Energy recovery of waste using incineration process

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Keywords: Energy Recovery Facility, Energy Resource Efficiency, CHP, Operational Issues
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Introduction

In light of the ambitious goals set by the National Waste Management Plan (Ministerial Decision 30 31.8.2020 Government Gazette 185/A 29.09.2020) promoting the development of Energy from Waste plants (EfW), combustion seems the most viable solution for the treatment of residual waste albeit public objections. An opportunity has arisen given the circumstances; including the introduction of the Landfill tax which would make energy recovery cheaper than Landfill disposal, the decarbonization strategy as well as the energy and fuel crisis seeking for renewable energy sources and the goals set by the government to minimise coal usage. This study neither adds any information on optimising operational parameters nor questions the proven and robust operating technological principles of an Energy Recovery Facility (ERF). This report provides an overview of how an ERF operates and highlights various operational issues that need to be considered by the operator.

Discussion

A state of the art EfW with an annual capacity of 400.000 tonnes operating in 2 processing Lines of roughly 25 tonnes/hr has a capital investment cost of roughly 120.000.000[1]. A typical ERF operates approximately 7.800 hours annually circ. 90% availability. To reduce downtimes and operational issues, an Outage period for maintenance activities is scheduled, usually taking place twice per annum with a duration of 2 weeks. The operational cost varies depending on the capacity of the unit due to economies of scale eg 100.000 at per tonne 65, 200.000 at 45 per tonne. The operator on behalf of the waste disposal authority would be overcovering the EfF operational costs including the treatment, maintenance and disposal by the gate fee. Additionally, the operator would have additional sources of profit. The operator would charge the authorities for the electricity that would be exported to the grid ie on the scale of a 400.000 tonnes per annum facilities could be exporting a net electrical power of 34,7 $MWth_{el}$ considering parasitic loads. Additionally as an ERF encompasses a CHP infrastructure the operator would be charging the authorities the steam exported to nearby facilities ie 65 tonnes/hr of Intermediate Pressure steam of 16 bar, 236C or the steam distributed at a lower range to district heating networks. Given the arrangements in place ie the use of vibrating tables, overband magnets or drums the operator could make additional profit secondarily from the metals that could be recovered from the bottom ash fraction. Figure 1 gives an outline of how a typical ERF operates and it’s main stages.

[1] Please, note that all the figures are provided in sterling pounds (£) currency, base year 2013

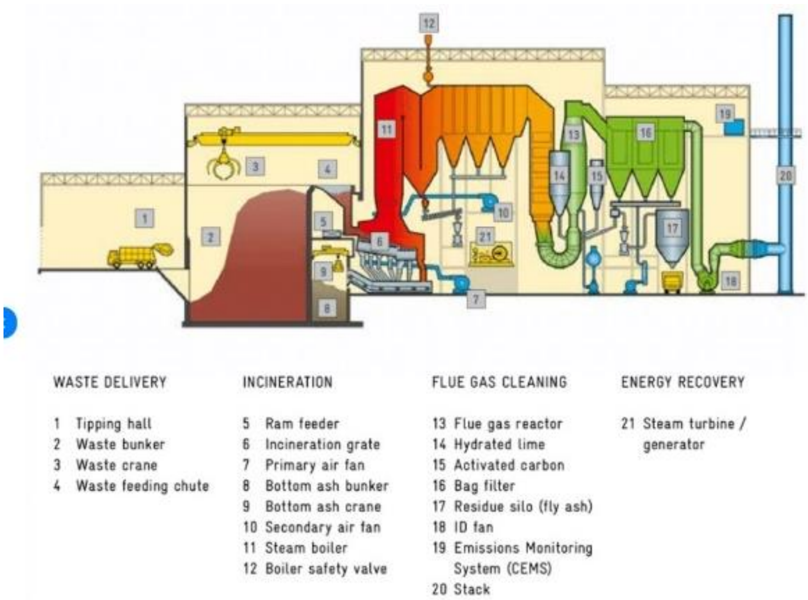
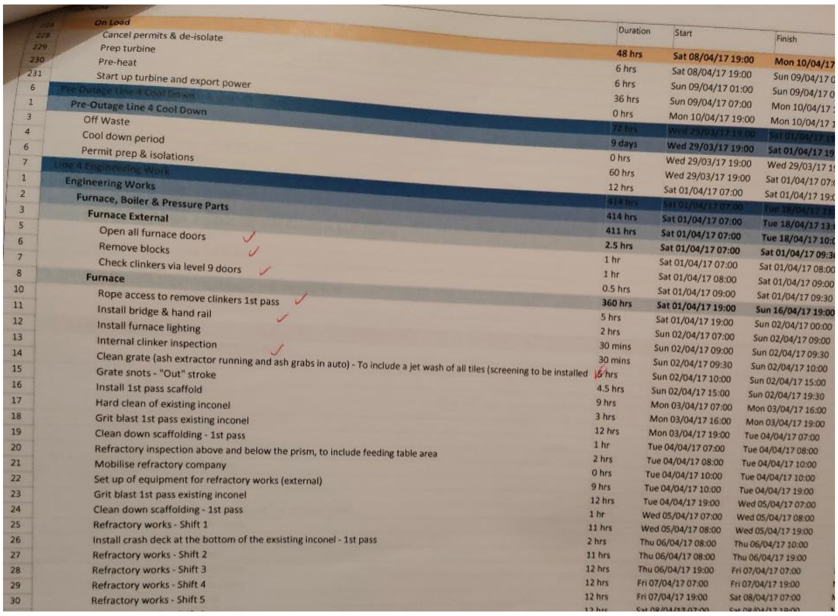


Figure 1 An *overview of the plant operations pointing out the inputs and the outputs of the incineration process. The whole process starts from the Tipping Hall were waste is disposed and fed with cranes to the grate. Flue gas is generated that heats up the water in the boiler. When the saturated steam reaches it's superheated properties in the Superheater section, it is driven to the Turbine and turned to electricity that is exported to the grid as well as heat that is extracted from the Turbine to be utilised via pipework to district heating networks and nearby facilities. Part of the remaining heat is absorbed at the boiler part by the Economiser bundles. The Economiser bundles are cooling down smoothly the flue gas to reach the proper Temperature to enter the FGT setion. In the FGT part the flue gas with a series of chemical addition inside a scrubber and a bag filter it exits the stack. CEMS monitors the flue gas performance to make sure that it is free from harmful contaminants. The ash and APCr are disposed as appropriately. Their disposal is subject to strict monitoring surveilance.*

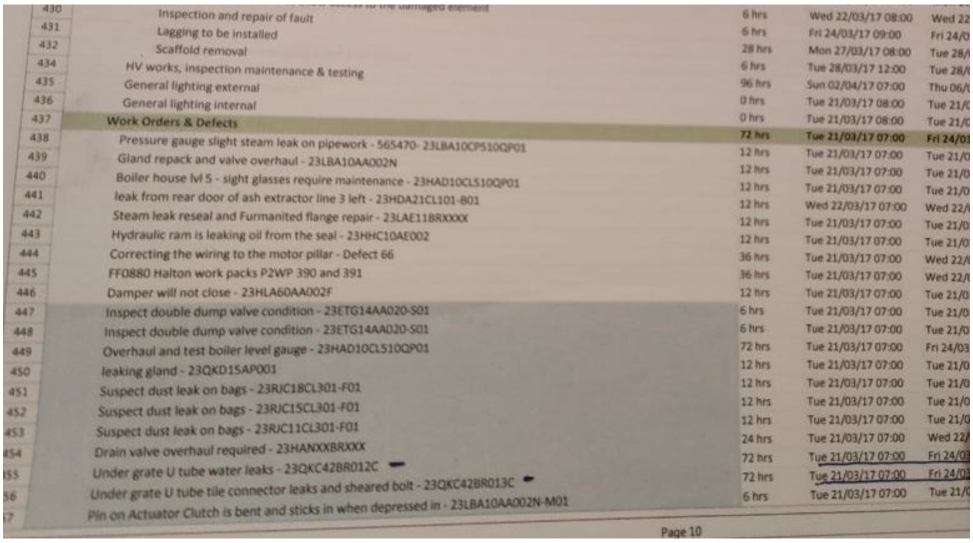
As part of the maintenance activities and the annual maintenance plan, by law there are requirements for periodic inspection and testing of Pressure Equipment by the competent authorities, checks of the steam boiler, expansion valves and so on. Additionally, preventative maintenance shall cover calibration of measuring equipment, regular periodic inspections, e.g. Non Destructive Tests (NDT) and inspections of the heat exchangers part for wear ie measuring the thickness of heat tube exchangers, replacement of refractory materials, regular cleaning of parts ie the boiler, tensioning belts, lubrication of moving parts, filters change and parts of the auxiliary equipment ie lifting beams to be inspected by notified body etc. An overview of the boiler Outage activities is highlighted in Figure 2. Outage covers the Worker Orders that can be conducted as appropriately. The primary objective is to run the plant at the highest availability and offset any downtime costs. These so called Work Orders are presented in Figure 3A.

