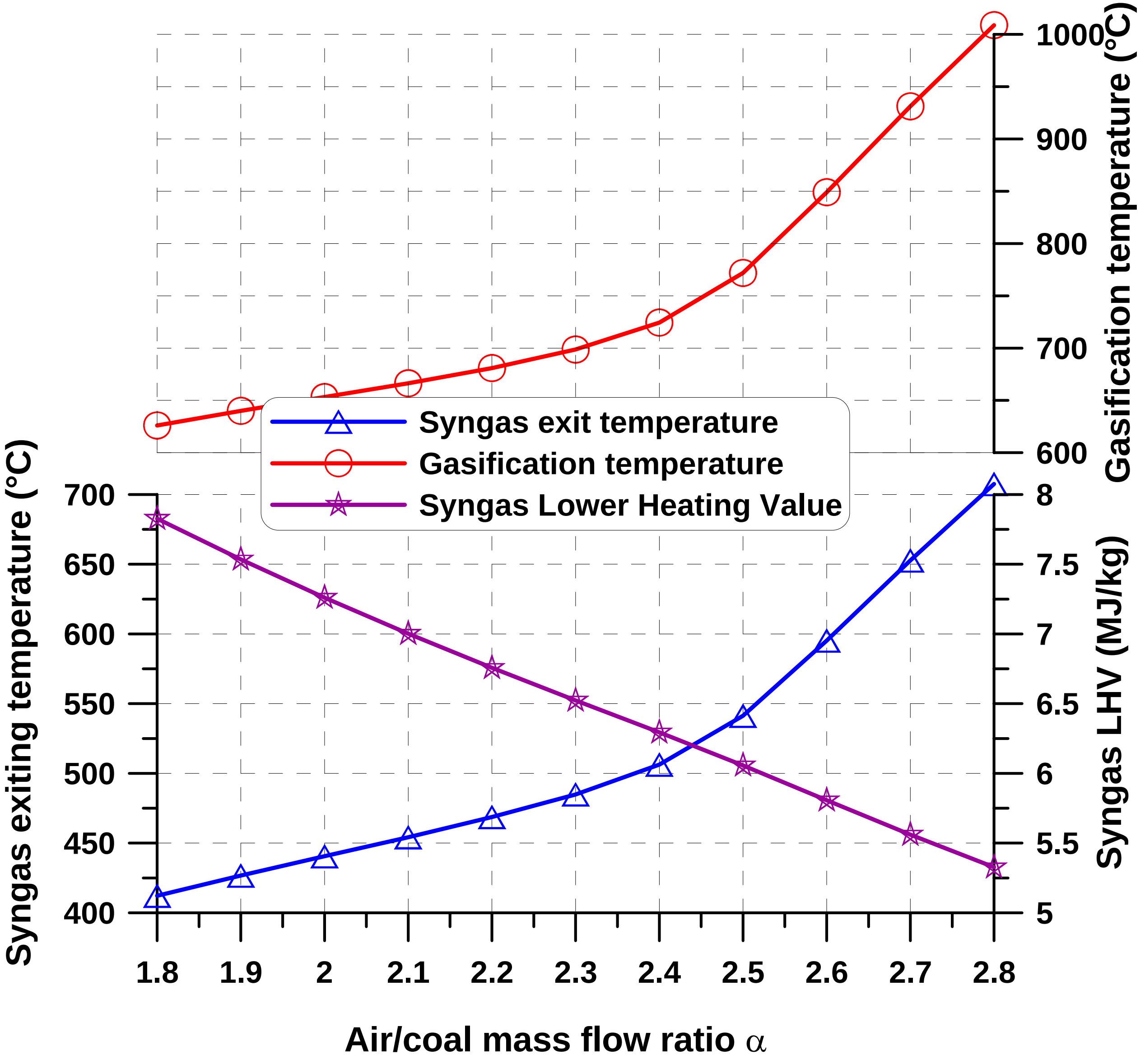
Gasification and syngas temperature and LHV vs steam/coal mass ratio

