

TREATISE FOR MEMBERSHIP OF THE CHARTERED
INSTITUTION OF BUILDING SERVICES ENGINEERS

DEVELOPMENT OF STEAM GENERATION TO MEET THE NEEDS OF A
GROWING PHARMACEUTICAL COMPANY



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Summary

The pharmaceutical industry uses state-of-the-art facilities that support the latest techniques to discover the next drug for the market place; the profits from these drugs are reinvested in medical technology to support the research and development for the next drug. The patents on approved drugs have a very short life span before any generic pharmaceutical company can manufacture them; hence the constant pressures to reduce the research and development time and cost from launch to market.

This environment adds pressures on the support facilities like engineering to plan ahead, anticipate the Company's development, and install the infrastructure to support the scientists' needs and demands to enable them to achieve and meet their target drug discovery programme. This treatise covers some of the areas where engineering is involved in anticipating the steam demand. Providing the right quality steam within agreed budgets for installation and maintenance.

1. Introduction

1.1. Ten-year project of steam development in the pharmaceutical industry

AstraZeneca Charnwood is a pharmaceutical Research & Development site.

The site has expanded from the former Fisons Pharmaceuticals site of 10 hectares in the 1960s, through Astra ownership in 1995 to the present leading edge facility for drug discovery and development. The site increasing to 33-hectares over this time.

In the 1970s, the steam generation plant consisted of three heavy oil fired boilers. Later, as the site expanded, larger boilers were installed and the production of steam required was more closely monitored with respect to steam quality and quantity to meet the customers'

increasing demands. The current steam requirement is for a capacity of 108,000 kg/hr at 10 bar at the right quality to perform the processes and procedures to meet regulatory standards for the finished products of a worldwide pharmaceutical market.

The New Energy Centre (NEC) facility of today with its six identical boilers each with an output of 18,000 kg/hr rated at 10 bar meets this demand and satisfies the Environment Agency emissions controls and boiler efficiency.

1.2. Engineering Challenges

This treatise has been structured to highlight some of these challenges and how they were resolved and developed from the agreed engineering strategies supporting processes to maintain our increased steam demands.

- a) Increase in site facilities requiring more steam output to meet the customer needs.
- b) Lack of steam load management across the site.
- c) Poor maintenance techniques resulting in costly repairs and poor management decisions due to lack of maintenance records and reports.

2. Background

2.1. Development of steam load management

The steam demand control was achieved by use of the site Building Management System and by various steam controls installed on the main steam inlets to the appropriate buildings at the AstraZeneca site.

The maximum steam demand of any building is difficult to predict when intermittent process loads are present. However, the majority of the load on the site is used for heating

purposes and this is predictable for a given outside temperature provided the accurate design or actual usage information is made available.

The exercise of assessing each building was carried out and the results are summarised in figure 1, but each building is considered in detail as follows.

Building 18

The original design by Integrated Design Consultant Ltd (IDC) for an external air temperature of -3°C gave a design ventilation and heating load of 3913kg/hr. Fisons design engineers revised the building ventilation to certain areas in building 18, to enable the systems to hold design conditions with an external air temperature of -15°C . This resulted in an additional design load of 817 kg/hr giving a total design load of 4730 kg/hr excluding any autoclaves or direct steam cleaning devices.

A trend log from the Building Management System (BMS) correlated the steam demand and external temperatures, but the variations with equipment load made it difficult to extrapolate the result to give a meaningful demand at -15°C . However, the demand profile from the trend logs yields a “maximum” and minimum” steam demand at -15°C . The minimum steam demands needed to be treated with some caution, as peak demands of approximately 4200 kg/hr have been recorded at external air temperature above 6°C .

Building 21

The original design by Oscar Faber Consulting Engineers was for an external air temperature of -5°C and gave a design loading of 7900 kg/hr. Steam serves two steam to water calorifiers that provide all the heating to the building.

From the Building Operational and Maintenance Manuals, the air handling units which constitute the majority of the heat load are designed to achieve the required air flow rate and off coil temperatures with external air temperatures as low as -10°C .

In addition, the two steam to water calorifiers have been selected to give a capacity of 65 percent of the design load of 5000 kg/hr steam load each.

This results in the fact that the building has the capability of absorbing steam at a rate of up to 10,000 kg/hr at temperatures below the design ambient.

However, this must be offset by the fact that the laboratory airflow rates assume a number of fume cupboards have sashes “up” rather than “down”. During unoccupied night time periods when weather will be at its coldest, it is unlikely that there will be a combination of very low temperatures and design airflow rates.

Steam flow rates measured by the BMS trend log gave actual steam usage lower than the design, this fact was assumed to be low usage of the fume cupboards or lower staff numbers at the time the data were taken. The results of the trend log gave an anticipated steam flow at -5°C ambient temperature of 5000 kg/hr. The operational control of the building and the fact that no data on consumption during daytime periods of cold weather was available, a load of 6100 kg/hr was allowed.

Building 17

This building has no steam metering and no design information available.

The maximum steam demand allowance of 600 kg/hr has been based on the size of temporary boiler plant used for the building during steam main alterations and data accrued by Ove Arup & Partners during their site investigations for the site development study.

Buildings 1, 2, & 7.

There is no available design information on these buildings.

Building 25

This building was at the construction stage during the steam site demand assessment and the information has been based upon design data provided by Oscar Faber Consulting Engineers.

The load allowance has been the subject of a number of revisions, which have resulted in the reduction from 10,600 kg/hr to the current allowance of 7,500 kg/hr.

The load allowance per square meter correlates closely to that of the building 18 building which the ventilation and steam usage these building are very similar.

Building 23

This building at the time of site steam usage was under construction and the peak load was assessed by Snamprogetti Ltd who designed and project managed the construction.

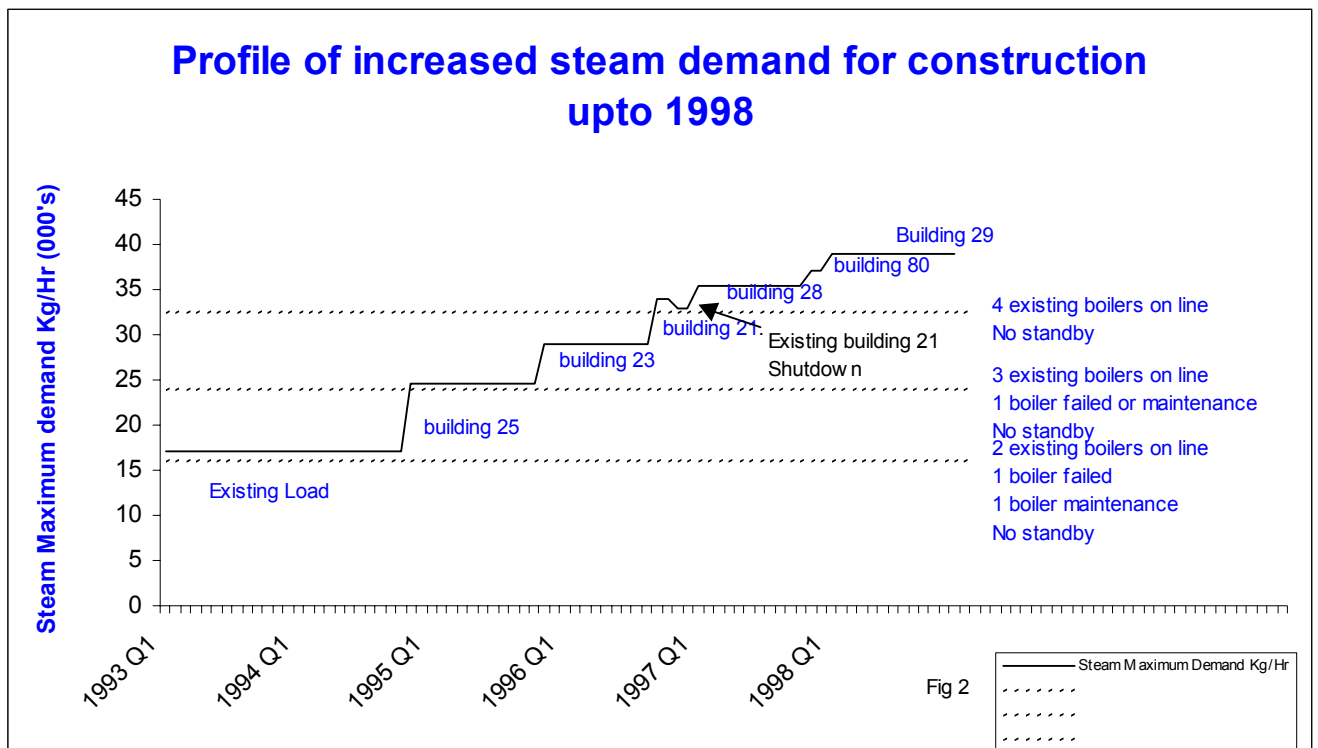
The peak load was the subject of a number of revisions, which resulted in an increase from 3,000 kg/hr of steam to the current allowance of 4,100 kg/hr of steam for services and process loads.

Effects of ambient temperature on steam demands

The minimum and maximum steam demands referred to figures 1 and 2 are the potential peak steam demand where graphs of actual demand have been extrapolated to give consumption at extreme design conditions.

From these results, the following conclusions are drawn: -

- The existing site demand can be satisfied by two boilers with ambient temperatures as low as -7°C or -11°C dependent upon whether the maximum or minimum peak demand profile is considered.
- The site demand once Building 25 and Building 23 are in operation can be satisfied with four boilers but this resulted in the standby boiler needing to operate when the



- ambient temperature is below -3.5°C or -7.5°C dependent upon whether the maximum or minimum peak demand profile is considered.
- When Building 28 and building 29 are fully constructed the site steam demand will exceed the capacity of the four existing boilers when the ambient temperature is below -8°C or -13°C dependent upon which profile is considered.
- When Building 28 and Building 29 are fully constructed the site steam demand will exceed the capacity of three existing boilers when the ambient temperature is below 1°C or -2°C dependent upon which demand profile is considered. This means that below these temperatures any boiler failure or maintenance down time will result in a shortage of steam on site.

Building demand profiles

The steam demands of the buildings vary dependent upon the time of the day and their function. Typically all buildings use less steam at night when they are not occupied, they

have a temperature set back to 10°C which is controlled by the Building Management System, as all process type loads are not in use during this time.

Animal buildings, which have high continuous ventilation rates, have a relative high demand at night whereas laboratory buildings have a lower demand at night even though ventilation runs continuously. This is due to ventilation rates being reduced when fume cupboards' sashes are in their down position.

Office buildings, which have low ventilation rates, have a very low demand outside occupied hours provided that any frost prevention control does not bring on the heating system.

To establish a demand profile for all buildings would require the insertion of extensive metering equipment or chart recorders and a detailed knowledge of how the building controls operate to use the steam to enable the results to be interpreted.