In addition to preventive maintenance requirements, there are ongoing issues that require continuous monitoring and frequent attention while being online ie treatment of blockages. As part of the plant daily operation routine, the operator must monitor a number of critical issues to ensure maximum availability, energy utilisation and compliance. Therefore, critical parameters have been set to be monitored. Each shift before starting does the necessary checks including plant equipment and by the end of the shift, reports critical issues as part of the shift handover process. Plant performance is tracked on the daily operations report. Figure 3 B depicts a number of issues the operator deals with on a daily basis.



	Task Name	Duration	Start	Finish
226	On Load	48 hrs	Sat 08/04/17 19:00	Mon 10/04/17
228	Cancel permits & de-isolate	6 hrs	Sat 08/04/17 19:00	Sun 09/04/17 0
229	Prep turbine	6 hrs	Sun 09/04/17 01:00	Sun 09/04/17 0
230	Pre-heat	36 hrs	Sun 09/04/17 07:00	Mon 10/04/17
231	Start up turbine and export power	0 hrs	Mon 10/04/17 19:00	Mon 10/04/17 1
6	Pre Outage Line 4 Cool Down	72 hrs	Wed 29/03/17 19:00	Sat 01/04/17 19
1	Pre-Outage Line 4 Cool Down	9 days	Wed 29/03/17 19:00	Sat 01/04/17 19
3	Off Waste	0 hrs	Wed 29/03/17 19:00	Wed 29/03/17 1
4	Cool down period	60 hrs	Wed 29/03/17 19:00	Sat 01/04/17 07
6	Permit prep & isolations	12 hrs	Sat 01/04/17 07:00	Sat 01/04/17 19
7	Line 4 Engineering Work	414 hrs	Sat 01/04/17 07:00	Tue 18/04/17 13
1	Engineering Works	414 hrs	Sat 01/04/17 07:00	Tue 18/04/17 13
2	Furnace, Boiler & Pressure Parts	411 hrs	Sat 01/04/17 07:00	Tue 18/04/17 10
3	Furnace External	2.5 hrs	Sat 01/04/17 07:00	Sat 01/04/17 09:3
5	Open all furnace doors	1 hr	Sat 01/04/17 07:00	Sat 01/04/17 08:00
6	Remove blocks	1 hr	Sat 01/04/17 08:00	Sat 01/04/17 09:00
7	Check clinkers via level 9 doors	0.5 hrs	Sat 01/04/17 09:00	Sat 01/04/17 09:30
8	Furnace	360 hrs	Sat 01/04/17 19:00	Sun 16/04/17 19:00
10	Rope access to remove clinkers 1st pass	5 hrs	Sat 01/04/17 19:00	Sun 02/04/17 00:00
11	Install bridge & hand rail	2 hrs	Sun 02/04/17 07:00	Sun 02/04/17 09:00
12	Install furnace lighting	30 mins	Sun 02/04/17 09:00	Sun 02/04/17 09:30
13	Internal clinker inspection	30 mins	Sun 02/04/17 09:30	Sun 02/04/17 10:00
14	Clean grate (ash extractor running and ash grabs in auto) - To include a jet wash of all tiles (screening to be installed	5 hrs	Sun 02/04/17 10:00	Sun 02/04/17 15:00
15	Grate snots - "Out" stroke	4.5 hrs	Sun 02/04/17 15:00	Sun 02/04/17 19:30
16	Install 1st pass scaffold	9 hrs	Mon 03/04/17 07:00	Mon 03/04/17 16:00
17	Hard clean of existing inconel	3 hrs	Mon 03/04/17 16:00	Mon 03/04/17 19:00
18	Grit blast 1st pass existing inconel	12 hrs	Mon 03/04/17 19:00	Tue 04/04/17 07:00
19	Clean down scaffolding - 1st pass	1 hr	Tue 04/04/17 07:00	Tue 04/04/17 08:00
20	Refractory inspection above and below the prism, to include feeding table area	2 hrs	Tue 04/04/17 08:00	Tue 04/04/17 10:00
21	Mobilise refractory company	0 hrs	Tue 04/04/17 10:00	Tue 04/04/17 10:00
22	Set up of equipment for refractory works (external)	9 hrs	Tue 04/04/17 10:00	Tue 04/04/17 19:00
23	Grit blast 1st pass existing inconel	12 hrs	Tue 04/04/17 19:00	Wed 05/04/17 07:00
24	Clean down scaffolding - 1st pass	1 hr	Wed 05/04/17 07:00	Wed 05/04/17 08:00
25	Refractory works - Shift 1	11 hrs	Wed 05/04/17 08:00	Wed 05/04/17 19:00
26	Install crash deck at the bottom of the exsisting inconel - 1st pass	2 hrs	Thu 06/04/17 08:00	Thu 06/04/17 10:00
27	Refractory works - Shift 2	11 hrs	Thu 06/04/17 08:00	Thu 06/04/17 19:00
28	Refractory works - Shift 3	12 hrs	Thu 06/04/17 19:00	Fri 07/04/17 07:00
29	Refractory works - Shift 4	12 hrs	Fri 07/04/17 07:00	Fri 07/04/17 19:00
30	Refractory works - Shift 5	12 hrs	Fri 07/04/17 19:00	Sat 08/04/17 07:00

Figure 2 *Typical Outage breakdown*



	... access to the damaged element	6 hrs	Wed 22/03/17 08:00	Wed 22
430	Inspection and repair of fault	6 hrs	Fri 24/03/17 09:00	Fri 24/0
431	Lagging to be installed	28 hrs	Mon 27/03/17 08:00	Tue 28/
432	Scaffold removal	6 hrs	Tue 28/03/17 12:00	Tue 28/
434	HV works, inspection maintenance & testing	96 hrs	Sun 02/04/17 07:00	Thu 06/
435	General lighting external	0 hrs	Tue 21/03/17 08:00	Tue 21/
436	General lighting internal	0 hrs	Tue 21/03/17 08:00	Tue 21/
437	Work Orders & Defects	72 hrs	Tue 21/03/17 07:00	Fri 24/03
438	Pressure gauge slight steam leak on pipework - 565470- 23LBA10CP510QP01	12 hrs	Tue 21/03/17 07:00	Tue 21/0
439	Gland repack and valve overhaul - 23LBA10AA002N	12 hrs	Tue 21/03/17 07:00	Tue 21/0
440	Boiler house lvl 5 - sight glasses require maintenance - 23HAD10CL510QP01	12 hrs	Tue 21/03/17 07:00	Tue 21/0
441	leak from rear door of ash extractor line 3 left - 23HDA21CL101-B01	12 hrs	Wed 22/03/17 07:00	Wed 22/
442	Steam leak reseal and Furmanited flange repair - 23LAE11BRXXXX	12 hrs	Tue 21/03/17 07:00	Tue 21/0
443	Hydraulic ram is leaking oil from the seal - 23HHC10AE002	12 hrs	Tue 21/03/17 07:00	Tue 21/0
444	Correcting the wiring to the motor pillar - Defect 66	36 hrs	Tue 21/03/17 07:00	Wed 22/
445	FF0880 Halton work packs P2WP 390 and 391	36 hrs	Tue 21/03/17 07:00	Wed 22/
446	Damper will not close - 23HLA60AA002F	12 hrs	Tue 21/03/17 07:00	Tue 21/0
447	Inspect double dump valve condition - 23ETG14AA020-S01	6 hrs	Tue 21/03/17 07:00	Tue 21/0
448	Inspect double dump valve condition - 23ETG14AA020-S01	6 hrs	Tue 21/03/17 07:00	Tue 21/0
449	Overhaul and test boiler level gauge - 23HAD10CL510QP01	72 hrs	Tue 21/03/17 07:00	Fri 24/03
450	leaking gland - 23QKD15AP001	12 hrs	Tue 21/03/17 07:00	Tue 21/0
451	Suspect dust leak on bags - 23RJC18CL301-F01	12 hrs	Tue 21/03/17 07:00	Tue 21/0
452	Suspect dust leak on bags - 23RJC15CL301-F01	12 hrs	Tue 21/03/17 07:00	Tue 21/0
453	Suspect dust leak on bags - 23RJC11CL301-F01	12 hrs	Tue 21/03/17 07:00	Tue 21/0
454	Drain valve overhaul required - 23HANXXBRXXX	24 hrs	Tue 21/03/17 07:00	Wed 22/
55	Under grate U tube water leaks - 23QKC42BR012C	72 hrs	Tue 21/03/17 07:00	Fri 24/03
56	Under grate U tube tile connector leaks and sheared bolt - 23QKC42BR013C	72 hrs	Tue 21/03/17 07:00	Fri 24/03
7	Pin on Actuator Clutch is bent and sticks in when depressed in - 23LBA10AA002N-M01	6 hrs	Tue 21/03/17 07:00	Tue 21/0