South African coal



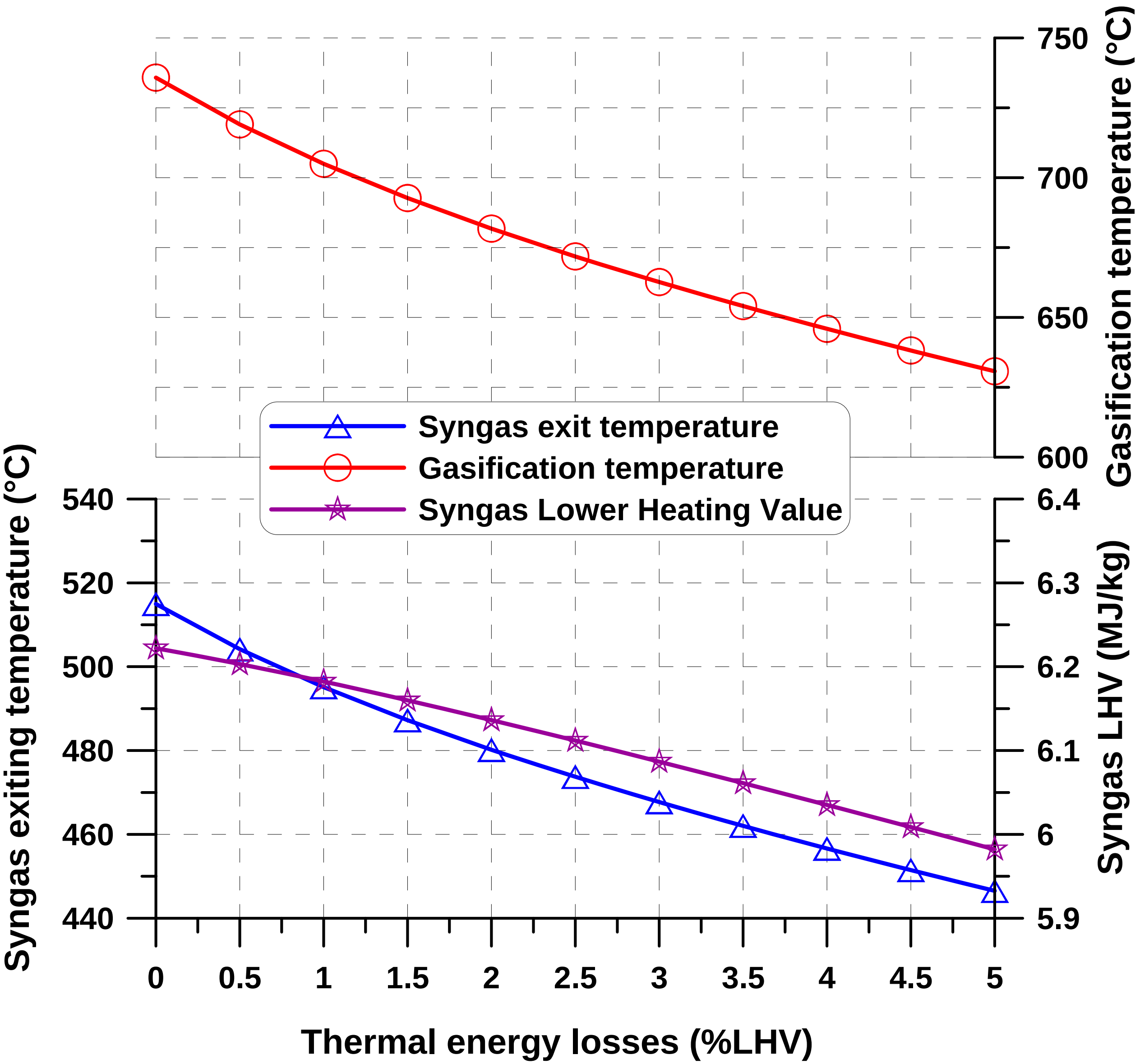
Gasification and syngas temperature and LHV vs air/coal mass ratio