Total steam demands, estimated of Steam usage (source from DSSR)

Fig 3

Buildings	Kg	% Including losses Steam consumption
14	649,610	2.1
Stage 1 &2	5,917,050	19.0
7	313,709	1.0
18	4,067,159	13.1
1	421,400	1.4
2	1,897,364	6.1
21	10,656,062	34.2
25	7,209,964	23.1
Total	31,132,318	100

Figure 3 is an estimation of the total steam demand for each building over the period of 5/1/95 to 15/5/95 together with the percentages of total site consumption, source from DSSR report on steam metering.

There is no published data available on the existing boiler house on steam availability over its life cycle, or any supporting information from the manufacturers advising us.

The older boilers were anticipated to be off-line for an average of 36 hours per month to carry out maintenance and breakdowns; this is a boiler operative estimate.

There were risks associated with the existing old boiler house being able to operate four boilers at peak load, and these risks are outlined below: -

- 1) Capability of the oil system (35,000 sec oil) to provide sufficient fuel at the required temperature, to allow four boilers to deliver their full output. The fuel oil requires constant pre-heat to keep the low viscosity to enable flow from the oil tanks to the burner units.
- 2) Capability of the two older boilers to provide their rated output. This matter required detailed investigation by the introduction of steam metering to these boilers if the New Energy Centre was not implemented.
- 3) The capacity of the water treatment plant and the associated water storage volume was questioned due to age and lack of support documentation. This plant has no standby capacity so detailed assessment of water storage volumes needed to be made if peak steam output is necessary when water treatment plant is regenerating when being maintained.
- 4) Capability of the steam distribution pipework within the boiler house to allow full output from four boilers to be delivered into the site distribution system is questionable, if the pipework sizes have the steam capacity not to exceed a delivery velocity of 25 m/s.

At times, it is certain that demand for steam will exceed the ability of the existing boiler house to meet this demand. This would result in all boilers progressively locking out due to low pressure in the system drawing water from the boilers (known as boiler priming). If this occurs there will be a total loss of steam to the site until the steam supply can be restored after manually resetting and restarting the boilers and after demand has been manually reduced by shutting off the steam supply to certain buildings. The priority of steam isolation to building had yet to be established.

2.1.1 Steam main distribution calculations

The sizing of a steam main is very important. If it is too small, sufficient steam may not be able to reach the equipment. If the pipe is too large, the capital installation cost will be unnecessarily expensive and heat loss could be greater than necessary.

The size of a pipework is affected by pressure drop between the ends, flow velocity and flow rate.

There are two sets of formulae generally used for sizing steam pipes. One set assumes that velocity is fixed and the other assumes the pressure drop is known. In practice, the pressure drop and flow are actually related and it is difficult to calculate each assumed value until the pipe size is known. The table below has been developed from related flow velocity sourced from “Efficient Use of Process Steam”, TLV Co 1996.

	Wet	Dry	Dry up hill	Super heated
Velocity m/s	Up to 20	20 to 30	15 to 20	45 to 60

The equation below is taken from the CIBSE guide Section 4c Flow of fluids in pipe and ducts, derivation from Bernoulli’s theorem.

$$P_1 - P_2 = \frac{3.032 M^{1.889}}{10^3 d^{5.027} L} \quad \text{C4.41}$$

P_1 Initial pressure P_2 Final pressure M mass flow rate

d diameter in metres L length of pipe

If the steam velocities are too high, pipe work and fittings may be eroded and noise levels may be excessively high.

The maximum steam demand from the facilities on site is approximately 53,400 kg/h with no allowance for diversity.

The allowance for pipe fitting and associated equipment

The length of travel from the Energy Centre to the steam input requirements to the individual facilities see (fig 4) is known, but an additional allowance must be included for the frictional resistance of the pipework fittings, bends, isolation valves, expansion bellows etc. This additional resistance is generally expressed in terms of “equivalent pipework length.” If the size of the steam pipework is known, the resistance of the fittings can be calculated. In this case the pipework size is not known at the initial design stage of the steam distribution across the site. This project had the additional complication of using existing steam distribution pipework from the old boiler house. From a number of design studies to utilize some of the old steam distribution pipework, the steam flow from the New Energy Centre was required to be reversed in directional flow as the old boiler house was situated at the opposite end of the site. This entailed checks on the original position of the main steam pipework distribution condense return traps and the position of the expansion bellows. This configuration was ratified and agreed over a number of weekends. Steam isolations were carried out and the modification done accordingly to suit the current steam distribution pipework layout as it is today.

As a rule of thumb, if the pipework size is not known, the following principles backed-up by industrial experience are used.

- If the pipework is less than 50 metres long, an allowance for fitting is 5% extra of pipework length.
- If the pipework is over 100 metres long and is fairly straight runs with few fittings, an allowance for fitting of 10% would be made.
- Again a similar pipework length, but with more fittings, would increase the allowance toward 20%.

From fig 4 , the approximate length of leg “A” from the New Energy Centre to the first isolation valve in PDF is 700 metres, and from the New Energy Centre to the first isolation valve in SAB is approximately 850 metres.

Therefore the revised lengths for leg “A” is :-

$$700 + 10\% = 770 \text{ metres}$$

For leg “B” is:-

$$850 + 10\% = 935 \text{ metres}$$

The allowance for the heat losses from pipework

In the worst case scenario for leg ”A”, total steam required at point 12 on fig 4 is

$$10,300 + 7,900 = 18,200 \text{ kg/h}$$

The unit heat required of 18,200kg/h at point 12 of the steam distribution, therefore the pipework must be able to carry this quantity plus the quantity of steam condense by heat losses from leg “A”.

As the size of this leg “A” is yet to be determined, the true calculations cannot be made, but assuming that the pipework is insulated to the relative British Standards, it is reasonable to add 3.5% of the steam load per 100m of the revised length as heat losses.

$$\text{Leg "A"} \quad \frac{770}{100} \times 3.5\% = 26.45\%$$

$$\text{Leg "B"} \quad \frac{935}{100} \times 3.5\% = 32.725\%$$

Revised boiler house load for leg "A" = 18,200 + 26.45% = 23,013.9 kg/h

For leg "B" total steam required at point 9 on this pipework is:

$$7,500 + 4,700 = 12,200\text{kg/h}$$

Revised boiler house load for leg "B" = 12,200 + 32.73% = 16,193.06 kg/h

For leg "B" total steam required at point 9 in fig 4 on this pipework is:

$$7,500 + 4,700 = 12,200\text{kg/h}$$

From steam tables (fig 5) "F" can be found by pressure factors P_1 and P_2 and substituting into the equation below:

From the output of the boilers steam is rated at 10.0 barg $F = 104.4$

Steam pressure into buildings is designed for 8.0 barg $F = 70.8$

$$\text{Therefore leg "A"} = \frac{P_1 - P_2}{L} = \frac{104.4 - 70.8}{770} = 0.0436$$

$$\text{Therefore leg "B"} = \frac{P_1 - P_2}{L} = \frac{104.4 - 70.8}{935} = 0.0359$$

$F_A = 0.0436$ with a capacity of 23,013.9 kg/h

$F_B = 0.0359$ with a capacity of 16,193.06 kg/h

From table, fig 6, Pipeline capacity and pressure factor table 200 mm diameter would meet the current requirements at point 9; in fig 4 this also applies to point 12.

From interpolation from fig 6, this table does not confirm to a straight-line graph, therefore interpolation cannot be guaranteed to be absolutely correct.

With this site development in the near future, allowance of 20% was given for this future requirement.

From factors 0.0436, it can be seen that a demand of 23,013.9 kg/h shows a 200 mm diameter is capable of 25,354 kg/h at a F factor of 0.4. With the site development programme, it was agreed to install 300 mm diameter pipework from the Energy Centre.

Fig 5 Pressure drop factor ("F"), source Spirax Sarco steam distribution module.

Pressure bar a	Pressure factor (F)	Pressure bar g	Pressure factor (F)	Pressure bar g	Pressure factor (F)
0.05	0.0301	2.05	8.748	7.60	84.84
0.10	0.0115	2.10	9.026	7.70	86.31
0.15	0.0253	2.15	9.309	7.80	87.79
0.20	0.0442	2.20	9.597	7.90	89.29
0.25	0.0681	2.25	9.888	8.00	90.80
0.30	0.0970	2.30	10.18	8.10	92.33
0.35	0.1308	2.35	10.48	8.20	93.88
0.40	0.1694	2.40	10.79	8.30	95.44
0.45	0.2128	2.45	11.10	8.40	97.02
0.50	0.2610	2.50	11.41	8.50	98.61
0.55	0.3140	2.55	11.72	8.60	100.22
0.60	0.3716	2.60	12.05	8.70	101.84
0.65	0.4340	2.65	12.37	8.80	103.49
0.70	0.5010	2.70	12.70	8.90	105.14
0.75	0.5727	2.75	13.03	9.00	106.81
0.80	0.6489	2.80	13.37	9.10	108.50
0.85	0.7298	2.85	13.71	9.20	110.20
0.90	0.8153	2.90	14.06	9.30	111.92
0.95	0.9053	2.95	14.41	9.40	113.66
1.013	1.0250	3.00	14.78	9.50	115.41
		3.10	15.18	9.60	117.18
		3.20	15.58	9.70	118.96
		3.30	16.00	9.80	120.75
		3.40	16.43	9.90	122.57
		3.50	16.87	10.00	124.40
		3.60	17.33	10.20	126.25
		3.70	17.80	10.40	128.11
		3.80	18.28	10.60	129.99
		3.90	18.77	10.80	131.89
		4.00	19.27	11.00	133.80
		4.10	19.78	11.20	135.73
		4.20	20.30	11.40	137.68
		4.30	20.83	11.60	139.64
		4.40	21.37	11.80	141.62
		4.50	21.92	12.00	143.61
		4.60	22.48	12.20	145.62
		4.70	23.05	12.40	147.64
		4.80	23.63	12.60	149.68
		4.90	24.22	12.80	151.73
		5.00	24.82	13.00	153.80
		5.10	25.43	13.20	155.88
		5.20	26.05	13.40	157.98
		5.30	26.68	13.60	160.09
		5.40	27.32	13.80	162.21
		5.50	27.97	14.00	164.35
		5.60	28.63	14.20	166.50
		5.70	29.30	14.40	168.67
		5.80	29.98	14.60	170.85
		5.90	30.67	14.80	173.05
		6.00	31.37	15.00	175.26
		6.10	32.08	15.20	177.48
		6.20	32.80	15.40	179.71
		6.30	33.53	15.60	181.96
		6.40	34.27	15.80	184.22
		6.50	35.02	16.00	186.49
		6.60	35.78	16.20	188.77
		6.70	36.55	16.40	191.06
		6.80	37.33	16.60	193.36
		6.90	38.12	16.80	195.67
		7.00	38.92	17.00	197.99
		7.10	39.73	17.20	200.32
		7.20	40.55	17.40	202.66
		7.30	41.38	17.60	205.01
		7.40	42.22	17.80	207.37
		7.50	43.07	18.00	209.74