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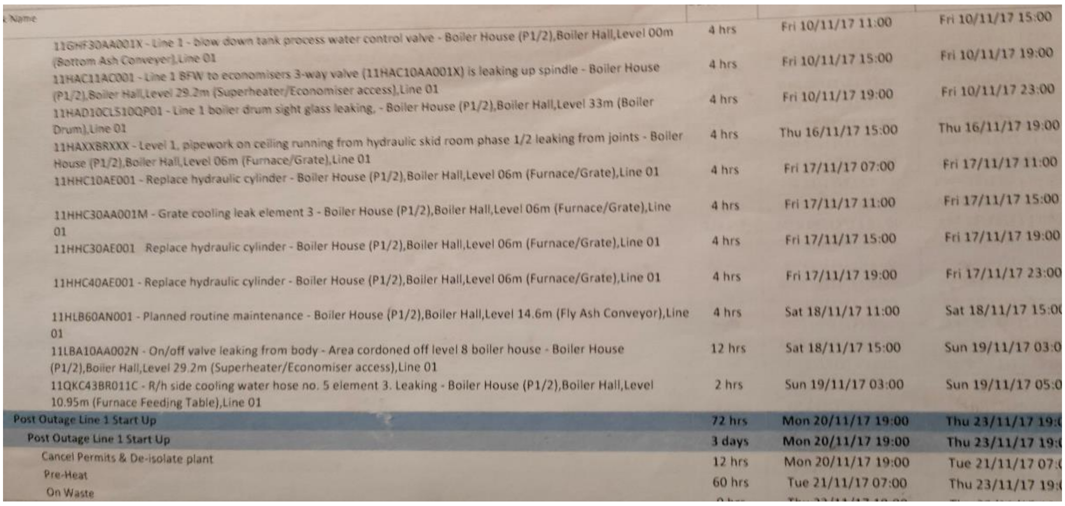
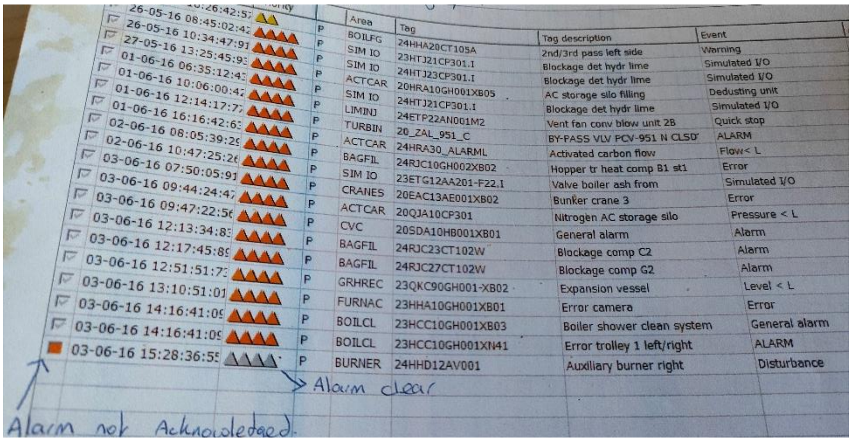


Name			
11GHF30AA001X - Line 1 - blow down tank process water control valve - Boiler House (P1/2),Boiler Hall,Level 00m (Bottom Ash Conveyer),Line 01	4 hrs	Fri 10/11/17 11:00	Fri 10/11/17 15:00
11HAC11AC001 - Line 1 BFW to economisers 3-way valve (11HAC10AA001X) is leaking up spindle - Boiler House (P1/2),Boiler Hall,Level 29.2m (Superheater/Economiser access),Line 01	4 hrs	Fri 10/11/17 15:00	Fri 10/11/17 19:00
11HAD10CL510QP01 - Line 1 boiler drum sight glass leaking. - Boiler House (P1/2),Boiler Hall,Level 33m (Boiler Drum),Line 01	4 hrs	Fri 10/11/17 19:00	Fri 10/11/17 23:00
11HAXXBRXXX - Level 1. pipework on ceiling running from hydraulic skid room phase 1/2 leaking from joints - Boiler House (P1/2),Boiler Hall,Level 06m (Furnace/Grate),Line 01	4 hrs	Thu 16/11/17 15:00	Thu 16/11/17 19:00
11HHC10AE001 - Replace hydraulic cylinder - Boiler House (P1/2),Boiler Hall,Level 06m (Furnace/Grate),Line 01	4 hrs	Fri 17/11/17 07:00	Fri 17/11/17 11:00
11HHC30AA001M - Grate cooling leak element 3 - Boiler House (P1/2),Boiler Hall,Level 06m (Furnace/Grate),Line 01	4 hrs	Fri 17/11/17 11:00	Fri 17/11/17 15:00
11HHC30AE001 Replace hydraulic cylinder - Boiler House (P1/2),Boiler Hall,Level 06m (Furnace/Grate),Line 01	4 hrs	Fri 17/11/17 15:00	Fri 17/11/17 19:00
11HHC40AE001 - Replace hydraulic cylinder - Boiler House (P1/2),Boiler Hall,Level 06m (Furnace/Grate),Line 01	4 hrs	Fri 17/11/17 19:00	Fri 17/11/17 23:00
11HLB60AN001 - Planned routine maintenance - Boiler House (P1/2),Boiler Hall,Level 14.6m (Fly Ash Conveyor),Line 01	4 hrs	Sat 18/11/17 11:00	Sat 18/11/17 15:0
11LBA10AA002N - On/off valve leaking from body - Area cordoned off level 8 boiler house - Boiler House (P1/2),Boiler Hall,Level 29.2m (Superheater/Economiser access),Line 01	12 hrs	Sat 18/11/17 15:00	Sun 19/11/17 03:0
11QKC43BR011C - R/h side cooling water hose no. 5 element 3. Leaking - Boiler House (P1/2),Boiler Hall,Level 10.95m (Furnace Feeding Table),Line 01	2 hrs	Sun 19/11/17 03:00	Sun 19/11/17 05:0
Post Outage Line 1 Start Up	72 hrs	Mon 20/11/17 19:00	Thu 23/11/17 19:
Post Outage Line 1 Start Up	3 days	Mon 20/11/17 19:00	Thu 23/11/17 19:
Cancel Permits & De-isolate plant	12 hrs	Mon 20/11/17 19:00	Tue 21/11/17 07:
Pre-Heat	60 hrs	Tue 21/11/17 07:00	Thu 23/11/17 19:
On Waste			

Figure 3A *Work Orders are executed, defects are rectified, changes are implemented during the Outage as a window of opportunity arises*