South African coal



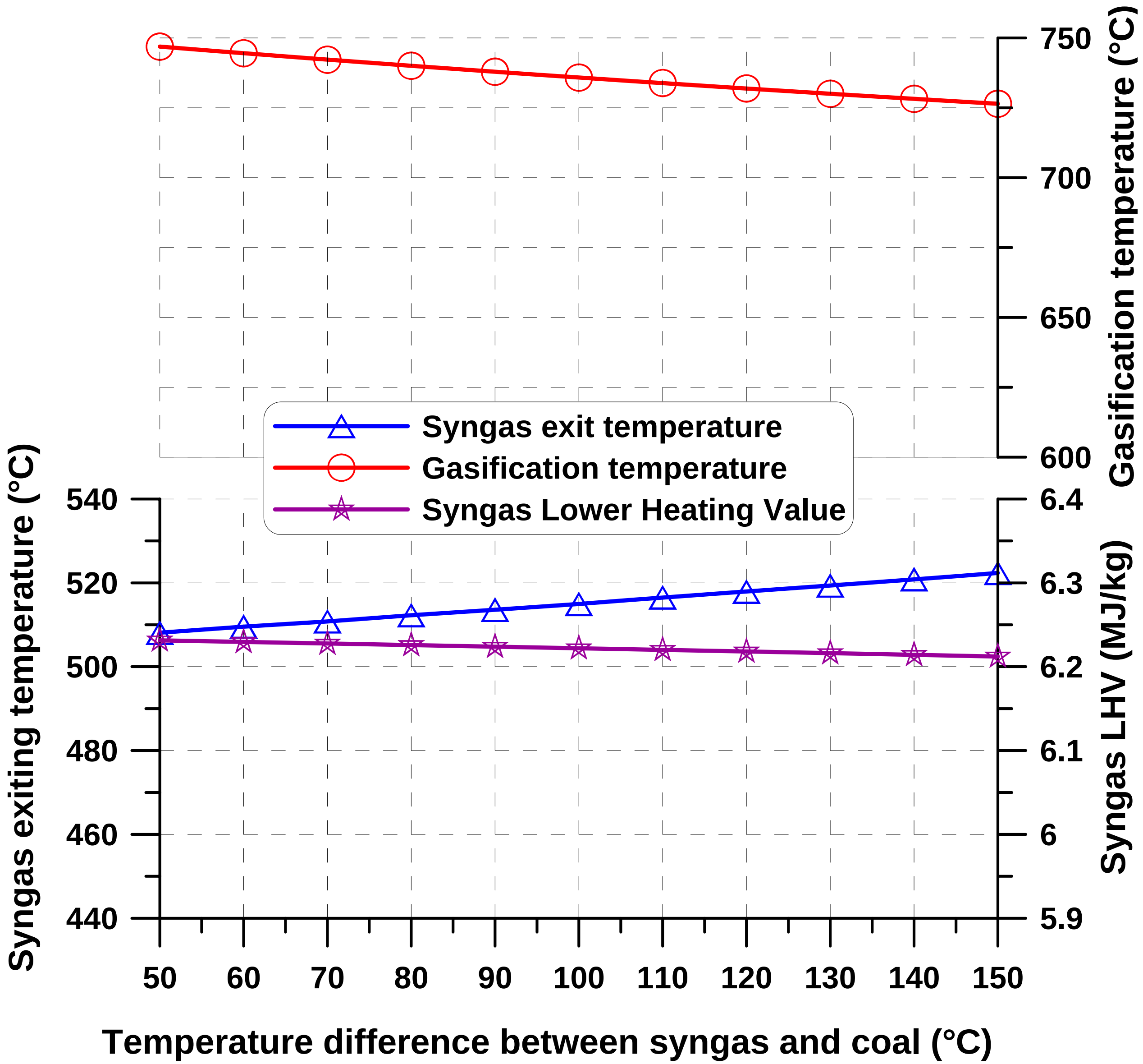
Gasification and syngas temperature and LHV vs thermal energy losses