Pressure bar g	Pressure factor (F)
0	1.025
0.05	1.126
0.10	1.230
0.15	1.339
0.20	1.453
0.25	1.572
0.30	1.694
0.35	1.822
0.40	1.953
0.45	2.090
0.50	2.230
0.55	2.375
0.60	2.525
0.65	2.679
0.70	2.837
0.75	2.999
0.80	3.166
0.85	3.338
0.90	3.514
0.95	3.694
1.00	3.878
1.05	4.067
1.10	4.260
1.15	4.458
1.20	4.660
1.25	4.866
1.30	5.076
1.35	5.291
1.40	5.510
1.45	5.734
1.50	5.961
1.55	6.193
1.60	6.429
1.65	6.670
1.70	6.915
1.75	7.164
1.80	7.417
1.85	7.675
1.90	7.937
1.95	8.203
2.00	8.473

Fig 6 Pipeline capacity and pressure factor, source Spirax Sarco steam distribution module

Factor F	Pipe size (mm)												
	15	20	25	32	40	50	65	80	100	150	200	250	300
Capacity (kg/h)													
0.00016					16.18	30.40	55.41	90.72	199.1	598.2	1275	2329	3800
0.00020					17.92	34.32	62.77	103.0	225.6	662.0	1437	2623	4276
0.00025				10.84	17.92	38.19	69.31	113.2	249.9	735.5	1678	2904	4715
0.00030				11.95	19.31	41.83	75.85	124.1	271.2	804.5	1733	4172	5149
0.00035			8.86	12.44	20.59	43.76	80.24	130.0	285.3	845.3	1823	3348	5406
0.00045		3.62	7.94	14.56	23.39	50.75	92.88	150.9	333.2	979.7	2118	3884	6267
0.00055		4.04	8.99	16.18	26.52	57.09	103.8	170.8	373.1	1101	2382	4338	7057
0.00065		4.46	9.56	17.76	29.14	62.38	113.8	186.7	409.8	1207	2595	4781	7741
0.00075		4.87	10.57	19.31	31.72	68.04	124.1	203.2	445.9	1315	2836	5172	8367
0.00085		5.32	11.98	21.88	35.95	77.11	140.7	230.2	505.4	1490	3215	5881	9482
0.00100	1.96	5.84	12.75	23.50	38.25	81.89	148.8	245.2	539.4	1579	3383	6228	10052
0.00125	2.10	6.26	13.57	24.96	40.72	87.57	159.8	261.8	577.9	1699	3634	6855	10839
0.00150	2.39	7.35	15.17	28.04	45.97	98.84	179.3	295.1	652.8	1908	4091	7493	11999
0.00175	2.48	7.51	16.30	29.61	49.34	103.4	188.8	311.1	686.5	2017	4291	7852	13087
0.0020	2.84	8.58	18.83	33.83	56.39	118.2	215.8	355.5	784.8	2305	4904	8974	14956
0.0025	3.16	9.48	20.75	37.25	61.30	132.0	240.5	391.3	881.7	2456	5422	10090	16503
0.0030	3.44	10.34	22.5	40.45	66.66	143.4	262.0	429.8	924.4	2767	6068	11033	18021
0.0040	4.17	12.50	26.97	48.55	80.91	173.1	313.8	514.9	1128	3330	7208	13240	21625
0.0050	4.71	14.12	30.40	54.92	90.23	196.1	354.0	578.6	1275	3727	8189	14858	24469
0.0060	5.25	15.89	35.80	60.31	99.05	215.8	392.3	647.3	1412	4148	9072	16478	26970
0.0080	6.08	18.34	39.23	70.12	116.2	251.5	456.0	750.3	1648	4879	10543	19173	31384
0.0100	6.86	20.84	44.13	79.44	130.4	283.9	514.9	845.9	1863	5492	11867	21576	35307
0.0125	7.35	22.20	47.28	81.00	140.1	302.1	547.3	901.9	1983	5867	12897	23074	37785
0.0150	8.27	25.00	53.33	95.62	157.2	342.0	620.5	1020	2230	6620	14251	25974	42616
0.0175	8.58	26.39	55.78	100.4	165.6	360.4	665.1	1073	2360	6994	15017	27461	44194
0.0200	9.80	30.16	63.75	114.7	189.3	411.9	760.1	1226	2697	7993	17163	31384	50508
0.0250	10.99	33.48	70.73	127.3	209.8	459.7	834.6	1367	2970	8817	19332	34750	56581
0.0300	12.00	36.78	77.23	137.9	229.9	501.1	919.4	1480	3264	9792	20917	37697	62522
0.0400	14.46	44.16	93.17	169.2	279.5	600.7	1093	1790	3923	11622	25254	45604	75026
0.0500	16.43	49.53	104.4	191.2	313.8	676.7	1231	2020	4413	13044	28441	51489	85324
0.060	18.14	52.96	115.7	210.8	343.2	750.3	1373	2231	4855	14368	31384	57373	
0.080	21.08	62.28	134.8	245.2	402.1	872.8	1594	2599	5888	16672	36532		
0.100	24.03	70.12	152.0	277.0	456.0	980.7	1804	2942	6424	18879			
0.120	25.99	77.48	167.7	306.5	500.2	1079	1986	3236	7110	20841			
0.150	28.50	84.13	183.9	334.2	551.7	1195	2161	3494	7769				
0.200	34.32	102.0	220.7	402.1	622.0	1427	2599	4217	9317				
0.250	37.72	112.7	245.2	447.9	735.5	1565	2876	4668					
0.300	41.37	122.7	266.6	487.3	804.5	1710	3126	5057					
0.350	43.34	128.7	283.2	514.9	841.0	1802	3261						
0.400	49.93	147.1	323.6	588.4	961.1	2059	3727						
0.450	50.31	150.0	326.6	600.2	979.9	2083							
0.500	55.90	166.7	362.9	666.9	1089	2314							
0.600	62.28	185.3	402.1	735.5	1201								
0.700	63.07	188.8	407.6	750.9									
0.800	72.08	215.8	465.8	858.1									
0.900	73.28	218.4	476.6										

On leg "A" at the Energy Centre point 1, the maximum demand is 26,100 kg/h

Therefore $F_{A1} = \frac{P_1 - P_2}{L} = \frac{10.0 - 9.5}{10.0} = 0.05$
 10.0 meters from the manifold pipe work inside the boiler house

From fig 6, the table shows a 200mm diameter with a capacity of 28,441 kg/h. Due to the future development it was agreed to install 300 mm diameter pipework that has the capacity to supply 85,324 kg/h.

On leg “B” at the Energy Centre at point 1, the maximum demand is 26,700 kg/h

$$\text{Therefore } F_{B1} = \frac{P_1 - P_2}{L} = \frac{10.0 - 9.5}{10.0 \text{ meters}} = 0.05$$

It was agreed that both pipework supplies were to be installed at 300 mm diameters.

From the pipework size using the pressure drop method, the velocity can be checked by

$$\text{Steam velocity} = \frac{\text{Volume flow (m}^3\text{/s)}}{\text{Cross sectional area of pipe (m}^2\text{)}} = \text{m/s}$$

$$\text{Steam velocity} = \frac{\text{Steam flow rate} \times V_g}{3,600 \times \pi \times D^2}$$

Steam flow at point 12 = 23,013,9 kg/h (equation 1)

Specific volume at 8 bar $V_g = 0.215 \text{ m}^3\text{/kg}$ – from steam table fig 7

Pipework size at 300 mm diameter

$$\text{Steam velocity} = \frac{23,013.9 \times 0.215 \times 4}{3,600 \times \pi \times 0.3^2}$$

$$= \frac{19791.954}{1017.876}$$

Velocity = 19.44 m/s at point 9 (leg “B”)

Steam Tables

Pressure		Temperature	Specific Enthalpy			Specific Volume Steam m ³ /kg
			Water (hf) kJ/kg	Evaporation (hfg) kJ/kg	Steam (hg) kJ/kg	
bar	kPa	°C				
0.3	30.0	69.10	289.23	2336.1	2625.3	5.229
0.5	50.0	81.33	340.49	2305.4	2645.9	3.240
0.75	75.0	91.78	384.39	2278.6	2663.0	2.217
0.95	95.0	98.20	411.43	2261.8	2673.2	1.777
0	0	100.00	419.04	2257.0	2678.0	1.673
0.10	10.0	102.66	430.2	2250.2	2680.2	1.533
0.20	20.0	105.10	440.8	2243.4	2684.2	1.414
0.30	30.0	107.39	450.4	2237.2	2687.6	1.312
0.40	40.0	109.55	459.7	2231.3	2691.0	1.225
0.50	50.0	111.61	468.3	2225.8	2693.9	1.149
0.60	60.0	113.56	476.4	2220.4	2696.8	1.088
0.70	70.0	115.40	484.1	2215.4	2699.5	1.024
0.80	80.0	117.14	491.6	2210.5	2702.1	0.971
0.90	90.0	118.80	498.9	2205.8	2704.5	0.923
1.00	100.0	120.42	505.5	2201.1	2706.7	0.881
1.10	110.0	121.96	512.2	2197.0	2709.2	0.841
1.20	120.0	123.46	518.7	2192.8	2711.5	0.806
1.30	130.0	124.90	524.8	2188.7	2713.3	0.773
1.40	140.0	126.28	530.5	2184.8	2715.3	0.743
1.50	150.0	127.62	536.1	2181.0	2717.1	0.714
1.60	160.0	128.89	541.6	2177.3	2718.9	0.689
1.70	170.0	130.13	547.1	2173.7	2720.8	0.665
1.80	180.0	131.37	552.3	2170.1	2722.4	0.643
1.90	190.0	132.54	557.3	2166.7	2724.0	0.622
2.00	200.0	133.69	562.2	2163.3	2725.5	0.603
2.20	220.0	135.88	571.7	2156.9	2728.6	0.568
2.40	240.0	138.01	580.7	2150.7	2731.4	0.536
2.60	260.0	140.00	589.2	2144.7	2733.9	0.509
2.80	280.0	141.92	597.4	2139.0	2736.4	0.483
3.00	300.0	143.75	605.3	2133.4	2738.7	0.461
3.20	320.0	145.48	612.9	2128.1	2741.0	0.440
3.40	340.0	147.20	620.0	2122.9	2742.9	0.422
3.60	360.0	148.84	627.1	2117.8	2744.9	0.405
3.80	380.0	150.44	634.0	2112.9	2746.9	0.389
4.00	400.0	151.98	640.7	2108.1	2748.8	0.374
4.50	450.0	155.55	656.3	2096.7	2753.0	0.342
5.00	500.0	158.92	670.9	2086.0	2758.9	0.315
5.50	550.0	162.08	684.6	2075.7	2760.3	0.292
6.00	600.0	165.04	697.5	2066.0	2763.5	0.272
6.50	650.0	167.83	709.7	2056.8	2766.5	0.255
7.00	700.0	170.50	721.4	2047.7	2769.1	0.240
7.50	750.0	173.02	732.5	2039.2	2771.7	0.227
8.00	800.0	175.43	743.1	2030.9	2774.0	0.215
8.50	850.0	177.75	753.3	2022.9	2776.2	0.204
9.00	900.0	179.97	763.0	2015.1	2778.1	0.194
9.50	950.0	182.10	772.5	2007.5	2780.0	0.185
10.00	1000.0	184.13	781.6	2000.1	2781.7	0.177
10.50	1050.0	186.05	790.1	1993.0	2783.3	0.171
11.00	1100.0	188.02	798.8	1986.0	2784.8	0.163
11.50	1150.0	189.82	807.1	1979.1	2786.3	0.157
12.00	1200.0	191.68	815.1	1972.5	2787.6	0.151
12.50	1250.0	193.43	822.9	1966.4	2788.8	0.148
13.00	1300.0	195.10	830.4	1959.6	2790.0	0.141
13.50	1350.0	196.62	837.9	1953.2	2791.1	0.136
14.00	1400.0	198.35	845.1	1947.1	2792.2	0.132
14.50	1450.0	199.92	852.1	1941.0	2793.1	0.128
15.00	1500.0	201.45	859.0	1935.0	2794.0	0.124
15.50	1550.0	202.92	865.7	1928.8	2794.9	0.119
16.00	1600.0	204.38	872.3	1923.4	2795.7	0.117
17.00	1700.0	207.17	885.0	1912.1	2797.1	0.110
18.00	1800.0	209.90	897.2	1901.3	2798.5	0.105
19.00	1900.0	212.47	909.0	1890.5	2799.5	0.100
20.00	2000.0	214.96	920.3	1880.2	2800.5	0.0994
21.00	2100.0	217.35	931.3	1870.1	2801.4	0.0996
22.00	2200.0	219.65	941.9	1860.1	2802.0	0.0888
23.00	2300.0	221.85	952.2	1850.4	2802.6	0.0832
24.00	2400.0	224.02	962.2	1840.9	2803.1	0.0797
25.00	2500.0	226.12	972.1	1831.4	2803.5	0.0768
26.00	2600.0	228.15	981.6	1822.2	2803.8	0.0740
27.00	2700.0	230.14	990.7	1813.3	2804.0	0.0714