		Area	Tag	Tag description	Event
...:26:42:5	P	BOILFG	24HHA20CT105A	2nd/3rd pass left side	Warning
26-05-16 08:45:02:4	P	SIM IO	23HTJ21CP301.I	Blockage det hydr lime	Simulated I/O
26-05-16 10:34:47:9	P	SIM IO	24HTJ23CP301.I	Blockage det hydr lime	Simulated I/O
27-05-16 13:25:45:9	P	ACTCAR	20HRA10GH001XB05	AC storage silo filling	Dedusting unit
01-06-16 06:35:12:4	P	SIM IO	24HTJ21CP301.I	Blockage det hydr lime	Simulated I/O
01-06-16 10:06:00:4	P	LIMINJ	24ETP22AN001M2	Vent fan conv blow unit 2B	Quick stop
01-06-16 12:14:17:7	P	TURBIN	20_ZAL_951_C	BY-PASS VLV PCV-951 N CLSD	ALARM
01-06-16 16:16:42:6	P	ACTCAR	24HRA30_ALARML	Activated carbon flow	Flow< L
02-06-16 08:05:39:2	P	BAGFIL	24RJC10GH002XB02	Hopper tr heat comp B1 st1	Error
02-06-16 10:47:25:2	P	SIM IO	23ETG12AA201-F22.I	Valve boiler ash from	Simulated I/O
03-06-16 07:50:05:9	P	CRANES	20EAC13AE001XB02	Bunker crane 3	Error
03-06-16 09:44:24:4	P	ACTCAR	20QJA10CP301	Nitrogen AC storage silo	Pressure < L
03-06-16 09:47:22:5	P	CVC	20SDA10HB001XB01	General alarm	Alarm
03-06-16 12:13:34:8	P	BAGFIL	24RJC23CT102W	Blockage comp C2	Alarm
03-06-16 12:17:45:8	P	BAGFIL	24RJC27CT102W	Blockage comp G2	Alarm
03-06-16 12:51:51:7	P	GRHREC	23QKC90GH001-XB02	Expansion vessel	Level < L
03-06-16 13:10:51:01	P	FURNAC	23HHA10GH001XB01	Error camera	Error
03-06-16 14:16:41:0	P	BOILCL	23HCC10GH001XB03	Boiler shower clean system	General alarm
03-06-16 14:16:41:0	P	BOILCL	23HCC10GH001XN41	Error trolley 1 left/right	ALARM
03-06-16 15:28:36:5	P	BURNER	24HHD12AV001	Auxiliary burner right	Disturbance

Figure 3B *A number of alarms on the plant's critical parameters been monitoed listed as part of the operator's daily routine*

Training and supervision have been provided by the EPC, however equipment defects and issues could not always be claimed under contracts, as the EPC might prove that these failures are attributed to operational misuse. Although the contractor has provided the operator with the necessary warranties e.g. 40.000 guaranteed hours of operation for a type of heating tubes and the number of critical spare parts required, many times wear resulting from omissions or failures by the operator, e.g. not properly monitoring the demineralised water, ineffective cleaning of soot deposits etc. can halve lifespan of tubes. An indicative part of a critical spares inventory list is given in Figure 4 considering the spares consumption and lead times.

Lifetime of tubes at elevated temperatures is reduced exponentially and relatively to the Temperature drifting, resulting in thinning of tubes which has a knock on effect on the steam boiler and on plant operations. Frequent breakdowns in the feeding system ie failure of the cranes can hinder the grate supply. The level of water in the Boiler Drum could cause operational issues. The non-calibration of measuring equipment could lead to operational parameters drifting and major operational control issues. The damage of the cooling system in a water-cooled grate could cause the fast reduction of the grate tiles lifespan. The ineffectiveness of boiler cleaning e.g. insufficient Pressure on rapping gear system in the heat exchangers section, or the interruption of cleaning flow on the shower cleaning system, could lead to fouling, transfer heat inefficiencies, thinning and wear to the heat exchanger tubes. The deficient monitoring of water quality could cause scale, deposition attack, scabbing, pitting and cracks to the tubes and other parts of the plant by carry over. Auxiliary Burners failure, the non-calibration of the Continuous Emissions Monitoring System (CEMS), the incorrect supply of chemicals ie NH3 solution or failure of equipment ie SNCR supply, may result in abnormal operation and could result in environmental fines. Figures 5, 5A till K illustrate a number of critical issues that must be monitored regularly.

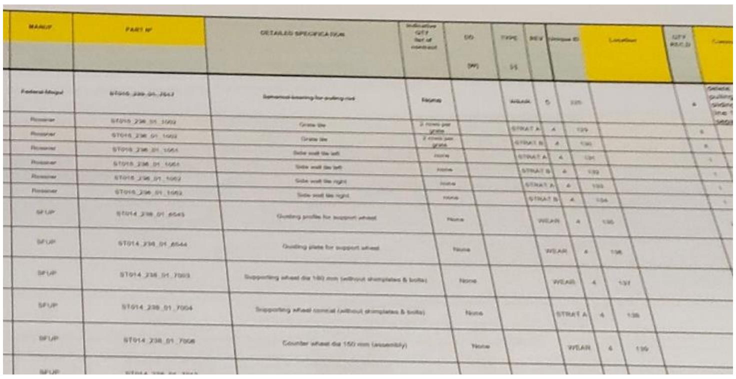


Figure 4 *Part of the critical spares list inventory supplied by the EPC which is monitored by the operator considering the spares consumption and lead time*

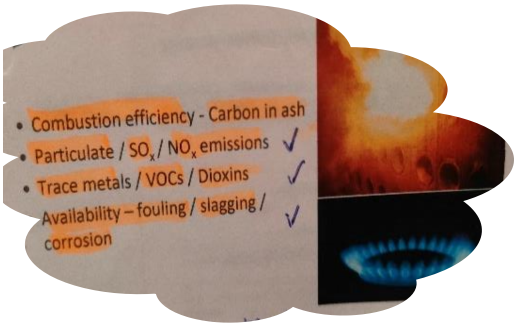


Figure 5 *Indicative key operational parameters which must be monitored*

Figure 5A *Waste cranes operation might be hindered as a result of stresses generated by the crane's movement at different angles and the diverse nature of waste composition leading to failures*

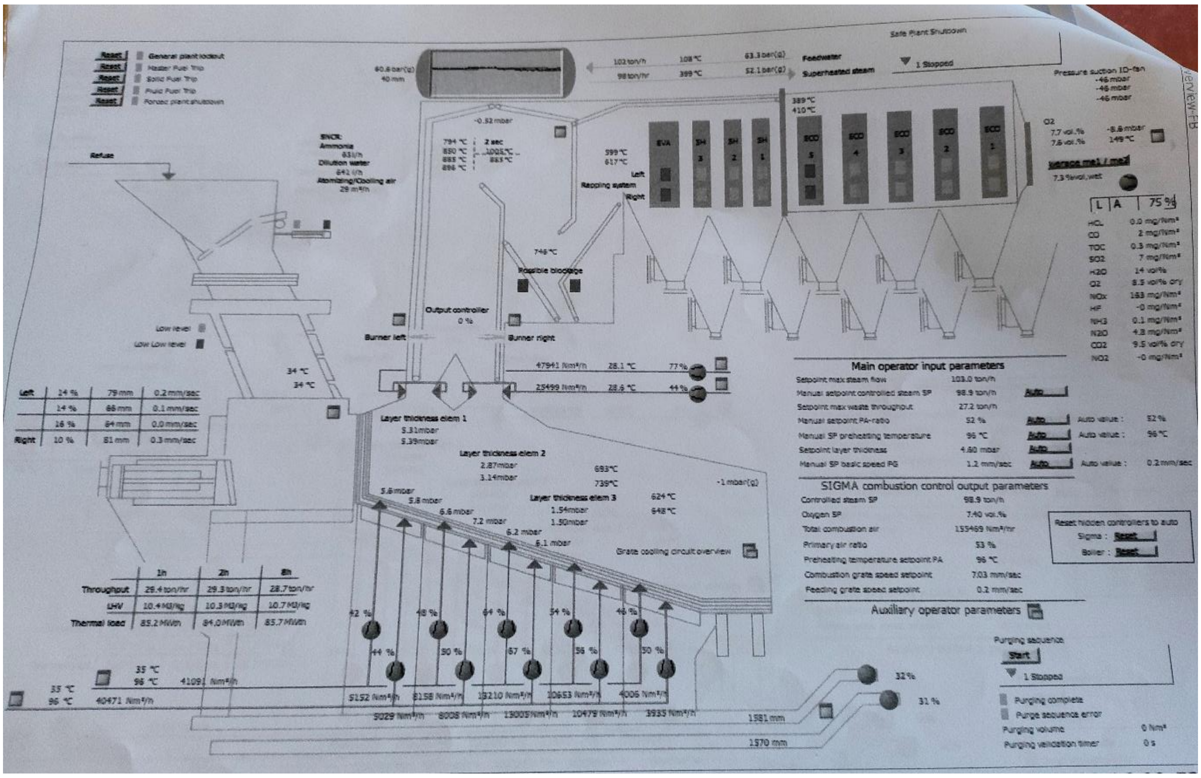


Figure 5B *DCS screen of the Furnace and Boiler section indicating critical operational parameters including the waste throughput, the Calorific Value, the waste layer of thickness, the Primary and Secondary Air, Temperature probes monitoring the 2 seconds combustion compliance, the Boiler Drum Level etc.*