South African coal



Gasification and syngas temperature and LHV vs temperature difference

South African coal



Gasifier performance vs mass flow ratio μ

Steam/coal mass ratio	0,16	0,18	0,2	0,22	0,24	0,26	0,28	0,3	0,32	0,34	0,36
CO (%vol, dry)	0,3400	0,3343	0,3260	0,3174	0,3088	0,3005	0,2924	0,2846	0,2770	0,2697	0,2627
CO_2	0,0049	0,0091	0,0153	0,0217	0,0281	0,0344	0,0404	0,0463	0,0519	0,0573	0,0626
H_2	0,1413	0,1561	0,1655	0,1735	0,1806	0,1873	0,1935	0,1994	0,2050	0,2103	0,2154
N_2	0,4442	0,4365	0,4315	0,4274	0,4236	0,4202	0,4169	0,4138	0,4109	0,4082	0,4055
CH_4	0,0474	0,0422	0,0400	0,0386	0,0375	0,0366	0,0358	0,0351	0,0345	0,0340	0,0334
H_2S	0,0151	0,0150	0,0150	0,0149	0,0149	0,0149	0,0148	0,0148	0,0147	0,0147	0,0146
COS	0,0019	0,0017	0,0015	0,0014	0,0013	0,0012	0,0012	0,0011	0,0010	0,0010	0,0009
Ar	0,0052	0,0051	0,0051	0,0050	0,0050	0,0050	0,0049	0,0049	0,0048	0,0048	0,0048
H_2O	0,0638	0,0639	0,0649	0,0662	0,0677	0,0694	0,0712	0,0732	0,0753	0,0776	0,0800
Gasification Temperature [°C]	783,2	723,5	703,0	692,2	685,1	679,9	675,9	672,5	669,6	667,1	664,8
Lower Heating Value [MJ/kg]	7,011	6,989	6,942	6,890	6,836	6,783	6,729	6,675	6,623	6,570	6,519
H_2/CO	0,416	0,467	0,508	0,547	0,585	0,623	0,662	0,701	0,740	0,780	0,820
Cold gas efficiency	0,913	0,916	0,917	0,916	0,916	0,915	0,914	0,913	0,912	0,911	0,910
Syngas Exit Temperature [°C]	441,3	415,7	409,1	407,1	406,9	407,5	408,5	409,8	411,3	412,8	414,3
m_{SYNG}/m_{COAL}	2,774	2,794	2,814	2,834	2,854	2,874	2,893	2,913	2,933	2,953	2,973
m_{SYNG}/m_{COAL} (dry)	2,639	2,656	2,673	2,688	2,703	2,718	2,732	2,746	2,759	2,773	2,785
Lower Heating Value [MJ/Nm^3]	7,405	7,305	7,218	7,136	7,056	6,979	6,904	6,831	6,760	6,691	6,623
Syngas/coal flow ratio [Nm^3/kg]	2,458	2,501	2,530	2,555	2,577	2,598	2,619	2,638	2,657	2,675	2,692

Gasifier performance versus steam/coal mass flow ratio μ for Sulcis coal

Gasifier performance vs mass flow ratio α

Air/coal mass ratio	1,2	1,3	1,4	1,5	1,6	1,7	1,8	1,9	2	2,1	2,2
CO (%vol, dry)	0,3263	0,3206	0,3154	0,3113	0,3075	0,3039	0,3005	0,2971	0,2932	0,2880	0,2824
CO_2	0,0388	0,0384	0,0378	0,0368	0,0358	0,0350	0,0344	0,0340	0,0341	0,0355	0,0372
H_2	0,0940	0,1135	0,1312	0,1479	0,1627	0,1759	0,1873	0,1964	0,2015	0,1970	0,1863
N_2	0,3800	0,3885	0,3961	0,4027	0,4088	0,4146	0,4202	0,4260	0,4333	0,4453	0,4603
CH_4	0,1346	0,1139	0,0953	0,0781	0,0627	0,0489	0,0366	0,0260	0,0178	0,0144	0,0139
H_2S	0,0176	0,0175	0,0171	0,0165	0,0160	0,0154	0,0149	0,0144	0,0139	0,0137	0,0135
COS	0,0041	0,0030	0,0024	0,0019	0,0016	0,0014	0,0012	0,0011	0,0010	0,0010	0,0010
Ar	0,0045	0,0046	0,0047	0,0047	0,0048	0,0049	0,0050	0,0050	0,0051	0,0053	0,0054
H_2O	0,0821	0,0791	0,0765	0,0742	0,0722	0,0706	0,0694	0,0687	0,0694	0,0737	0,0805
Gasification Temperature [°C]	590,6	607,3	621,6	635,5	649,2	663,5	679,9	701,9	740,2	823,7	932,5
Lower Heating Value [MJ/kg]	8,856	8,436	8,051	7,699	7,373	7,068	6,783	6,511	6,243	5,958	5,667
H_2/CO	0,288	0,354	0,416	0,475	0,529	0,579	0,623	0,661	0,687	0,684	0,660
Cold gas efficiency	0,946	0,940	0,935	0,930	0,925	0,920	0,915	0,909	0,901	0,887	0,871
Syngas Exit Temperature [°C]	296,2	319,8	341,1	357,8	374,0	390,4	407,5	427,3	456,3	510,0	577,4
m_{SYNG}/m_{COAL}	2,274	2,374	2,474	2,574	2,674	2,774	2,874	2,973	3,073	3,173	3,273
m_{SYNG}/m_{COAL} (dry)	2,136	2,234	2,331	2,428	2,525	2,622	2,718	2,813	2,906	2,990	3,069
Lower Heating Value [MJ/Nm^3]	9,603	9,052	8,555	8,103	7,693	7,320	6,979	6,667	6,383	6,128	5,893
Syngas/coal flow ratio [Nm^3/kg]	1,925	2,038	2,150	2,264	2,377	2,489	2,598	2,704	2,797	2,857	2,894

