APPENDIX A CASE STUDY: BASIC ENERGY CONVERSION MODEL FOR THE SASOL SECUNDA OXYGEN PLANT

A.1. MODEL INPUTS AND OUTPUTS

Table A.1 lists the empirical values for the oxygen compressor (refer to equation (9) of chapter 4). Factored into these constants are the respective electromechanical efficiencies of the oxygen compressor motors.

Table A.1: Oxygen compressor empirical values.

Train	a	b	c	d
1	0.004013	0.008215	0.002814	0.820563
2	0.004853	0.009605	0.002887	0.960213
3	0.005213	0.004361	0.003537	0.960292
4	0.001955	0.005158	0.001532	0.193396
5	0.004018	0.008176	0.002817	0.820563
6	0.005104	0.01082	0.002722	0.960236
7	0.003524	0.005223	0.003751	0.960292
AC’s	0.000871	-0.853386	0.0019996	0.067631

With reference to equation (8) of chapter 4, the system constants from the air compressor side are the following: $h = 0.14$ and $g = 1.2$, which have been assumed the same for all trains.

The average recovery efficiencies for each train are as listed in table A.2.

Table A.2: Coldbox average recovery efficiencies.

Train	AR
1	94.67 %
2	90.55 %
3	95.18 %
4	96.13 %
5	95.28 %
6	91.52 %
7	95.09 %

Refer to figure A.1 for model input and output nametags.

Model inputs:

- *Management rules:* Specifies production constraints i.e. the minimum and maximum levels of the different commodities involved in the oxygen production process.
- *Oxygen demand:* This input is mainly determined by the gasification and gas-reforming processes, and will vary in response to their demand.
- *Oxygen supply pressure:* This is the pressure with which oxygen is supplied to the Gasification and Gas-Reforming plants. The supply pressure should be kept between the constraints as set forth by these two plants.
- *Minimum and maximum limits of process outputs and equipment:* Specifies the constraints in which the equipment should function in normal operation. This includes:
    - *Max. & Min. limits of air compressor:* 37*MW* & 28*MW* (when online), respectively.
    - *Max. & Min. limits of oxygen compressor:* 13.7*MW* & 10*MW* (when online), respectively.
    - *Max. & Min. limits of oxygen purity:* 99.4% & 98.5%, respectively
    - *Max. & Min. limits of Pressure in oxygen common header:* 3480kPa & 3350kPa, respectively
    - *Max. & Min. limits of* N_2/O_2 *ratio:* 30% & 20% respectively
- *HP* N_2*/LP* O_2 *ratio:* Defines the relationship between the HP nitrogen and LP Oxygen and is assumed a constant value.
- *Instrument Air flow:* The plant also produces instrument air and for the purpose of the model, a constant value is assumed.
- O_2 *purity:* The main product purity is assumed constant.
- *Other constants:* This includes the following:
    - Atmospheric pressure at Secunda (85kPa).

  - O_2 pressure at cold box outlet (95kPa).
  - Cooling water temperature (20°C):
  - Average recovery efficiencies of each train (AR).

Model outputs:

- *Specific energy:* This is defined as the energy efficiency of the oxygen plant, i.e. the efficiency with which energy is utilized in producing oxygen. It has units of kWh/Nm^3, i.e. the amount of kilowatts that should constantly be applied for one hour in order to produce one normal cubic meter of oxygen.

- *New load profiles:* This includes:
  - Load profiles of all trains
  - Load profile of whole industry (train 1-7)

- *Cost of energy:* Gives the cost of energy based on the tariff structure.

For the model simulation, the following input values, listed in table A.3, were used.

Table A.3: Input values used for model simulation.