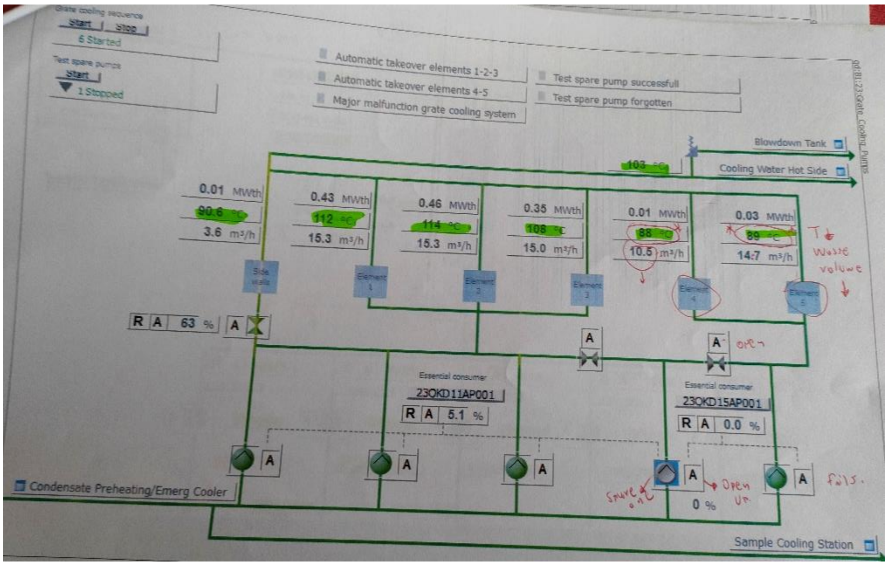


Figure 5C *DCS screen of grate cooling system*

Figure 5D *DCS extracted graph indicating the corelation between Calorific Value the orange line, waste throughput the blue line and HP steam production the green line*

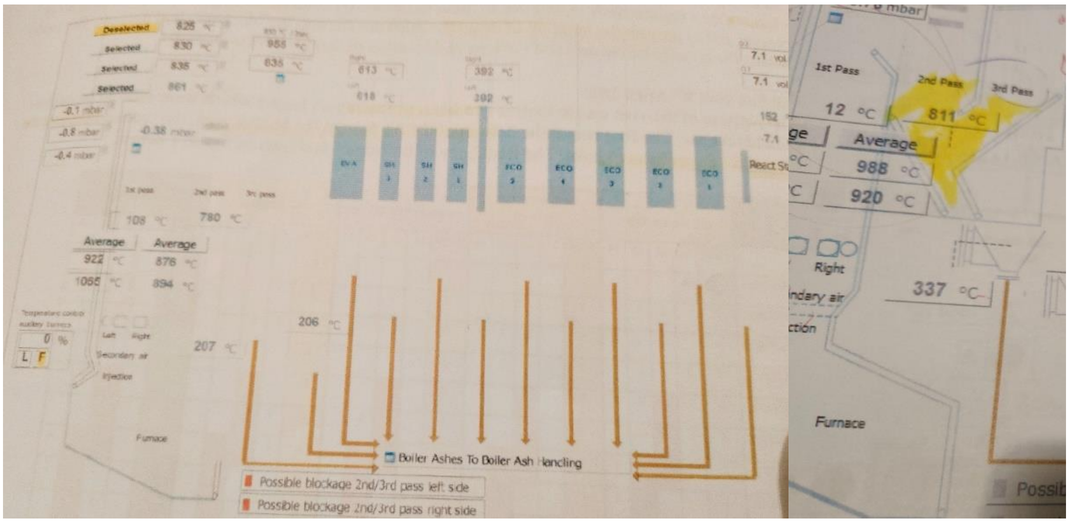


Figure 5E *DCS screen on the Boiler side highlighting the 2nd and 3rd pass narrow passage*

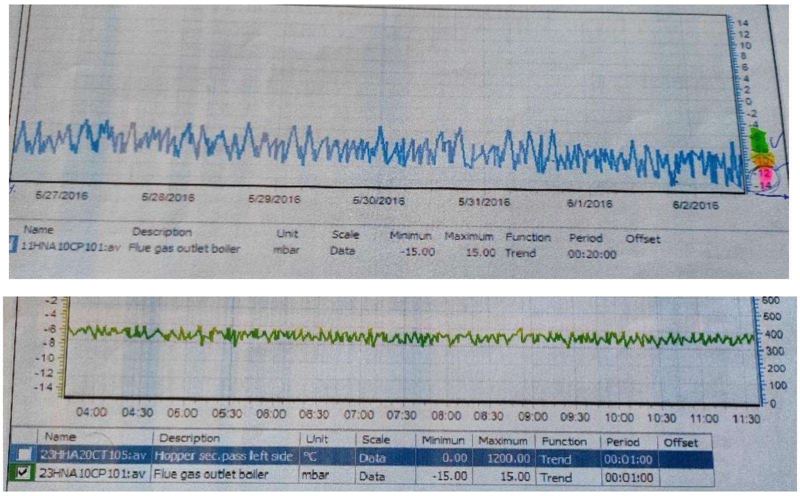


Figure 5F *DCS extracted graphs of flue gas path monitoring. The optimal operational range lies within -6 to -8 mbar*