Gasifier performance versus air/coal mass flow ratio α for Sulcis coal

Gasifier performance vs mass flow ratio μ

Steam/coal mass ratio	0,24	0,26	0,28	0,3	0,32	0,34	0,36	0,38	0,4	0,42	0,44
CO (%vol, dry)	0,3456	0,3401	0,3335	0,3267	0,3199	0,3133	0,3068	0,3005	0,2944	0,2885	0,2827
CO_2	0,0030	0,0070	0,0119	0,0169	0,0219	0,0268	0,0316	0,0362	0,0408	0,0452	0,0494
H_2	0,1661	0,1756	0,1823	0,1882	0,1934	0,1983	0,2029	0,2072	0,2113	0,2153	0,2191
N_2	0,4571	0,4519	0,4482	0,4450	0,4421	0,4395	0,4370	0,4346	0,4323	0,4302	0,4281
CH_4	0,0216	0,0189	0,0176	0,0168	0,0162	0,0158	0,0154	0,0151	0,0149	0,0146	0,0144
H_2S	0,0011	0,0011	0,0011	0,0010	0,0010	0,0010	0,0010	0,0010	0,0010	0,0010	0,0010
COS	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
Ar	0,0054	0,0053	0,0053	0,0053	0,0052	0,0052	0,0052	0,0051	0,0051	0,0051	0,0051
H_2O	0,0428	0,0434	0,0445	0,0458	0,0473	0,0489	0,0506	0,0525	0,0544	0,0564	0,0585
Gasification Temperature [°C]	792,3	763,3	750,8	743,9	739,2	735,8	733,2	731,1	729,4	727,8	726,3
Lower Heating Value [MJ/kg]	6,402	6,379	6,343	6,304	6,263	6,222	6,181	6,140	6,099	6,059	6,019
H_2/CO	0,481	0,516	0,547	0,576	0,604	0,633	0,661	0,689	0,718	0,746	0,775
Cold gas efficiency	0,886	0,887	0,887	0,887	0,886	0,885	0,884	0,883	0,882	0,881	0,880
Syngas Exit Temperature [°C]	537,6	522,6	517,3	515,8	514,9	515,0	515,6	516,4	517,3	518,3	519,3
m_{SYNG}/m_{COAL}	3,501	3,521	3,541	3,560	3,580	3,600	3,620	3,640	3,660	3,680	3,700
m_{SYNG}/m_{COAL} (dry)	3,385	3,402	3,417	3,433	3,448	3,462	3,476	3,490	3,503	3,516	3,529
Lower Heating Value [MJ/Nm^3]	6,660	6,593	6,532	6,473	6,416	6,360	6,306	6,252	6,200	6,148	6,098
Syngas/coal flow ratio [Nm^3/kg]	3,220	3,257	3,284	3,308	3,329	3,349	3,368	3,387	3,404	3,421	3,438