Fig 7 Source from Spirax Sarco

Steam flow at point 9 = 16,193.06 kg/h (equation 2)

Specific volume at 8 barg $V_g = 0.215 \text{ m}^3/\text{kg}$

Pipework size at 300 mm diameter

$$\text{Steam velocity} = \frac{16,193.06 \times 0.215 \times 4}{3,600 \times \pi \times 0.3^2}$$

$$= \frac{1326.032}{1017.876}$$

Velocity = 13.86 m/s at point 9

The velocity of steam at point 1 just outside the Energy Centre

Leg "A" = 26,100 kg/m

$$\text{Steam velocity} = \frac{\text{Volume flow (m}^3/\text{s)}}{\text{Cross sectional area of pipe (m}^2)} = \text{m/s}$$

$$\text{Steam velocity} = \frac{\text{Steam flow rate} \times V_g}{3,600}$$

$$\text{Steam velocity} = \frac{26,100 \times 0.215 \times 4}{3,600 \times \pi \times 0.3^2}$$

$$= \frac{22,446}{1017.876}$$

$$= 22.05 \text{ m/s}$$

Leg "B" = 26,700 kg/m

$$\text{Steam velocity} = \frac{\text{Volume flow (m}^3/\text{s)}}{\text{Cross sectional area of pipe (m}^2)} = \text{m/s}$$

$$\text{Steam velocity} = \frac{\text{Steam flow rate} \times V_g}{3,600}$$

$$\text{Steam velocity} = \frac{26,700 \times 0.215 \times 4}{3,600 \times \pi \times 0.3^2}$$

$$= \frac{22962}{1017.876}$$

$$= 22.55 \text{ m/s}$$

All steam velocities are within acceptable design velocities of 30 m/s.

To check the pipework size

v = Flow velocity (m/s)

Vg Specific volume (m³/kg)

Ms = Mass flow rate (kg/s)

Q = Volumetric flow rate (m³/s) = ms x Vg

From this information, the cross sectional area (A) of the pipework can be shown as:

$$\text{Cross Sectional Area (A)} = \frac{\text{Volume flow rate (Q)}}{\text{Flow velocity (v)}}$$

$$\text{CSA (A)} = \frac{\pi D^2}{4} = \frac{Q}{v}$$

By transformation :-

$$D^2 = \frac{4Q}{\pi \times v}$$

$$D = \sqrt{\frac{4Q}{\pi \times v}}$$

At point 1 fig 4 on leg A

Flow velocity (design) = 30m/s

$V_g = @ 8 \text{ barg} = 0.215 \text{ m}^3/\text{kg}$

Mass flow rate $M_s = 30,200 \text{ kg/h} = 8.388 \text{ kg/s}$

Volumetric flow rate $Q = m \times V_g = 8.3888 \times 0.215$
 $= 1.803 \text{ m}^3/\text{s}$

Cross Sectional Area = $\frac{\text{Volumetric Flow rate (Q)}}{\text{Flow velocity}} = A \text{ (m}^2\text{)}$

$$\frac{\pi \times D^2}{4} = \frac{Q}{v} = D = \sqrt{\frac{4 \times v}{\pi \times \mu}}$$

$$= \sqrt{\frac{4 \times 1.803}{\pi \times 30}} = \sqrt{\frac{7.212}{94.24}}$$

= 0.276 metres, therefore the nearest size of pipe is 300 mm diameter.

At a velocity of 25.51 m/s

$$\frac{\pi \times D^2}{4} = \frac{Q}{v} = D = \sqrt{\frac{4 \times v}{\pi \times \mu}}$$

$$= \sqrt{\frac{4 \times 1.803}{\pi \times 25.51}} = 0.299 \text{ m}$$

= 0.299 metres, therefore 300 mm diameter.

Within acceptable limits of low velocity at 22.55 m/s

$$\frac{\pi \times D^2}{4} = \frac{Q}{v} = D^2 = \frac{4 \times Q}{\pi \times v}$$

$$= \sqrt{\frac{4 \times 1.803}{\pi \times 22.55}} = 0.319 \text{ m}$$

= 0.319 meters = 319 mm diameter.

Providing the steam velocities are above 25.5 m/s the main steam distribution meets the required demand across the site

2.1.2. Recommendations

1) The evaluation of the consequences of a steam shortage or failure needed to be carried out by Fisons at the time to establish the magnitude of the potential risk.

This risk was addressed by using the techniques of Reliability Centred Maintenance (RCM) to assess the modes of failure and the consequences of failure, see item 3.1 of AstraZeneca maintenance strategy for further details.

2) Upgrade and / or installation of steam metering to confirm significant steam loads with respect to outside temperature and time of day.

3) From the steam demand report and the associated problems of the ability to produce steam and control to meet the increasing demand for this developing site.

The Astra board of directors gave the approval to proceed with the construction of the New Energy Centre and install controls to the main facilities to control steam demands so to have priority control over the facilities in the future.

2.1.3 Synopsis of emission calculation

Induction

Estimations of the total production of sulphurous and nitrous oxides, CO₂ and particulates can be derived from measurements of the total fuel burned, and parameters for the fuel

and combustion characteristics. This section defines the methods used to arrive at the results which are directly reported.

Background

There are two classes of stack emissions that can be derived using different methodologies.

Emissions of class one are those which can be calculated directly from the mass of fuel burned using simple relations based on elementary chemistry. These include sulphur compounds and CO₂.

Class two emissions are derived from measurements of concentrations taken from periodic flue gas samples. These include oxides of nitrogen and particulates.

Understanding the atmospheric combustion practice and burner efficiencies.

For any given fuel, it can be shown that there is a chemically correct (stoichiometric) air to fuel ratio to give the best combustion from the fuel supplied.

For the liquid and gaseous industrial fuel, normally used in boiler houses are: -

Gas oil (35 sec) Stoichiometric	0.5 kgs of oil needs	7.305 kgs of air
Air to fuel ratio Natural gas	0.5 kg's gas needs	8.25 kg's of air

If a CO₂ percentage was to be taken, the gases given off by this combustion would be equal to: -

Gas oil (35 second) 15.5%	Known as the stoichiometric CO ₂
Natural Gas 11.5%	

Shell boilers similar to the New Energy Centre achieve the above conditions without excessive smoke when firing on oil and an unacceptable level of carbon monoxide when firing on gas, due to limited combustion residence time and furnace volume.

To overcome these problems and clean up the combustion process, forced draft fans were installed to increase the volume of air available for combustion.

However, this excess air gave rise to two other problems: -

- a) It causes the CO₂ percentage to fall below the Stoichiometric value, hence reducing the overall combustion efficiency, and
- b) It absorbs heat that it exhausts to the atmosphere via the flue stack, hence increasing the stack losses and again reducing the combustion efficiencies, also wasting fuel in the process.

To achieve maximum combustion efficiency a compromise is reached whereby a precise amount of excess air is used to achieve clean combustion and no more. The assessment of clean combustion on a normal boiler and burner configuration is determined by: -

- Gas oil firing CO₂ percentage and smoke spot number viewed on a standard smoke indicator is below number 3.
- Gas fired O₂ percentage and CO parts per million to be less than 150.

SAACKE burner parameters

Fuel	Firing rate	CO ₂ %	O ₂ %	CO mg/m ³	Smoke Spot Numbers
Gas oil	High fire	11.5 – 13.0	3.3 – 5.3	Max 150	4 or below
	Low fire	9.5 – 11.0	6.0 - 8.0	Max 150	4 or below
Natural Gas	High Fire	9.5 – 10.25	3.2 – 5.0	Max 100	N/A
	Low Fire	7.0 – 8.5	5.8 – 8.5	Max 100	N/A

The aim of good combustion is to achieve the highest CO₂ percentage, consistent with clean combustion at all firing positions - high or low firing combustion performance.

The Environment Agency is responsible for protecting and improving the environment hence this government body sets acceptable limits and ensures that we maintain our energy centre within our licence tolerance for emissions and thus limit the pollution or damaging effects for the surrounding area.

Environmental Agency limits

NO _x mg/m ³	CO ₂ mg/m ³	CO/mg/m ³
Maximum 200	Maximum 350	Maximum 150
Maximum 200	Maximum 350	Maximum 150
Maximum 100	Maximum 5	Maximum 100
Maximum 100	Maximum 5	Maximum 100

Enclosed is a short list of what gases are emitted during the combustion process and to give the reader an understanding as to why the Environment Agency monitors these pollutants.

The following calculations are used within the NEC, SCADA Sentinel computer system; the results are forwarded to the EA in an agreed standard format every three months.

Molecular table;-

	Carbon	Oxygen	Hydrogen	Sulphur	Nitrogen
Atomic weight	12	16	1	32	14
Molecular Mass M	12	32	2	32	28

Carbon Dioxide production

Carbon atoms in the fuel are neither created nor destroyed during the combustion process.

If the combustion process is stoichiometric (adequate inlet air is available and the fuel is fully burned) then the percentage of CO₂ produced can be assumed negligible.

The complex compounds of Carbon, commonly known as Volatile Organic Compounds (VOCs) are shown by sample measurement to be also negligible. It is therefore

reasonable to use the simplifying assumption that each atom of Carbon (atomic weight

12) combines with two atoms of Oxygen (atomic weight 16) to give a single molecule of CO₂.