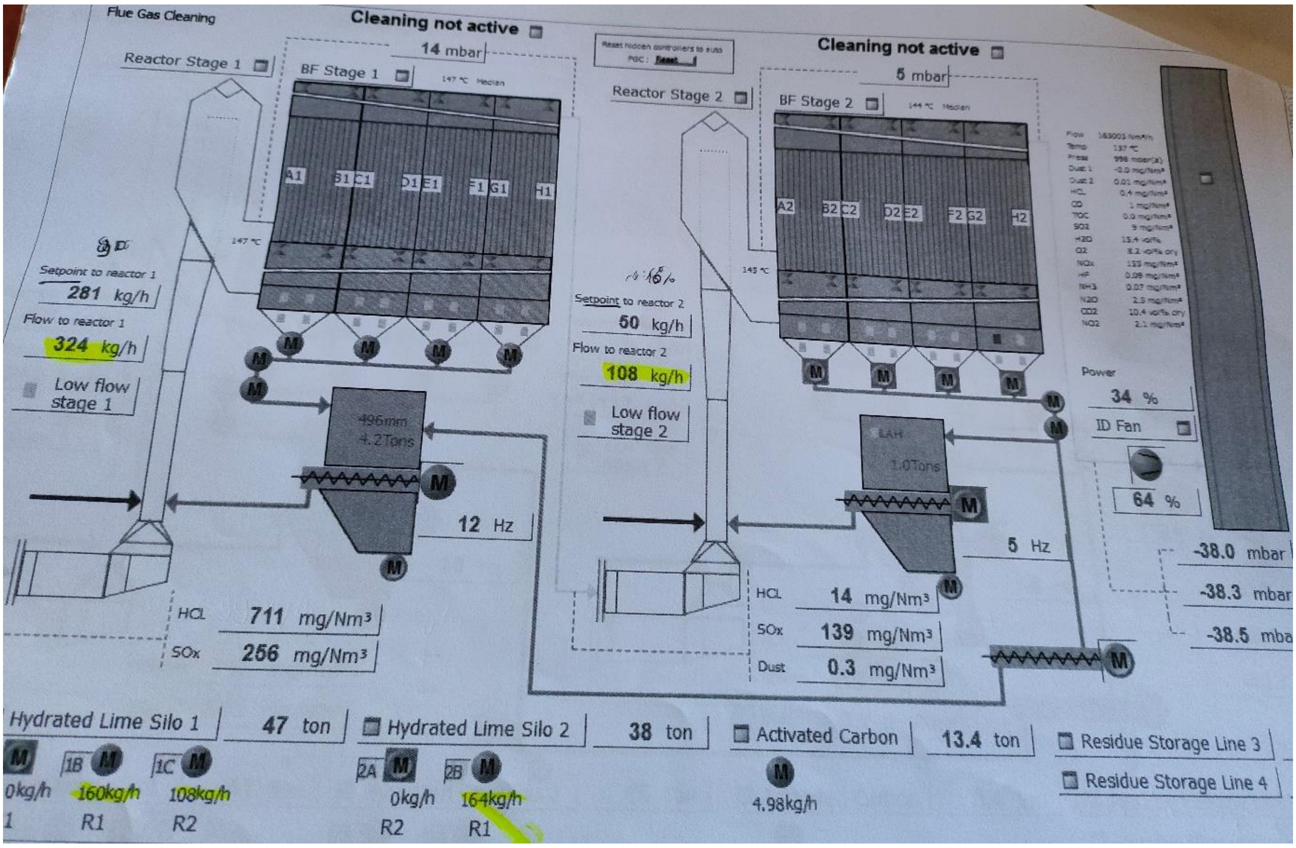


Figure 5G *DCS layout monitoring the FGT section*

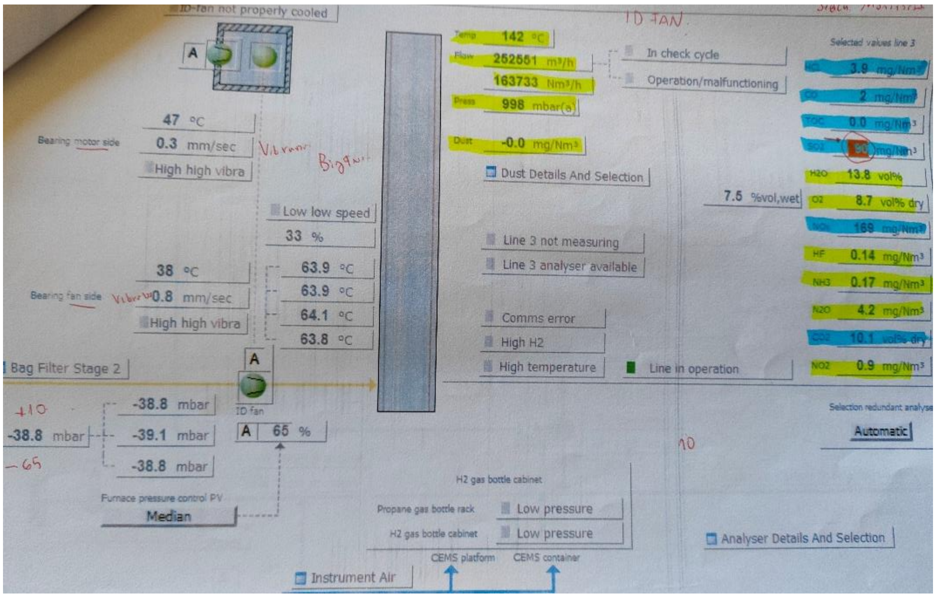


Figure 5H *DCS layout monitoring ID Fan and emissions monitoring system*

Figure 5I *Boiler Drum Level Indicator*

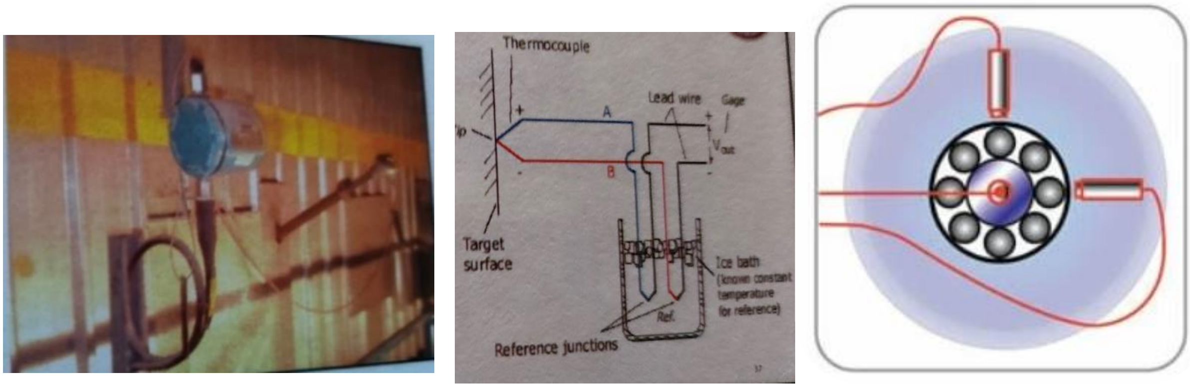


Figure 5 J1 *Measuring equipment and condition monitoring techniques been used*

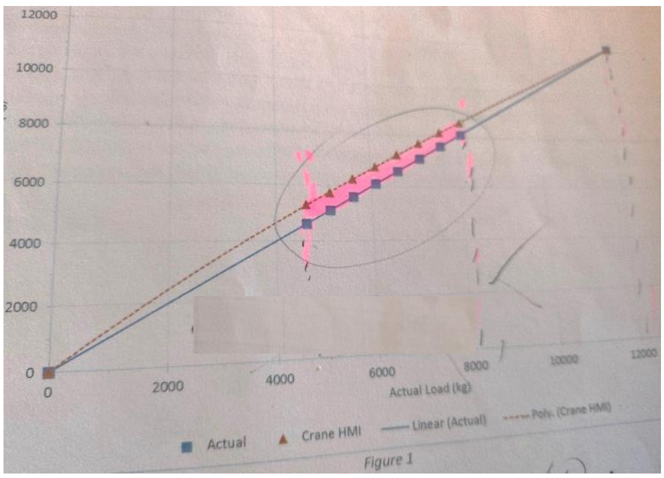
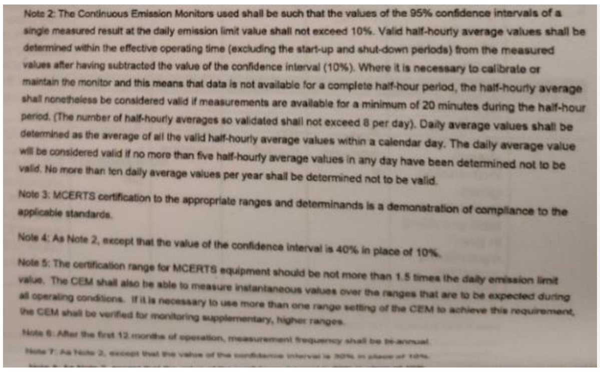


Figure 5 J2 Waste Cranes *load cells quarter callibration* regime *against calibrated weighbridge carried out with the use of load tests. Calibration results to be plotted to monitor inconsistencies of drifting between the DCS values and the actual operating envelope*


Note 2: The Continuous Emission Monitors used shall be such that the values of the 95% confidence intervals of a single measured result at the daily emission limit value shall not exceed 10%. Valid half-hourly average values shall be determined within the effective operating time (excluding the start-up and shut-down periods) from the measured values after having subtracted the value of the confidence interval (10%). Where it is necessary to calibrate or maintain the monitor and this means that data is not available for a complete half-hour period, the half-hourly average shall nonetheless be considered valid if measurements are available for a minimum of 20 minutes during the half-hour period. (The number of half-hourly averages so validated shall not exceed 8 per day). Daily average values shall be determined as the average of all the valid half-hourly average values within a calendar day. The daily average value will be considered valid if no more than five half-hourly average values in any day have been determined not to be valid. No more than ten daily average values per year shall be determined not to be valid.

Note 3: MCERTS certification to the appropriate ranges and determinands is a demonstration of compliance to the applicable standards.

Note 4: As Note 2, except that the value of the confidence interval is 40% in place of 10%.

Note 5: The certification range for MCERTS equipment should be not more than 1.5 times the daily emission limit value. The CEM shall also be able to measure instantaneous values over the ranges that are to be expected during all operating conditions. If it is necessary to use more than one range setting of the CEM to achieve this requirement, the CEM shall be verified for monitoring supplementary, higher ranges.

Note 6: After the first 12 months of operation, measurement frequency shall be bi-annual.

Note 7: As Note 2, except that the value of the confidence interval is 30% in place of 10%.