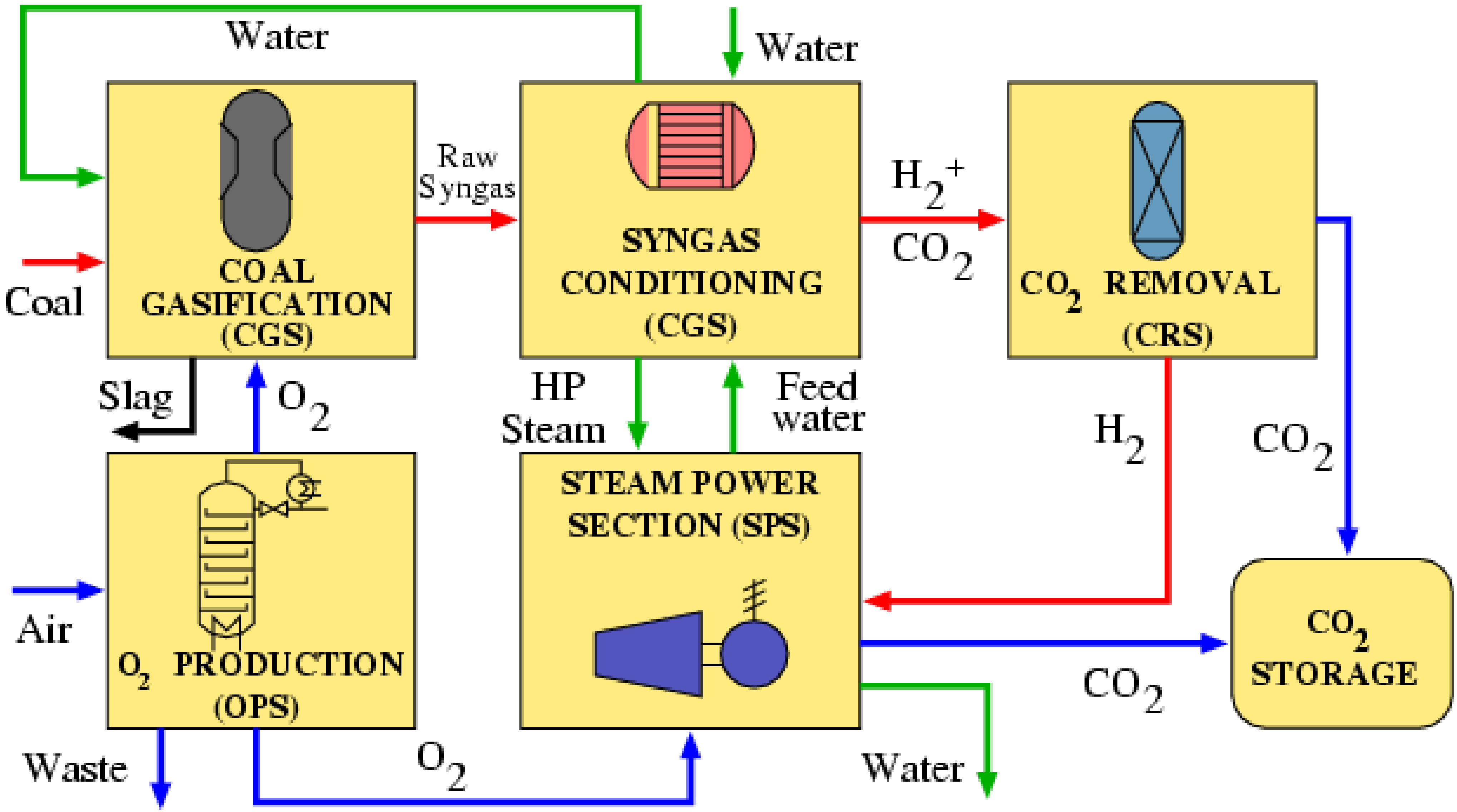
Gasifier performance versus steam/coal mass flow ratio μ for South African coal