The mass of CO₂ emitted therefore is given by the formula:-

$$CO_2 = \frac{44 \times C_F \times V_F \times D_F}{12}$$

Where: - C_F is the carbon content of the fuel by weight

V_F is the volume of fuel burned in m³ (units)

D_F is the density of the fuel in kg/m³ (unit)

And CO₂ is the mass of Carbon Dioxide released.

From the quarterly value for the NEC of 10,390,197 m³ of gas the following calculations follows:-

Correct the measured (uncorrected) gas volume by applying the gas correction factor.

Gas correction factor

The gas correction factor is the volumetric compensation that must be applied to the measurement of gas flow when using a meter with no built-in temperature or pressure correction. For example, if a flow meter responds by providing an output that is proportional to the actual volume of gas passing through it at temperature T and pressure P then the volume of gas at Standard Temperature and Pressure (STP) is defined as 273k (0 °C at 101.325 kPa). Since, according to Avogadro's hypothesis, equal volumes of different gases (at the same temperature and pressure) contain the same number of molecules. The STP is calculated as follows ,(see table 8) :-

Boyle's gas law states that when a given mass of gas is kept at constant temperature, its volume varies inversely as its absolute pressure for example double the absolute pressure gives half the volume, therefore for a combined gas law for an ideal gas states:-

$$\frac{P_1 \times V_1}{T_1} = \frac{P_2 \times V_2}{T_2}$$

Where temperature is in degrees Kelvin (°k), and pressure is absolute (not gauge), therefore for a volume of gas V₁ measured at pressure P₁ and temperature T₁, the volume V₂ at P₂ and T₂ would be:-

$$V_2 = \frac{P_1 \times V_1 \times T_2}{P_2 \times T_1}$$

For calculations based on gas volume at standard temperature and pressure (0°C and 1.013 bar) therefore, the gas correction factor can be re-written as:-

$$V_2 = \frac{P_1 \times V_1 \times 273}{101.325 (T_1 + 273)}$$

Where P₁ is in kPa and T₁ is in degrees °C.

The standard equation for calculating the energy consumption for the NEC is as follows:-

For gas measured at 200 mbar and 12 °C, $P_1 = 121.325$ kPa and the resulting correction factor C_f is: -

$$C_f = \frac{121.325 \times 273}{101.325 \times (12 + 273)} = 1.147$$

However, the standard usually adopted for gas measurements are referenced to 15°C (288 k) and absolute pressure 1013.25 mbar (NTP Normal temperature and pressure refers to the atmospheric conditions of a normal day). Therefore the correction factor is calculated with a slightly modified set of parameters:-

$$V_2' = \frac{P_1 \times V_1 \times 288}{101.325.1 \times (T_1+273)}$$

Therefore, the correction factor using the same values as above (200 mbar gauge pressure and at 12 °C) gives a correction factor of: -

$$C_f' = \frac{121.325 \times 288}{101.325 \times (12 + 273)} = 1.21$$

Gas density

Natural gas contains a number of components, each having a different thermo-physical characteristic. A typical gas sample analysis is shown on table 4. The method used to derive overall gas density is outlined below.

- 1) For each component of the gas (mixture), obtain the reference density at the required temperature and pressure (RTP)
- 2) Given the analysis in terms of the percentage of each component in the gas, a note of the number of molecules of each constituent for one mole of the mixture.

- 3) The volume at RTP occupied by the weight of the component corresponding to a reference of 1kg is calculated by the figures obtained from items 1) and 2).
- 4) The total volume for all the components by summing them together.
- 5) The average gas density is then the reciprocal of the result obtained in item 4)

From the Transco national grid company supplied data, the average density at STP for the mixture is 0.7674 kg/Nm³, see table 8 for details.

Carbon content of gas

If the assumption is made that all combustible (hydrocarbon) components in the gas are fully converted to a mixture of CO₂ and H₂O, then the determination of CO₂ produced can proceed as follows

- 1) Given the analysis in terms of the percentage of each component in the gas, determine the number of molecules of each constituent for one mole of the mixture.
- 2) Assume full combustion –i.e every carbon atom in the combustible components of the gas produces one molecule of CO₂. Calculate the number of CO₂ molecules produced for each component by multiplying the result from item 1) with the number of carbon atoms in each molecule of the component.
- 3) Calculate the mass of CO₂ produced for each component by multiplying the individual figures from item 2) by 44 (the molecular weight of Carbon Dioxide).
- 4) Calculate the total mass of CO₂ produced by summing the contributions from each combustible component.
- 5) Calculate the mass of each gas component by multiplying the number of molecules by its molecular weight.

- 6) Calculate the mass of all gas components by summing individual contributions derived in item 5.

Determination of CO₂

The creation of CO₂ follows similar route to that of SO_x. However, in order to arrive at an answer, several important, although fully justified, assumptions must be made.

As in the case of Sulphur, Carbon atoms in the fuel are neither created nor destroyed during the combustion process. Provided that the combustion process is stoichiometric (ie adequate inlet air is available and the fuel is fully burned) then the percentage of CO produced can be assumed to be negligible. Furthermore, more complex compounds of Carbon, commonly known as VOCs (Volatile Organic Compounds) have been shown by sample measurement to be also negligible. It is therefore reasonable to use the simplifying assumption that each atom of Carbon (atomic weight 12) combines with two atoms of Oxygen (atomic weight 16) to give a single molecule of CO₂. The mass of CO₂ emitted therefore is given by the formula:-

$$\text{CO}_2 = \frac{44 \times C_c \times V_f \times D_f}{12}$$

From calculations, the correct measured (uncorrected) gas volume by applying the gas correction factor 1.21. Then applying the formula to the correction gas volume to determine CO₂.

$V_f = \text{Measured volume} \times \text{correction factor}$

$$V_f = 10210806 \times 1.21$$

$$\text{Volume of fuel burned } V_f = 11,436,102 \text{ m}^3$$

Therefore:-

$$\text{CO}_2 = \frac{44 \times C_c \times V_f \times D_f}{12}$$

Where Cc is the parameter for the carbon content of the fuel by weight, using data supplied by Transco for each kg of gas burned it produces 2.54 kg of CO₂. This corresponds to the value for the Cc gas parameter in table 1 of 69.4 %. For commonly used values for natural gas of 15 °C and 1.01325 bar, the density is 0.7271 kg/Nm³ see table 8

$$\text{CO}_2 = \frac{44 \times 0.694 \times 11,436,102 \times 0.727}{12} \text{ kg}$$

$$\text{CO}_2 = 21,156.4 \text{ tonnes released during 2005}$$

Nitrogen Oxides (NO_x)

During the combustion process of hydrocarbon fuels, Nitrogen Oxides (NO_x) are formed due to the reaction of atmospheric Nitrogen in the combustion air and the combustion air and the atomically bound Nitrogen within the fuel.

The expression NO_x (Nitrogen Oxides) refers to the summation of all Nitrogen Oxides. Most predominant of these, as far as pollution is concerned, are the strains Nitrogen Monoxide (NO) and Nitrogen Dioxide (NO₂).

Nitrogen Monoxide is produced during the combustion process, but this is then converted to Nitrogen Dioxide in the atmosphere due to further oxidation. Nitrogen Monoxide is the most predominant Nitrogen Oxide present in the combustion process and accounts for approximately 95% of the total NO_x.

The formation of Nitrogen Oxides during combustion is a highly complex process and there are basically three different formation mechanisms: -

- a) Thermal NO_x
- b) Prompt NO_x

c) Fuel NO_x

a) Thermal NO_x

Thermal NO_x is formed by the oxidation of atmospheric Nitrogen as it passes through the flame zone. It requires high activation energy and is influenced adversely by peak flame temperatures, oxygen concentration and residence time at peak temperature.

b) Prompt NO_x

This also results from atmospheric Nitrogen, but is produced through a reaction with fuel hydrocarbons in the high reaction zone of the flame. It is not influenced by flame temperature, but depends on the residence time in the fuel rich mixture and sub-stoichiometric mixture zones.

c) Fuel NO_x

This is the result from the chemically bound Nitrogen in liquid or solid fuel. Nitrogen in the fuel is quickly broken down in the flame to produce Nitrogen-Hydrogen. This reacts further with Oxygen to give NO_x.

This type of NO_x is essentially dependent on the local oxygen concentration and to a lesser extent flame temperature.

In the combustion of gas oil and natural gas, the NO_x content of the combustion gases is attributed almost entirely to thermal Nitrogen Monoxide formation. Chemically bound Nitrogen is present in only small amounts in gas oil. Therefore, it has only a secondary influence on the total NO_x emissions level, whereas with heavy fuel oil and coal combustion processes, where "bound Nitrogen" is significant (fuel Nitrogen > 0.2 percentage), the formation of fuel NO_x is the dominant factor. Prompt NO_x represents a

very small percentage of the total NO_x emission levels and consequently the main mechanisms for NO_x reduction are targeted at thermal and fuel NO_x.

NO_x Calculations

The determination of oxides of Nitrogen is more complex as these are intimately related to the combustion process and density will vary across the firing range for each fuel. For the purposes of the following calculations, it is assumed that sample measurements of NO_x concentrations in flue gases (suitably normalised) will suffice to cover all circumstances. These measurements of NO_x concentrations in the flue gases are made quarterly for each fuel type and for each burner and the parameters are used in conjunction with the measured fuel volume, and the calculation of normalised (1) flue gas volume.

The deviations of an estimate of total NO_x emissions is as follows:-

$$\text{NO}_x = C_N \times V_G$$

Where C_N is the measured concentration of Nitrous Oxides in the flue gases.

and V_G is the normalised volume of flue gases released.

The volume of flue gasses produced is calculated using the parameters " Oil to flue gas" and "Gas to flue gas" from table 8.

The complete equation used to determine NO_x emissions is:-

$$\text{NO}_x = C_N \times V_F \times D_F \times K_F$$

Where V_F is the volume of fuel burned

D_F is the density of the fuel

K_F is the parameter for the volume of flue gasses per kg of fuel burned.

For example, how the NO_x figures are calculated for the quarterly Environment Agency report for this boiler are: -

Using the same (corrected) gas consumption figures values for gas density "gas to flue gas" and sample measurement for NO_x concentration from table 8 (source from Transco)

$$\begin{aligned} \text{NO}_x &= \frac{45 \times 12572138 \times 0.727 \times 12.04}{1,000,000} \\ &= 4,952 \text{ kg.} \end{aligned}$$

SO_x calculation

The most predominant factor here is Sulphur Dioxide, which is formed by the reaction of Sulphur in the fuel with Oxygen in the combustion air.

Boiler and burner design cannot influence the level of SO_x emission, as it is totally dependent on the Sulphur content of the fuel burnt. SO_x emissions are a major factor when considering oil as a fuel because to meet the Environment Agency's requirement, with respect to SO_x emissions, some expensive ancillary equipment is needed to clean up this emission before it enters the flue stack and passes out to atmosphere.