Figure 5K *Continuous Emissions Monitoring System (CEMS) working principle and requirements against EN 14181*

The purpose of the EfWs following the waste hierarchy is to recover the non recyclable waste which would otherwise been driven to Landfill for subsequent disposal. Although incentives are given for the use of recyclates as a raw material to Producers converting recyclates into new materials thereby reducing the usage of virgin raw materials including plastics, there can be issues and unforeseeable events that pose challenges. In a constantly changing and highly adaptive market with many drivers affecting the supply chain ie prices, purity protocols, China waste Ban policy effect etc. it is not always possible for the Producers to use all the recyclates as a raw material and as a result would create recyclate streams disposed to Landfill. Based on the legal framework under the extended producer's responsibilities obligation system the use of energy recovery can be used complimentary for the waste fraction that cannot be recycled based on the Article 10 of the Waste Framework Directive 2008/98/EC.

Primarily non-hazardous Municipal Solid Waste (MSW) and similar waste may be fed to the incinerator. The grate type that has predominantly been used, is the moving grate technology one. It's widespread application relies on the robust design and it's technological advanced features. The moving grate has been built in a manner that allows the feeding of unprocessed waste. The untreated waste offers in theory several benefits including the avoidance of treatment costs and the processing of a wider range of feedstock. By doing so, the operator is provided with more benefits and flexibility however, there is a number of limitations that shall be considered. By the diverse nature of the treating waste and the incineration practice, combustion could create several issues to mechanical equipment, frequent blockages, unstable operation due to inhomogeneous calorific value, non-combustible materials coming of the bottom ash, while they could also create pollution problems. Waste that by its state is non hazardous ie plastics a predominant type of non hazardous waste that is common in the refuge which offers a good heating value, during the burning process it releases harmful pollutants such as high Cl, S emissions. Figure 6 indicates the different combustion Temperature range of the various waste feedstock used as well as the associated formation of hazardous flue gas contaminants and treatment.

The recovered biodried RDF or certified SRF gives more confidence to the operator as it follows a standard regime which requires routine sampling procedures and monitoring laboratory analysis based on Ministerial Decision 56366/4351/2014, Government Gazette 3339/B` 12.12.2014. By doing so the feedstock is certified for it's performance on low moisture, ash percentages, suitable calorific value, low impurities ie Cl, Hg etc. To avoid operational issues, the Environmental Permit sets among other things, a list of accepted materials under the European Waste Catalogue (EWC) which can be treated. Under the Environmental Permit the operator shall demonstrate compliance by having strict protocols in place for accepting and dealing with non-conforming waste, carrying out regular sampling and monitoring analysis to assess compliance with their outputs including ash and emissions. Figures 7 A till D lists critical parameters of environmental compliance as instructed by the Environmental Permit.

When the waste arrives at the facility either by rail or road it is transported to the Tipping hall by vehicles taking into account transportation costs. The Tipping Hall is normally enclosed with Roller Shutter Doors to minimise nuisances while the air from the waste bunker is extracted for its use as a secondary air in the combustion process. The Tipping Hall encompasses a Traffic management system for the smooth operation of waste tipping. The disposed waste contained within the waste bunker gets mixed by the use cranes in a way that feedstock is homogenized for subsequent feeding to the chutes. Thereby, waste is fed to the moving grate with the aid of the feeding table. Figures 8 A till F highlights various parts and stages of the waste treatment process. The cranes as well as other critical parts of the plant are spares, redundant on standby mode to ensure the stable and uninterrupted plant operation in case of a failure. Figure 9 presents the master and slave function of SNCR, which is a critical part of the Boiler for the NOx abatement.

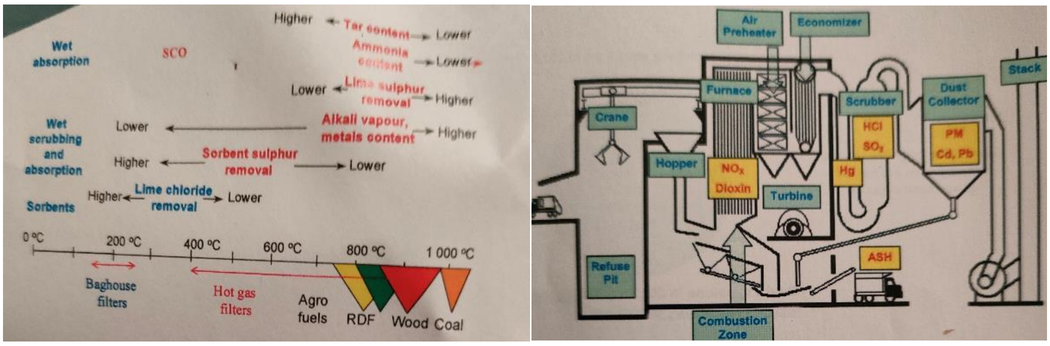
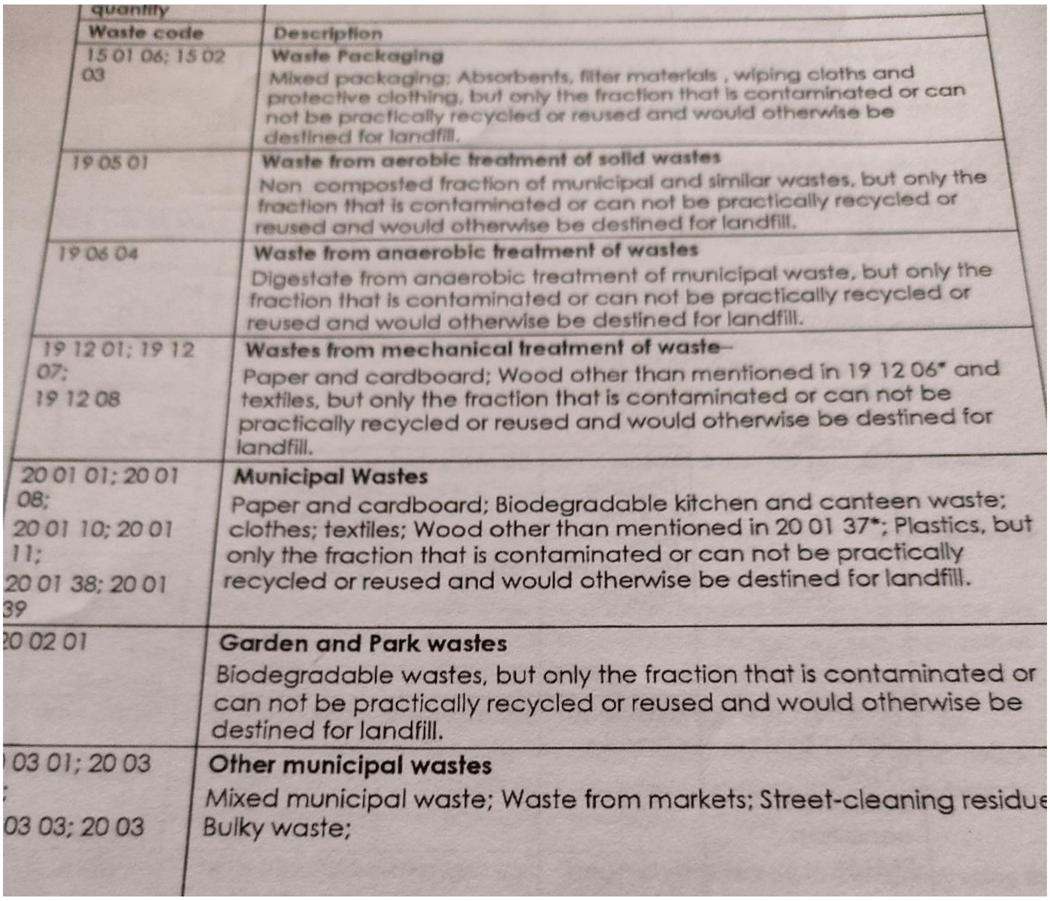


Figure 6 *Range of various feedstock combusted at different Temperatures, hazardous pollutants generated at different stages of the plant and treatment technologies*