Gasifier performance vs mass flow ratio α

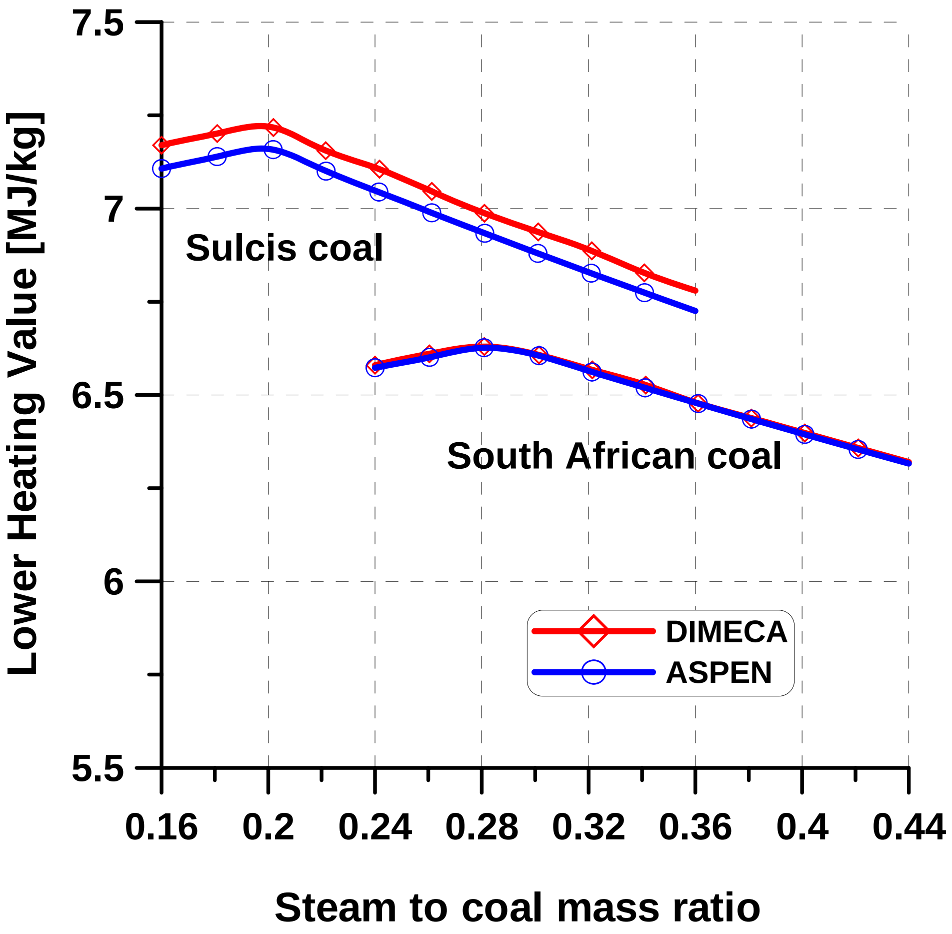
Air/coal mass ratio	1,8	1,9	2	2,1	2,2	2,3	2,4	2,5	2,6	2,7	2,8
CO (%vol, dry)	0,3440	0,3383	0,3332	0,3284	0,3239	0,3195	0,3149	0,3092	0,3022	0,2954	0,2889
CO_2	0,0236	0,0240	0,0243	0,0246	0,0250	0,0255	0,0263	0,0282	0,0312	0,0342	0,0370
H_2	0,1367	0,1501	0,1623	0,1733	0,1830	0,1913	0,1972	0,1983	0,1927	0,1849	0,1768
N_2	0,4096	0,4145	0,4191	0,4235	0,4279	0,4324	0,4376	0,4449	0,4557	0,4675	0,4793
CH_4	0,0799	0,0668	0,0548	0,0438	0,0339	0,0250	0,0176	0,0129	0,0116	0,0114	0,0112
H_2S	0,0012	0,0012	0,0012	0,0011	0,0011	0,0011	0,0011	0,0010	0,0010	0,0010	0,0010
COS	0,0003	0,0002	0,0002	0,0002	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
Ar	0,0048	0,0049	0,0049	0,0050	0,0050	0,0051	0,0052	0,0053	0,0054	0,0055	0,0057
H_2O	0,0526	0,0513	0,0502	0,0493	0,0487	0,0484	0,0486	0,0503	0,0541	0,0589	0,0638
Gasification Temperature [°C]	626,0	640,0	653,1	666,4	680,9	698,6	724,4	771,9	849,1	931,2	1008,8
Lower Heating Value [MJ/kg]	7,827	7,535	7,260	7,002	6,757	6,523	6,294	6,057	5,807	5,561	5,327
H_2/CO	0,397	0,444	0,487	0,528	0,565	0,599	0,626	0,641	0,638	0,626	0,612
Cold gas efficiency	0,919	0,914	0,910	0,905	0,900	0,894	0,888	0,878	0,865	0,850	0,835
Syngas Exit Temperature [°C]	412,2	426,7	440,6	454,2	468,7	484,9	506,3	541,3	595,2	652,7	707,5
m_{SYNG}/m_{COAL}	2,971	3,071	3,170	3,270	3,370	3,470	3,569	3,669	3,769	3,869	3,969
m_{SYNG}/m_{COAL} (dry)	2,852	2,950	3,047	3,145	3,242	3,338	3,433	3,525	3,610	3,693	3,775
Lower Heating Value [MJ/Nm^3]	8,255	7,889	7,552	7,240	6,951	6,682	6,433	6,204	5,994	5,794	5,601
Syngas/coal flow ratio [Nm^3/kg]	2,669	2,782	2,895	3,006	3,116	3,222	3,321	3,401	3,453	3,494	3,533