The determination of SO_x

Since Sulphur cannot either be destroyed or created during the combustion process, it is a relatively simple matter to calculate the total mass of SO₂ emitted from the fuel burned and a value for the Sulphur content of the fuel itself (obtained by analysis).

Assuming, for practical purposes, the SO_x is emitted in the form of Sulphur Dioxide (SO₂), then

$$\text{SO}_2 = 2 \times P_2 \times V_F \times D_F$$

Where:- P₂ is the Sulphur content of the fuel by weight

V_F is the volume of fuel burned in (units)

D_F is the density of the fuel in kg/(unit)

SO_2 is the mass of Sulphurous oxides released in kgs

During 2005 the Energy Centre consumed 38,377 litres of fuel oil at has a Sulphur content (measured)- Kg of sulphur/Kg of fuel 0.002 by weight, the density of oil is 0.86 kg/litre.

Therefore, the mass of SO_2 produced is:-

$$\begin{aligned}SO_2 &= 2 \times 0.002 \times 38,377 \times 0.86 \\ &= 132.016 \text{ kgs}\end{aligned}$$

Particulate Matter

Solid emission is the result of the ash content as well as the coking nature of the fuel concerned. This is a critical factor when considering heavy fuel oil combustion equipment.

The New Energy Centre Integrated Pollution Control licence is monitored by the Environment Agency for compliance with the issued "BA0790 Environment Agency Authorisation and Introductory Note Environment Protection Act 1990".

The above licence covers the New Energy Centre only and it serves to:-

- Define the boundaries for emission control
- Specify the limitations to the use of the building
- Defines procedural requirements
- Defines Operational Reporting Requirements
- Defines Record Keeping Requirements

(The Authorisation Note MUST be complied with at all times; non-compliance can lead to financial penalty and prosecution.)

Date is collected from the New Energy Centre each month on the following systems:-

- Fuel used (Gas and oil)
- Maximum Sulphur content in the oil from the delivery notes supplied by the preferred oil supplier
- SO₂ released
- NO_x released which is automatically calculated on the data submission to our SHE department.

The "Boiler house Environmental monitoring procedure see appendix B, "PRO2. 0083" covers the above procedure.

Item Conclusion

There was very little control or monitoring of the products of combustion in the old boiler using heavy oil 3,500 second as its main fuel. No documentation was kept on what level of NO_x and SO_x releases into the atmosphere or methods of monitoring of these gases.

In the past few years the Environment Agency has narrowed the discharges from boiler houses by issuing new statutory legalisation governing the level of pollution under the Environment Protection Act 1990 for emissions from boiler above 50 MWatts output.

The NEC has the capacity of producing 78 MWatts output if all six boilers are in use.

The New Energy Centre runs on natural gas and 35 sec oil (diesel oil) and both types of fuels have low levels of NO_x and SO_x when the burners are calibrated for optimum efficiency to meet the above specified levels: -

Parameters	Natural gas firing	Gas oil firing
Particulates mg/m ³	5*	100*
Sulphur dioxide mg/m ³	5	350
Oxides of Nitrogen (as NO ₂)	200	350
Carbon Monoxide mg/m ³	100	150
Volatile Organic Compounds (as carbon mg/m ³)	20	20

Table from EA authorisation BA 0790. * Particulate measurements shall be at a Maximum Combustion Rate (MCR) of 60%

The NEC is monitored on a six monthly visit by an EA recognised specialist emissions combustion specialist. My team works in conjunction with the combustion specialist and submits the emission reports to the EA on a yearly basis. The Originally these reports were on a quarterly basis but our procedures have been audited by the EA, and they are satisfied to receive these reports annually. We are now in the process of using the Sentinal system to submit all the reports direct to the EA.

2.1.4. The Building Prioritisation

The distribution of steam to critical processes in buildings such as pilot plants is given priority in the unlikely event of high peak demands exceeding the boiler plant capacity. This mode of operation was facilitated by the Building Management System, ensuring all non-critical plant is isolated in a controlled manner depending upon the building priority and the time of the year.

2.1.5. The Supply Protection

This is related to holding the steam supply in the event of a total site electrical power failure for a short period whilst the back-up generators come on-line (generators are programmed to be on-line after mains failure of 60 seconds). This includes recovery from a total site power failure and a scheduled restart process, which is fully automated from a cold start situation, thus preventing damage to plant due to thermal shock.

2.1.6. System Overview

The New Energy Centre communicates through a system package supported from the boiler and burner manufacturers called System Control and Data Acquisition (SCADA) Sentinel management controls.

The main objective of the steam load management strategy is to control the distribution of steam around the entire AstraZeneca site whilst maintaining the required operating pressure at the New Energy Centre.

The (SCADA) Sentinel system installed within the NEC has built-in facilities and software capabilities to automatically load up or download the boilers and enable the burners to cope with a varying steam demand.

However, in the event of several large demands for steam being requested at a similar time, for example, the first operational requirements in the morning start-up, or where, one or more boilers are off-line due to fault or maintenance, the steam distribution to the site could be greatly affected. Where the steam generation capacity is unavailable to meet peak demands, then the steam load management installation overcomes this potential problem thus ensuring optimum performance for the entire site.

2.1.7 Local Building Management System Outstations

The local Building Management system outstations within the other major buildings on the site are programmed to isolate the steam supplies to the non-critical plant.

In some cases this involved closing heating calorifier control valves, de-energising steam humidifiers and closing down larger plant such as absorption chillers.

In some instances, the entire steam-using plant of the whole building can become de-energised but generally this affects the lower priority buildings only. A combination of "Analogue positioning" signals and digital On/Off "switching signals" were programmed at the Building Management System outstations for the following buildings which are not equipped with an intelligent Valtek valve.

- 1) Safety Assessment Building (SAB) building 25
- 2) Pharmacology building 18
- 3) Pilot Plant PP3 building 23
- 4) Stages 1 and 2
- 5) Administration building 7

2.1.8. Description of Operation

The majority of the buildings at AstraZeneca are controlled by the Satchwell Building Management System BAS 2800, for temperature, humidification, cooling and airflow.

This system is responsible for the correct distribution of steam around the entire site during emergency periods when steam demand exceeds supply, or following an electrical power failure.

The steam raising boilers in the New Energy Centre are under the control of the "Sentinel" system, which is fully automatic and maintains constant flow pressure in the main steam header. The boilers are adequately sized to cope with the site demand under

normal working conditions. However, if more than one boiler is on lockout, faulty or down for maintenance or repairs, and if this occurs during the winter months, then there would be a requirement to distribute the steam around the site in priority order.

The Satchwell Building Management System takes into account the priority order in the following manner: -

A 4 to 20 mA output signal derived from the (SCADA) Sentinel System is connected into the Building Management System outstation in the New Energy Centre. The analogue signal determines the amount of steam "under capacity" which needs to be addressed, and thus prevents the steam header pressure from falling below a pre-determined low-limit level. The Building Management System is programmed to give priority to essential buildings. This is achieved by applying On/Off load shed signals to the least critical buildings via the site Building Management System network. Upon receipt of the signal within a particular building the Building Management System control facility will de-energise all or part of the associated steam-using plant within the building either by closing calorifier valves or disabling major plant such as the absorption chillers.

The Valtek valves are suitably equipped with an interface card, which allows the valve to be remotely positioned for load reduction or completely closed for the building isolation.

The remote control of the Valtek valve is integrated in the Satchwell Building Management System priority load shedding sequence.

Following a site power failure condition, the Building Management System caters for a staggered start programme. This programme ensures that the increasing demand does not over-burden the system, and buildings will be at "Hold-Off" status in the sequence until the load requirement matches the steam availability.

A fully active dynamic graphics display is provided at the Building Management System showing a plan of the site with different building colours denoting whether the steam

availability to a building is being restricted or if it is under normal control. The Shift Engineering Technician will be able to access the building information direct from the Building Management System on a site graphic display.

2.1.9. Site Control Strategy

The overall site control strategy is divided into three main areas, these being: -

- 1) Steam Distribution and Load Shedding.
- 2) Action on Power Failure.
- 3) Steam Demand Exceeding Supply.

2.1.10. Steam Distribution and Load Shedding

A steam load management system was installed to give effective control of site steam distribution under the automatic management of the Building Management System, working in conjunction with the burner manufacturer Saacke (SCADA) Sentinel system in the New Energy Centre.

The newer buildings have been equipped with a Valtek steam control valve, controlling the steam pressure to each building.

Each Valtek valve is equipped with a "Starpac 11" intelligent controller mounted on the control valve. The intelligent control is electronic microprocessor based which provides a stand-alone control of steam flow setting, based on the relationship of pressure to temperature curve.

The Valtek valve "Process" pressure sensors, flow sensors and temperature sensors are embedded in the Valtek valve body for data acquisition, and the valve can also act as a steam metering device in its own right.

For the Valtek valve to function it requires a 24-volt direct current electrical supply and air supply.

All data collected at the "Starpac 11" electronic microprocessor can be remotely recorded on the Satchwell (BMS) central computer which is located in the Shift Engineering Technician's control room.

The Valtek valve is fully configured and accessed either from the membrane keypad on the front of the "Starpac 11" unit or remotely from the Satchwell BMS computer over the Building Management System Local Area Network communications link. All set points and parameters can be remotely adjusted or switched between the emergency set point and the normal set point from the Building Management System.

The "Starpac 11" system continuously monitors the valve position, with its operational parameters notifying the remote Building Management System computer when improper operation occurs or when parameter limits are violated. All system warnings are mapped back to the site Building Management System computer.

The Building Management System has the ability to prioritise buildings and differentiate between critical and non-critical buildings. Each Building is programmed within the Building Management System with its "normal" pressure set point of 10.5 bar at atmospheric pressure and an "emergency" pressure set point of 8.5 bar at atmospheric pressure to control at load-shedding mode level.

Individual set points for "normal" and "emergency" pressure have been programmed into the Building Management System (BMS); this gives priority sequence of shedding steam loads to buildings in a controlled manner.

Separate priority orders have been provided for winter and summer conditions, which are based on external ambient temperature of 10°C set point with a 1°C dead band.

The buildings, which do not have the facility of a Valtek valve installed, are programmed via the Building Management System to reduce their steam demand by de-energising non-critical steam-using plant.

The automatic steam load shedding function is only required to be implemented in a situation where one or more boilers are not available due to a "fault", or when maintenance and steam demand exceeds the total available generating capacity.

The priority order schedule will be triggered, if the steam header pressure falls below a pre-set threshold of 9 bar at atmospheric pressure, working in collaboration with the excess spare capacity signal, which is programmed to generate a negative capacity as well as a positive capacity output at the main (SCADA) Sentinel system. This 4-20 mA signal is fed into the Building Management System (BMS) Outstation in the New Energy Centre. The outdoor air ambient temperature, at the time of the priority order being triggered, determines whether the summer schedule or winter schedule for priority order is applied.

The distribution of the steam supply around the site is determined by the adjustment of the pressure set points for the buildings fitted with the Valtek valves. The adjustment can be remotely and automatically achieved from the Building Management System.