Parameter held constant	**Value**
Oxygen supply pressure	3440 kPa
N_2/O_2 ratio	25%
Average recovery (AR)	Refer to table C.2
Instrument air flow	3.5 kNm^3/h
Oxygen purity	98.6%
Electricity tariff structure	WEPS (2002 Sasol structure)

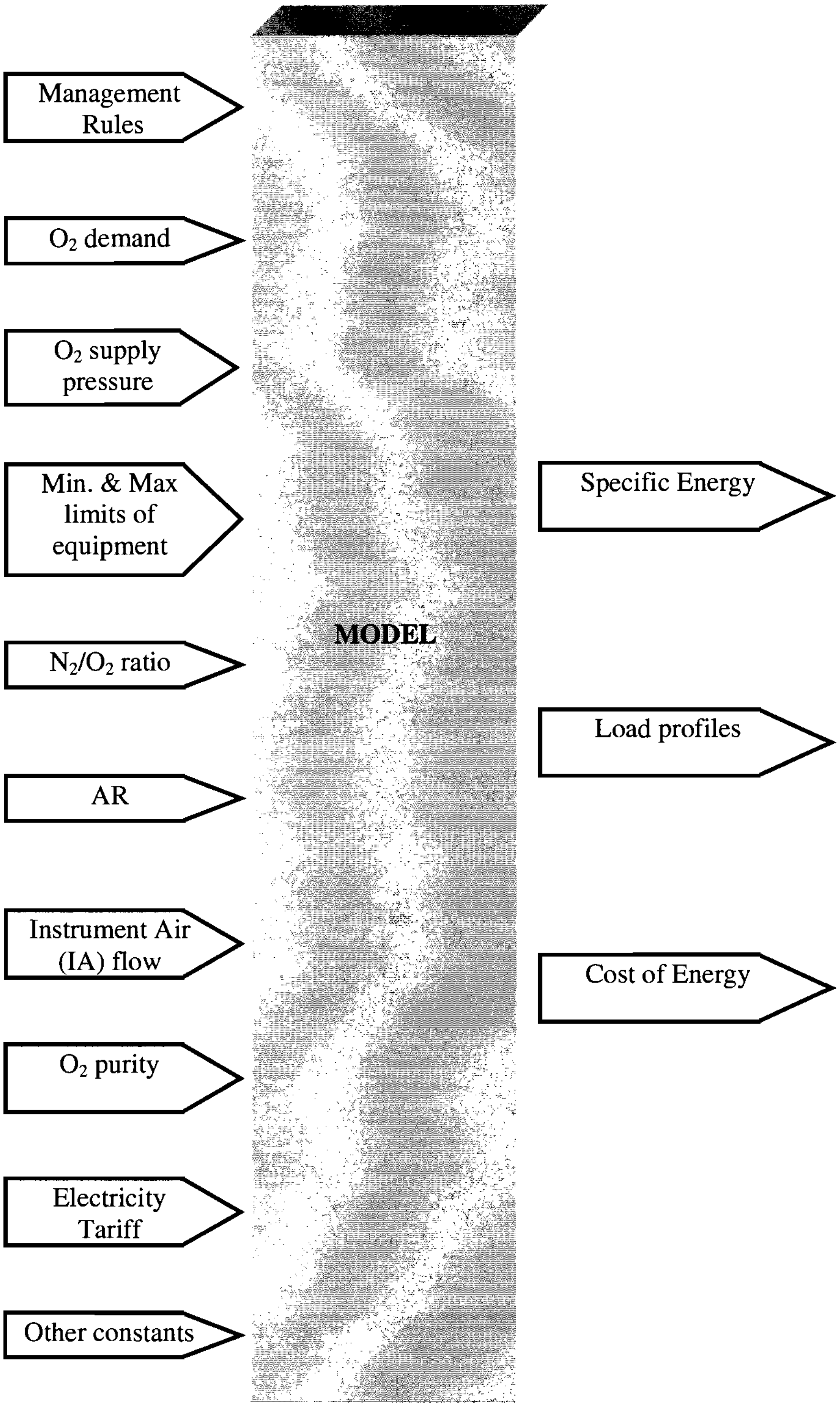

Figure A.1: Inputs and outputs for the basic energy conversion model.

Table A.4: Simulation results calculated over a period of one moth.