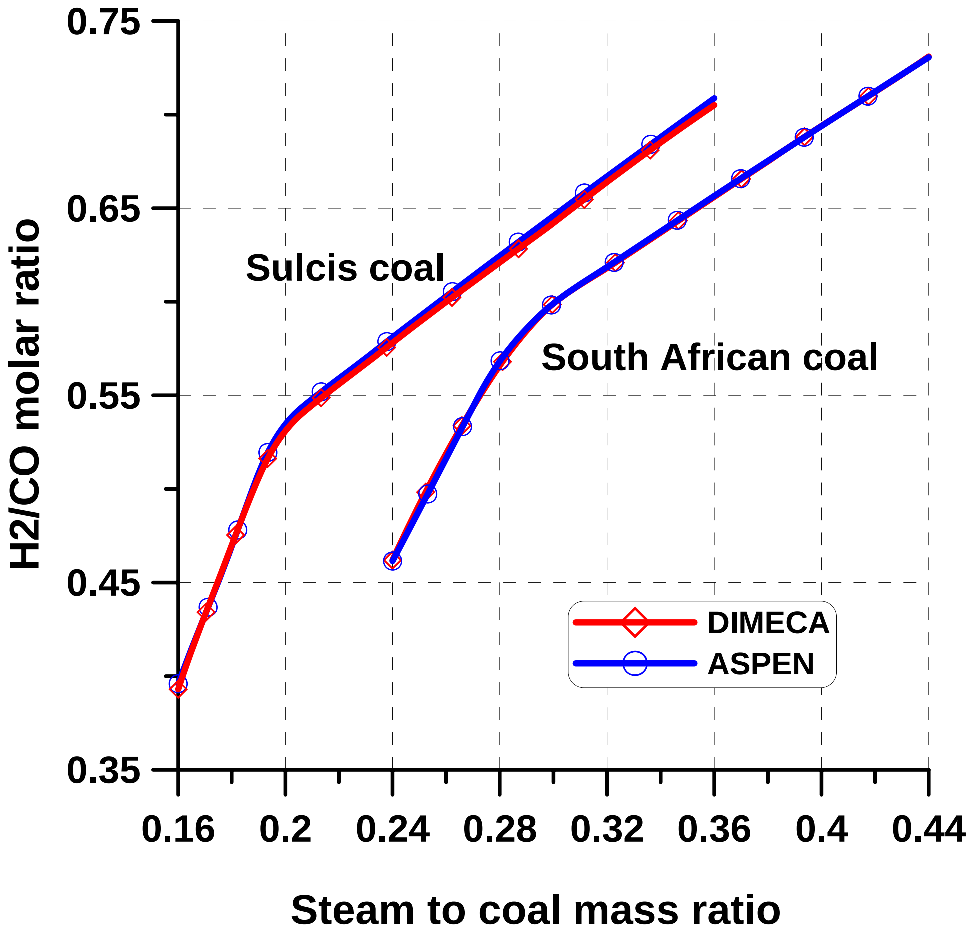
Gasifier performance versus air/coal mass flow ratio α for South African coal

IGHC: schema concettuale



LHV and H2/CO ratio vs mass ratio μ





LHV and H2/CO ratio vs mass ratio α