2.1.11. Action on Power Failure or Steam Generation Failure

In the event of a total power failure of the site electrical system, site back-up generators that supply power to the Valtek and the air compressors across site are programmed to be operational within 30 seconds.

If the back-up generator fails to supply the site, the following sequence is programmed to occur.

a) New Energy Centre:-

The entire steam system is designed to fail safe, providing the main steam header manifold remains pressurised in the New Energy Centre, full recovery will occur. The main computer will Auto Re-boot and the Shift Engineer Technician has the ability to "Log-On" to any part of the system across the site. The Shift Engineering Technician team can view any Building Management System set point or graph through a computer package on site called "PCAnywhere".

All boilers will restart automatically following restoration of power, providing the steam header manifold pressure has not fallen below its low-limit threshold of 9 bar pressure. The (SCADA) Sentinel computer has an un-interruptible Power System battery back-up support and will continue to operate for up to 15 minutes as will the (SCADA) Sentinel outstations within the New Energy Centre.

b) Steam control valves: -

All steam control valves (Valtek) are spring-return fail safe (closed) and will immediately shut off steam supply in a controlled manner.

Upon restoration of power, the steam control valve will automatically restart in a controlled manner to achieve its pressure set point, providing that the local Building Management System outstation is back on-line and steam pressure downstream of the valve is above its minimum limit.

c) Building Management System local outstations: -

The outstations will remain on-line through an integral un-interruptible power supply for a period of up to 18 hours.

The Building Management System outstations will automatically shut down, with loss of all communications and field instrumentation data, if the 18-hour back-up time is exceeded.

Communications' alarms will be raised at the central Building Management System computer for all outstations on battery support.

When power is restored to the outstations, the steam control valves or major plant will go through a controlled ramp-up sequence, thus avoiding any damage to steam equipment from thermal shock.

d) Central Building Management System computer: -

The central Building Management System computer will continue to operate as normal for a period of 15 minutes by its own un-interruptible Power System.

Upon mains power restoration the Building Management System main computer will initiate a gradual and sequential start-up of the buildings in the priority order.

The central Building System computer will determine that all remote Satchwell outstations are back on-line prior to initiating sequential start up of steam control valve building reinstatement.

All buildings are scheduled on a sequential start-up once the electrical supply to the outstation is restored.

e) The main (SCADA) Sentinel system and outstations in the New Energy Centre: -

The main outstation and the central (SCADA) Sentinel PC will continue to operate as normal for a period of 15 minutes by its own un-interruptible power supply.

Upon restoration of electrical power, the outstation and the (SCADA) Sentinel PC will automatically changeover onto main supply to regain control of the steam supply from the New Energy Centre.

If there is a total power failure of the site electrical, supply is experienced for a period greater than 15 minutes and a prolonged restart process will be implemented, which will prevent damage to the boilers due to thermal shock. This process will require initial manual restart on the main boiler control for burner control and circulating pumps in the New Energy Centre.

The (SCADA) Sentinel control system will inhibit any automatic restarts of boilers if low pressure is detected in the main steam header and for thermal protection of the boilers. This

would occur if the power failure to the site was greater than 15 minutes, during which cooling of boilers and the steam main could occur, with condensation in steam pipework being possible. Shift Engineering Technicians have received training from the boiler manufacturer, Wellman Robey, on avoiding this type of incident by isolating valve sections of the pipework and draining the build-up of potential condensate in steam mains to buildings and critical plant.

Once the steam header pressure is up to the normal 10 bar working pressure, the (SCADA) Sentinel system will generate the 4-20 mA output, excess or under capacity signal following which the gradual reinstatement of steam pressure to each building will be carried out by the Building Management System in the programmed priority order.

2.1.12. Steam Demand Exceeding Supply

If for any reason the site requires more steam than the New Energy Centre is capable of generating, there is a danger of causing damage to the New Energy Centre. The Building Management System implementing a fail-safe software programme, which limits the steam supply to the appropriate buildings in accordance with the priority sequence, would address the situation.

Due to the design of the communication between the steam control valves and major steam-using plant items, the site Building Management System is controlled by direct data operating through the Building Management System network. The system is able to determine and constantly log what excess spare steam capacity there is and the remaining supply steam operates on reduced steam consumption to the totally isolated equipment until the New Energy Centre recovers its steam generating ability.

Since all the data and communication between the major plant items and the site Building Management System is fully dynamic, the steam distribution needs only to be prioritised for the period of time during which the peak demand and fault conditions occur simultaneously. The steam load management system is configured to hold-off digital output signals from the local Building Management System outstation, which will inhibit selected items of plant from operating such as air conditioning humidifiers, steam calorifiers and frost coils.

2.1.13. Current engineering operations

This treatise is to give the reader an insight into how the technical challenges were identified and how the best options available were evaluated and selected at the time of the design.

This treatise covers the options whether to pursue the route of installing a Combined Heat and Power (CHP) unit or two new boilers which could produce the same amount of steam output, in relationship to installation costs versus operational running costs.

In the Engineering and Facilities department, we have developed a maintenance strategy using Reliability Centred Maintenance (RCM) analysis, through to contract outsourcing all the maintenance activities to a third party with Key Performance Indicators (KPI) to monitor performance against cost and time, see appendix 2 for Contract Optimisation programme.

The New Energy Centre (NEC) is located to one corner of the main site being strategically and pragmatically situated to cater for both current needs and probable future capacity requirements.

Phase one of the NEC was to install four identical in-line 18,000 kg/hr rated boilers to cater for the peak site steam consumption of approximately 30,000 kg/hr, with two boilers being commissioned and two boilers being “mothballed” initially, whilst the old boiler

house also remained operational. The old boiler house was positioned in the centre of the site, and was decommissioned in 1998 to release this space for a new £100 million site development project. To achieve this space, new steam main gantries were installed from the New Energy Centre to back feed a number of new buildings and the old part of the site. To accommodate this requirement a number of complicated steam isolations were carried out at weekends to connect these new sections of steam pipework back to the New Energy Centre. This operation was completed without affecting the steam requirements for the working week on this research and development site. All the old sections of the steam gantries were removed from site at the completion of the steam distribution installation.

Some 4 years after the initial NEC project, further planned site developments necessitated that the NEC be increased in capacity. This involved provision of two further identical boilers installed by removal of the end wall of the NEC to accommodate these boilers, steam manifolds, gas and oil pipework, and controls, after the decision not to pursue the CHP installation due to cost pay back period on equipment being too long.

An additional two 100,000-litre oil storage tanks were installed giving a total storage capacity of 600,000 litres, equating to approximately 5 days peak standby capacity. All six boilers are in-line, and a control room houses the computer systems. Adjacent to the control room are the water treatment tanks and the electrical control switchgear. Located above the control room are the hot well tanks and the water softening plant. Outside the New Energy Centre are the oil storage tanks together with brine tanks, all are installed in a purpose-built bunded area. Six stainless steel 50-metre high boiler flue stacks are symmetrically installed on a steel framework alongside the bunded area.

2.2 Conclusion of a CHP installation at Astra Charnwood

A CHP installation is technically viable but not economic using Astra's financial criteria. Taking this reasoning to a logical conclusion meant that in order to supply steam to meet the needs of the proposed expansion programme, two additional boilers would be required.

The two additional boilers were installed in 1999 and were mothballed in 2003 due to over steam capacity and the site having not grown as predicted by Astra's site expansion programme. With the merger with Zeneca in 2000, the site expansion development programme was revised to take into account that several drugs' patents were coming to the end of their life cycle.

An opinion is that, AstraZeneca should have explored the advantages of CHP knowing that the merger between Astra Pharmaceutical and Zeneca was imminent. With pharmaceutical sites requiring high demand for power and steam, this facility would have supported the other sites' energy demand for electrical power via the National Grid power to feed the other four AstraZeneca sites. In 2001, an AstraZeneca site at Macclesfield in Cheshire, which is of a similar size and capacity to Charnwood site, installed a CHP facility that was programmed to be fully commissioned and in operational use by the end of 2003. This CHP unit is planned to supply all the Macclesfield site's needs with respect to steam and electrical power and is envisaged to support the National Grid at peak demands and making cost savings.

At the time of the study, Astra was not in the business of making revenue by selling power to the National Grid. In addition, Astra did not have any other sites in England requiring the amount of electrical power generated by the CHP unit.

3. Aims

3.1 AstraZeneca Maintenance strategy development.

AstraZeneca Research and Development at Charnwood is a validated and compliant site with respect to the manufacture of the first batch of drugs for clinical trials on man.

This strategy needed to demonstrate to the scientists and the clinical staff that all engineering business critical systems and functions to support the manufacturing process should be capable of repeating the same environmental conditions for the manufacturing process.

A documentation system has been developed to demonstrate that these conditions meet the requirements of regulatory bodies such as the Food and Drug Administration (FDA) and the Medicines and Healthcare Products Regulatory Agency (MHRA). This system has been developed from the pharmaceutical guidelines of Good Laboratory Practice (GLP) and Good Manufacturing Practice (GMP).

This maintenance strategy was developed from the aircraft industry to review critical components, on a detailed maintenance analysis programme, with the effect of reducing maintenance to sustain known performance and to reduce maintenance downtime.

Conducting proactive and effective maintenance required sustaining known performance and reliabilities at minimum cost. This maintenance methodology termed Reliability Centred Maintenance (RCM), was developed by John Moubray (see acknowledgements).

RCM is used to determine systematically and scientifically what must be done to ensure that physical assets continue to operate as required. RCM leads to rapid, sustained, and substantial improvements in plant availability and reliability, product quality, safety and environmental integrity. RCM was used extensively in the aircraft industry to improve all the above attributes. RCM methodology was used to evaluate seven areas of the asset, or

systems under review. For instance, the process of producing steam at the right quantity and the right conditions with respect to pressure, temperature, recovery time, and dryness fraction, without affecting the product by carry-over of chemical treatment into the steam delivery system.

The following gives an overview of this maintenance strategy to provide an insight into the documentation development supporting the contracting outsourcing format deliverables.

Each component of the system is analysed to meet the following criteria: -

- What are the functions and associated performance standards of the asset in its present operating context?
- In which way does it fail to fulfil its functions?
- What causes each functional failure?
- What happens when each failure occurs?
- In which way does each failure matter?
- What can be done to predict or prevent each failure?
- What should be done if a suitable proactive task cannot be found?

Each function is divided into two main categories: -

Primary Functions are the main reason why the asset has been acquired.

Secondary Functions are used to review

- Environmental integrity
- Structural Integrity
- Control, containment, comfort
- Appearance
- Protection

- Economy and efficiency

See attached New Energy Centre RCM analysis in appendix 1.

3.2 Maintenance strategy Conclusion

The old boiler house maintenance regime did not have any planned maintenance activities except the statutory inspection of boilers and pressure testing. This maintenance strategy was on breakdown maintenance only, no preventative maintenance carried out on any critical items of plant. In many cases during the life of the old boiler house, electrical motors and burner equipment failed due to no preventative maintenance activities so the strategy was to store a complete spare of every moving part. This was not only costly but storage and identification of this equipment when needed had problems.