Parameter	Value
Specific energy	0.6589 kWh/Nm^3
Cumulative load profile	Refer to figure C.2
Cost of energy during sample month	R21 156 843

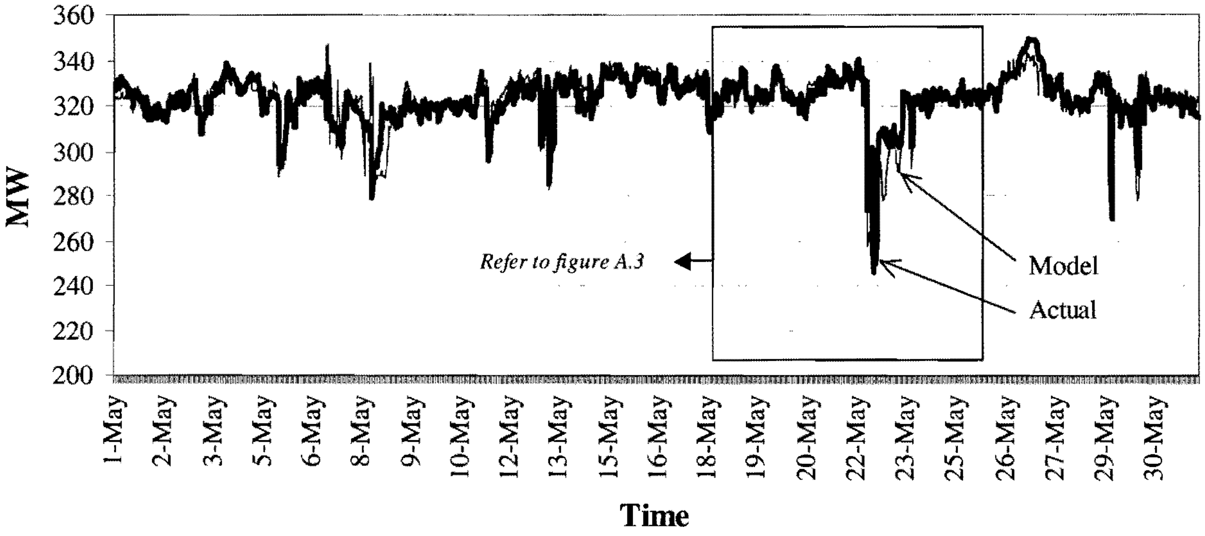

Figure A.2: Actual and simulated load profile for the oxygen plant at Sasol Secunda.

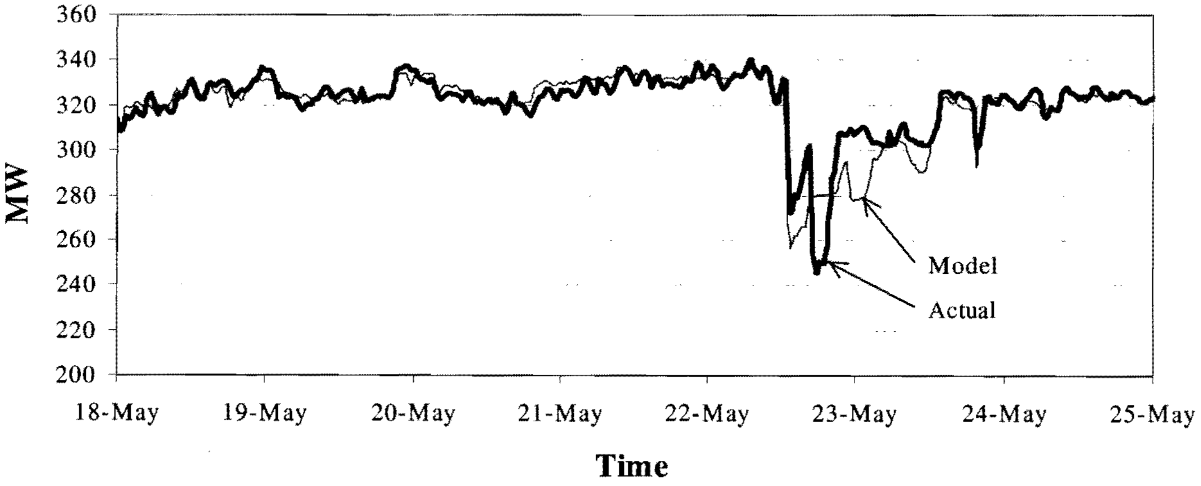

Figure A.3: Section of actual and simulated load profile of figure C.2

On 8th May the actual load profile plunges momentarily, while the model doesn't seem to be responding to this change in power consumption. This is due to the fact that the model assumes that only *one* oxygen compressor can be offline at any point in time, which is usually the case; on this particular day, however, between 07:30 and 9:30 train two's oxygen compressor tripped and was offline for approximately two hours, in addition to the oxygen compressor of train one. This has the implication that the spare oxygen compressor was summed twice for two hours. On 7th May the same incident happened for approximately one hour.