With the development of the NEC we used the RCM techniques to identify potential weak spots in the boiler equipment and developed a route level of preventative maintenance to greatly reduce equipment breakdown. The other advantage of this type of structured maintenance, was that team members who were going to perform these tasks developed the maintenance methods. The other improvements were the level of documentation identifying potential breakdown scenarios and how to restore the engineering system in a structured proactive manner without being in a reactive maintenance situation. A number of other AstraZeneca sites have now reviewed our maintenance strategy and are following in the same mode, another saving for the company as a whole.

3.3 Outsourcing strategy of maintenance activities

The strategy is based upon “Input”, Process,” and “Output” areas, these sections combined into a working maintenance contract.

The “Input” stage consists of technical data on the equipment design performance.

The “Process” stage is the detailed activities to carry out the maintenance tasks to the equipment to the agreed standards to meet the Service Level Agreement (SLA).

The SLA is the high level document that drives out the supporting Reliability Centred Maintenance documentation. The RCM analysis on the New Energy Centre was achieved by structured meetings with engineering teams comprising of designers, manufacturers and maintenance teams, see appendix 1 for RCM of the NEC.

All engineering systems within the NEC were reviewed on their primary functions and their possible ways of failure during their life cycle. Each component of the engineering system was analysed to determine what potential effect it has on the total system during service. The information is invaluable to service and maintenance engineers when attending system breakdowns. From the RCM information job plans were developed, which gave a step-by-step maintenance instruction with reference to supporting documentation for Standard Operating Procedure (SOP), and Work Instructions (WI) that give greater detail than the Job Plans (JP) on how to perform the maintenance task. The top-level document is the SLA that dictates the working tolerances and parameters to which the facility must perform too.

All the above documentation is collated into a Combined Utility Building Environment (CUBE) sheet concept, which lists in spreadsheet format all of the associated documentation to support the job plans.

Based on this data a maintenance contract for the NEC was placed with Wellman Robey. A contract of this magnitude and business criticality has a “quarterly contract” review to monitor the maintenance performance. The following topics are addressed: -

- Maintenance programme is to agreed timescales.

- Any corrective maintenance between maintenance periods and any system breakdowns are reviewed, and if necessary, the RCM for that system is reviewed and any corrective action taken. Any document changes are via a change control procedure and the RCM for that system is reissued.
- Review any optimisation opportunities in reducing task frequencies or replacement of parts.
- Any health and safety issues.
- Training issues.
- Any new legislation covering the installation.
- Budget profile review.

4. Concepts

4.1 Optimisation on maintenance tasks

All six boilers in operation would give the site steam output of 108,000 kg/hr rated at 10 bar pressure to meet the originally predicted site development requirements needed in 2005. AstraZeneca has now temporarily reduced the site development in the light of a number of major drugs completing their patent cycle, to concentrate finances onto drug development, thus reducing the envisaged steam requirements. Various options for “mothballing” two boilers are being considered to retain optimum efficiency, which will also have the knock-on effect of reducing the associated insurance workload.

The engineering team reviewed the maintenance strategy for the NEC, analysing performance data, and developing boiler burner controls efficiency, using engineering techniques such as Condition Based Monitoring (CBM) and Statistical Process Control (SPC) to obtain relevant data, for example, the different firing rates over time to reach the

required temperature and pressure. From the information gathered, it was possible to facilitate slightly increased fan motor speeds to atomise the oil from the burners when running on oil, thus improving the boiler efficiency and leading to improvements in the IPC requirements for this installation with respect to the emission output.

The engineering team is working to extend the maintenance periods on selected equipment which will give estimated cost savings of 20%, with other quarterly interval tasks being extended to four monthly, producing further annual savings of 15%. We have developed a Reliability Centred Maintenance based maintenance strategy for the steam distribution system, with a view to reducing future systems failures. This includes the steam trap sets to return only condensate water along the return condensate pipework system back to the condensate receiver units and eventually back to the boiler house hot well tanks (if steam enters this pipework its energy is wasted).

Innovative projects is in place involving steam ring main configuration, with dual-feed capability and development of the Building Management System programme to "hand shake" steam demands back to the NEC. High load equipment such as steam chillers, autoclaves and steam heating systems are currently being developed, thus ensuring readily available steam capacities to meet any combination of steam demand.

To give the reader an overview of what is involved with the change control of issued documentation covering the current operation of the New Energy Centre, please refer to the attached key task monitor sheet in appendix 1. This details what actions and steps are required to maintain our procedures and contracts, and these are amended in accordance with AstraZeneca change control procedures that are open to external audits from the Environment Agency.

5.0. Conclusion

AstraZeneca has made tremendous improvements to the operational requirement of the boiler house in respect to maintenance, control, monitoring efficiencies, and documentation process for maintenance activities and training compared to the Fisons days. This is the “state-of-the-art” for boiler house management in this industry.

Maybe in hindsight, a CHP system should have been explored in more depth that may have paid for the installation after 8 years running. With these uncertain times of electrical power interruptions, the site would have been more secure and have the ability to export electrical power earning money for the company from the national grid.

At this moment in time, the Senior Management Team is reviewing an option of removing the two-mothballed boilers and installing a CHP unit that would reduce the ever-increasing electrical load for this site. This project may come to fruition in the next 5 years on this site, meanwhile AstraZeneca will gain experience from the CHP unit at the Macclesfield site, only cost, and time will drive this decision.

5.1. Addressing the Engineering challenges

This treatise highlights the successes and the route taken in the “Development of steam generation to meet the needs of a growing pharmaceutical company” within the following areas: -

- a) The system as designed meets the Company’s requirements and steam supply has always been available where required between the developments from the old boiler house to the New Energy Centre. With the reduction of planned development of the site under AstraZeneca, the need for steam has been reduced and two boilers have been mothballed ready for future use.

b) The strategy of assessing the steam requirements across the site was by reviewing the current requirements and the anticipated loads for the future. When the site steam profile was known, the task of selecting a suitable solution out in the marketplace to control and monitor the steam loads and pressure was met by the Valtek valve installation. With its integrated microprocessor that communicated the performance data back to the Shift Engineering Technicians control centre via the BMS link. The advantage of this system is that the steam quantity can be controlled by the Valtek to suit the output from the NEC as necessary. This task is fully addressed with added advantage of monitoring the steam consumption for building and facilities costing purposes.

c) The RCM strategy demonstrates control of all the necessary maintenance activities to maintain the NEC within strict performance criteria to meet the Environment Agency Integrated Pollution Control licence.

The other advantage of this type of documented maintenance is the transparency of optimisation of maintenance tasks if it is noted that there is no failure between maintenance periods. This is demonstrated by increasing the burners and the combustion performance remained within IPC licence. This method can also identify cost savings and support the need to outsource the non-core AstraZeneca engineering activities within the engineering department.

Since construction of the NEC, the Facilities Management department at AstraZeneca have benefited from the following improvements: -

- Unmanned boiler facility, this has allowed the Shift Engineering Technicians team to work on other site utilities, for example, electrical power, water distribution, gases, and Building Management Systems alarms. The Shift Engineering Technicians are the

leading members of the company's "Major Incident Team" to respond to issues across the site with the emergency services.

- Improved transparency with greater control of environmental emissions supported with documentation and training of engineering staff working within the NEC.
- Contracted out non-core maintenance activities to specialist company (Wellman Robey) to maintain and sustain performance of boiler plant with agreed "Key Performance Indicators", for example, planned preventative maintenance versus corrective maintenance costs which are reviewed regularly and continuously improved.
- The documentation supports the requirements to meet audits carried out regularly by the Environment Agency covering emissions, AstraZeneca, ISO 14001, Operator Monitoring Assessment (OMA) and the Climate Change Levy (CCL) which is an energy rebate process that is audited by the Customs and Exercise government department.

6. Appendix 1

New Energy Centre (building 26)

Reliability Centred Maintenance analysis

System 26/025/01

7. Appendix 2

Wellman Robey contract optimisation programme.

8 Appendix 3

The boiler house environmental monitoring procedure “PRO2.0083

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11. Directory of Terms

Abbreviation

NEC	New Energy Centre
RCM	Reliability Centred Maintenance
CHP	Combined Heat and Power
CUBE	Combined Utility Building Environment
EA	Environmental Agency
SCADA	System Control and Data Acquisition
BMS	Building Management System
KPI	Key Performance Indicators
IPC	Integrated Pollution Control
SLA	Service Level Agreement
JP	Job Plan
WI	Work Instruction
SOP	Standard Operating Procedure
PDF	Pharmaceutical Development Facility
PAL	Pharmaceutical Analytical Laboratory
PP3	Pilot Plant number 3 building
LAN	Local Area Network
"PCAnywhere"	Personal Computer anywhere is an access to engineering systems via any computer terminal on site
UPS	Uninterruptible Power Supply
SET	Shift Engineering Technician
DSSR	Donald, Smith, Seymour and Rooley – Engineering Consultants
UKAQS	United Kingdom Air Quality Standards
PM	Plant and Machinery Guidance note

HSE	Health and Safety Executive
FDA	Food and Drug Administration
MHRA	Medicines and Healthcare Products Regulatory Agency
GLP	Good Laboratory Practice
GMP	Good Manufacture Practice
CBM	Condition Based Monitoring
SPC	Statistical Process Control
OMA	Operator Monitoring Assessment
CCL	Climate Change Levy
SHE	Safety Health and Environment

12. Technical Directory

Mechanical

Abbreviation

Kg/hr	Kilogramme per hour
mm	Millimetres
m ³ /s	Volume flow
m ²	Area in metres
m ³ /kg	Specific volume Vg
m/s	Velocity
m/s	Flow velocity μ
Kg/litre	Kilogramme per litre
Ms	Mass flow rate kg/s
Kg/Nm ²	Kilogramme per Newton meter ²

Kpa	1000 Newton per meter ²
Bar	10,000 Newton per meter ²
Mbar	100 Newton per meter ²
Nm	Newton meter
HP	High Pressure
LP	Low Pressure
°C	Degree Celsius
%	Percentage
M	Metre
1 atm (standard atmosphere)	101.325 kilonewton per meter ²
1 at (technical atmosphere)	98.066 kilonewton per meter ²
STP	Standard Temperature Pressure is defined as 288°k or 15°C at 101.325 kPa

Electrical

Abbreviation

V	Volts
Kv	Kilo volts (10 ³ v)
A	Ampere
MA	Milliampres (10 ⁻³ ampres)
VDC	Volts direct current
AC	Alternating Current
Ω	Ohm resistance
Hz	Hertz frequency

MW	Mega Watt (10^6 watts)
Mwe	Mega Watt (electricity)
HV	High Voltage
MCC	Motor Control Centre

Chemistry

Abbreviation

O	Oxygen
O ₂	Dioxide
C	Carbon
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
N	Nitrogen
NO	Nitrogen Monoxide
NO ₂	Nitrogen Dioxide
NO _x	Nitrogen oxides
S	Sulphur
SO	Sulphur Monoxide
SO ₂	Sulphur Dioxide
SO _x	Sulphur oxides