Two oxygen compressors are very rarely offline at the same time, and as these incidents happened only for a relatively small time the entire month (approximately three hours in total), it's impact is negligent and also for the sake of model simplicity, this aspect was neglected in modeling the oxygen plant.

As will be illustrated later in this section, an oxygen train's power consumption increases when a higher purity oxygen is produced. Between 1st and 2nd of May, the actual load profile seems to be slightly higher compared to that of the model. The model assumes that oxygen is produced at a constant purity (98.6%) however, in this case, oxygen was produced at a higher purity leading to an increased power consumption; this is also the case for the respective load profiles between 27th and 28th of May. The same reasoning can be applied to the results seen between 30th and 31st of May, except that in this case, lower purity oxygen (i.e. less than 98.6%) was produced.

When the power consumption of the oxygen plant drops, like for instance at 5, 7, 8, 9, 23 and 30th May, it seems that the model overshoots the minimum point at times; this is mainly due to the minimum permissible power consumption the compressors are allowed to have. The model assumes 28*MW* and 10*MW* for the air and oxygen compressor motors respectively, but these values vary from train to train (may be higher or lower than 28*MW*/10M*W*) and thus may overshoot at times or even undershoot the actual load profile at these conditions.

A.2. IMPACT OF KEY PARAMETERS ON ENERGY EFFICIENCY

The energy conversion model defined in the previous section will now be used to quantify the impact certain key process parameters have on the energy consumption, efficiency and cost of the plant. Normal operating conditions will be used as the baseline and are as listed in table A.5; at these conditions the model outputs are as listed in table A.6.

Table A.5: Normal operating conditions of the oxygen plant at Sasol Secunda.

O_2 Purity	98.6 %
HP N_2/LP O_2	25 %
IA flow	3.5 kNm^3/h
O_2 common header pressure	3440 kPa

Table A.6: Model results at normal operating conditions.

Specific energy	0.6589 kWh/Nm^3
Load profile of oxygen plant	Figure A.2
Average power consumed	323.44 MW
Total cost of energy	R 21,156,843

The effects of changing following parameters will be determined:

- Oxygen purity,
- Average recovery efficiency (AR),
- Instrument air flow (AI),
- Cold box availability.

Table A.7 lists the different simulation scenarios, with table A.8 displaying the respective model outputs in terms of specific energy, average power consumption and total cost of energy.

Table A.7: Model simulation scenarios.

Variables	**O_2 purity**	**IA flow per train**	**O_2 CH pressure**	**Recovery efficiencies**	**CB offline**
Oxygen purity					
- *Scenario 1*	98.5%	3.5kNm^3/h	3440kPa	Table A.2	None
- *Scenario 2*	98.7%	3.5kNm^3/h	3440kPa	Table A.2	None
AR efficiency					
- *Scenario*	98.6%	3.5kNm^3/h	3440kPa	Trains 2&6 changed to 95%.	None
IA flow					
- *Scenario*	98.6%	Load shifting IA of trains 2&6 to train 7	3440kPa	Table A.2	None
Cold box availability					
- *Scenario*	98.6%	3.5kNm^3/h	3440kPa	Table A.2	Train 1

Table A.8: Model outputs based on the scenarios listed in table A.7.

Variables	**Specific energy** ***(KWh/Nm^3)***	**Average power consumed** ***(MW)***	**Total cost of energy** ***(R)***	**Increase in specific energy**	**Increase in average power consumed**	**Increase in total cost of energy** ***(R)***
Oxygen purity						
- *Scenario 1*	0.6553	321.72	21,049,009	-0.55%	-0.53%	-107,834
- *Scenario 2*	0.6631	325.53	21,287,147	0.64%	0.65%	130,304
AR efficiency						
- *Scenario*	0.6524	320.29	20,960,289	-0.99%	-0.97%	-196,654
IA flow						
- *Scenario*	0.6578	322.91	21,123,850	-0.17%	-0.16%	-32,993
Cold box availability						
- *Scenario*	0.7360	311.89	20,401,463	12.35%	-3.57%	-755,380

APPENDIX B LIST OF TABLES

APPENDIX C LIST OF FIGURES