Waste code	Description
15 01 06; 15 02 03	**Waste Packaging** Mixed packaging; Absorbents, filter materials , wiping cloths and protective clothing, but only the fraction that is contaminated or can not be practically recycled or reused and would otherwise be destined for landfill.
19 05 01	**Waste from aerobic treatment of solid wastes** Non composted fraction of municipal and similar wastes, but only the fraction that is contaminated or can not be practically recycled or reused and would otherwise be destined for landfill.
19 06 04	**Waste from anaerobic treatment of wastes** Digestate from anaerobic treatment of municipal waste, but only the fraction that is contaminated or can not be practically recycled or reused and would otherwise be destined for landfill.
19 12 01; 19 12 07; 19 12 08	**Wastes from mechanical treatment of waste** Paper and cardboard; Wood other than mentioned in 19 12 06* and textiles, but only the fraction that is contaminated or can not be practically recycled or reused and would otherwise be destined for landfill.
20 01 01; 20 01 08; 20 01 10; 20 01 11; 20 01 38; 20 01 39	**Municipal Wastes** Paper and cardboard; Biodegradable kitchen and canteen waste; clothes; textiles; Wood other than mentioned in 20 01 37*; Plastics, but only the fraction that is contaminated or can not be practically recycled or reused and would otherwise be destined for landfill.
20 02 01	**Garden and Park wastes** Biodegradable wastes, but only the fraction that is contaminated or can not be practically recycled or reused and would otherwise be destined for landfill.
03 01; 20 03 ; 03 03; 20 03	**Other municipal wastes** Mixed municipal waste; Waste from markets; Street-cleaning residue Bulky waste;

Figure 7 A *List of acceptable waste indicated by the Environmental Permit including RDF and other waste fractions and other waste fractions ie digestate. Additional measures shall apply ie for the fractions contained in the mixed MSW under Chapter 20 of the EWC which might pose operational hazards. An example might be the bulkies which would require additional treatment such as shredding.*

Schedule 5 - Reporting

Parameters, for which reports shall be made, in accordance with conditions of this permit, are listed below.

Table S5.1 Reporting of monitoring data

Parameter	Emission or monitoring point/reference	Reporting period	Period begins
Continuously monitored emissions to air of SO_2, total organic carbon, NOx, HCl, particulate, CO and NH_3 - continuous monitoring as required by condition 3.6.1.	A1 [(point A1 on plan provided in pre-operational condition PM16)	Every 3 months	From the first date that waste is burned in the installation
Extractively sampled emissions to air of SO_2, total organic carbon, NOx, HCl, particulate and CO, periodic monitoring as required by condition 3.6.1.		Every 6 months	From the first date that waste is burned in the installation
Emissions to air of HF, N_2O, Cd/Tl, Hg, Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V and their compounds (total), dioxins/ furans (I-TEQ), dioxin-like PCBs (WHO-TEQ Humans/ Mammals), dioxin-like PCBs (WHO-TEQ Fish), dioxin-like PCBs (WHO-TEQ Birds), specific individual poly-cyclic aromatic hydrocarbons (PAHs), dioxins/furans (WHO-TEQ Humans/Mammals), dioxins/furans (WHO-TEQ Fish), dioxins/furans (WHO-TEQ Birds) periodic monitoring as required by condition 3.6.1.		Every 3 months for the first year of operation, and every 6 months thereafter.	From the first date that waste is burned in the installation
Exhaust gas temperature, pressure, oxygen content, water content and flowrate, continuous monitoring as required by condition 3.6.1		As requested by Agency site inspector. See Note 1.	From the first date that waste is burned in the installation
Furnace chamber temperature continuous monitoring as required by condition 3.6.1	Furnace PCC	As requested by Agency site inspector. See Note 1.	From the first date that waste is burned in the installation
Wind speed and direction continuous monitoring as required by condition 3.6.1	Installation	As requested by Agency site inspector. See Note 1.	From the first date that waste is burned in the installation
LOI of bottom ash as required by condition 3.6.1	Bottom Ash	Monthly for the first year of operation, and quarterly thereafter.	From the first date that waste is burned in the

Figure 7 B *Environmental monitoring parameters under the Environmental Permit*

Table S1.4 Pre-operational measures

Reference	Pre-operational measures
PM1	From the date of issue of this permit, the operator shall provide the Agency with a report every 6 months outlining the progress with the planned building of the installation. The report shall include but not be limited to, status of the existing waste transfer station, demolition and land remediation at the site and time frames for the introduction of key building works and plant infrastructure.
PM2	At least 3 months before any furnace operation, the Operator shall provide the Environment Agency with a written Commissioning Plan and timetable for the commissioning process, including plant trials, monitoring protocols and how combustion conditions will be verified to meet the requirements of Article 11(3) of WID. The plan should also detail the actions that will be taken to ensure that permit conditions and the requirements of the Waste Incineration Directive (WID) can be achieved under all anticipated operating conditions. The plan shall be implemented in accordance with the written approval of the Environment Agency.
PM3	At least 3 months before any furnace operation, a written report shall be submitted to the Environment Agency describing the arrangements for continuous and periodic monitoring of emissions to air with regards to Technical Guidance Notes M1 and M2. The report shall include the following: • plant and equipment details, including accreditation to MCERTS • methods and standards for sampling and analysis of all substances controlled by the Waste Incineration Directive plus continuous monitoring of NH^3 and periodic monitoring of N_2O • monitoring locations, access and working platforms. The plan shall be implemented in accordance with the written approval of the Environment Agency.
PM4	At least 3 months prior to commissioning the operator shall submit a written plan to the Environment Agency describing a detailed programme for the monitoring of metals, dioxins/furans, PAH's and dioxin like PCB's in the soils in the vicinity of the installation. The plan shall include but not be limited to • a baseline soil survey prior to commencement of the incineration of waste • sampling locations having regard to the receptors identified in the application • the frequency and duration of the monitoring programme • sampling methodology and analytical techniques The plan shall be implemented in accordance with the written approval of the Environment Agency.
PM5	At least 3 months prior to commissioning (but after cessation of the existing permitted activities at the site), the operator shall undertake a noise survey to establish background noise levels in accordance with BS 4142. A report recording the findings of the survey shall submitted to the Environment Agency for approval within 2 months of carrying out the survey.
PM6	At least six months prior to commissioning of the incineration plant, the operator shall submit a written report to the Environment Agency identifying the choice of alkaline reagent to be used for acid gas abatement. The report shall provide details of the reagent injection system and the associated design of the bag filter abatement system that enables acid gases to be controlled. The findings of the report shall be implemented into the plant design and construction in
PM7	At least 3 months prior to the incineration of municipal waste, the Operator shall submit a written plan to the Environment Agency describing the detailed ash sampling protocol that will be used for FGT residue and bottom ash monitoring, in conformance to Agency Guidance. The plan shall be implemented in accordance with the written approval of the Environment Agency.
PM8	At least 3 months prior to the incineration of municipal waste, the Operator shall submit a written plan to the Environment Agency that defines noise surveys that shall be undertaken to establish noise levels during operation of the plant when thermally treating waste. The surveys shall be in accordance with BS 4142 and a report shall be submitted to the Agency within 1 month of carrying out the surveys. The plan shall be implemented in accordance with the written approval of the Agency, and a report of the findings of the initial survey submitted to the Agency within 3 months of the commencement of burning waste. The report shall include proposals to eliminate any significant adverse impacts identified from the survey, and these proposals shall be implemented within 3 months of the report being submitted to the Agency.
PM9	At least two months prior to commissioning the Operator shall submit an additional site report for the installation. This report shall include, but not be limited to, • reference data characterising land condition within the installation prior to operations and with reference to previous activities at the site and any land remediation measures associated with cessation of the previous activities • a detailed site drainage plan and description of finalised drainage arrangements • a revised table D2 (as given in the guidance H7) recording a containment and integrity assessment for all installed liquid storage facilities and infrastructure • an integrity assessment for all installed subsurface structures.
PM10	At least six months before commissioning, the operator shall submit an updated site accident management plan to the Environment Agency for approval. The plan shall be in accordance with the requirements set out in Section 2.8 of Sector Guidance Note IPPC S5.01.
PM11	At least six months prior to commissioning, the operator shall submit a flood management plan for the installation that shall include but not be limited to the trigger level for flooding, which requires the site to be shut down and the measures in place to ensure relevant equipment is protected from flood waters. The flood management plan shall be approved by the Agency.
PM 12	On completion of commissioning of the incineration and electrical generation plant, the operator shall provide a report to demonstrate whether all components are fully operational and in accordance with design. The report shall include details of process parameter measuring devices and their calibration, including those for oxygen and temperature measurement within the combustion chambers. The report shall be submitted to the Environment Agency for approval, before the installation is brought into continuous operation. .
PM13	At least six months prior to commissioning of the plant, the operator shall have in place a documented management system that reflects the requirements of the PPC permit. The Operator shall submit an updated EPOPRA assessment.
PM14	At least two months prior to incineration of waste, the Operator shall

Figure 7 C *Pre Operational conditions set under the Environmental Permit*

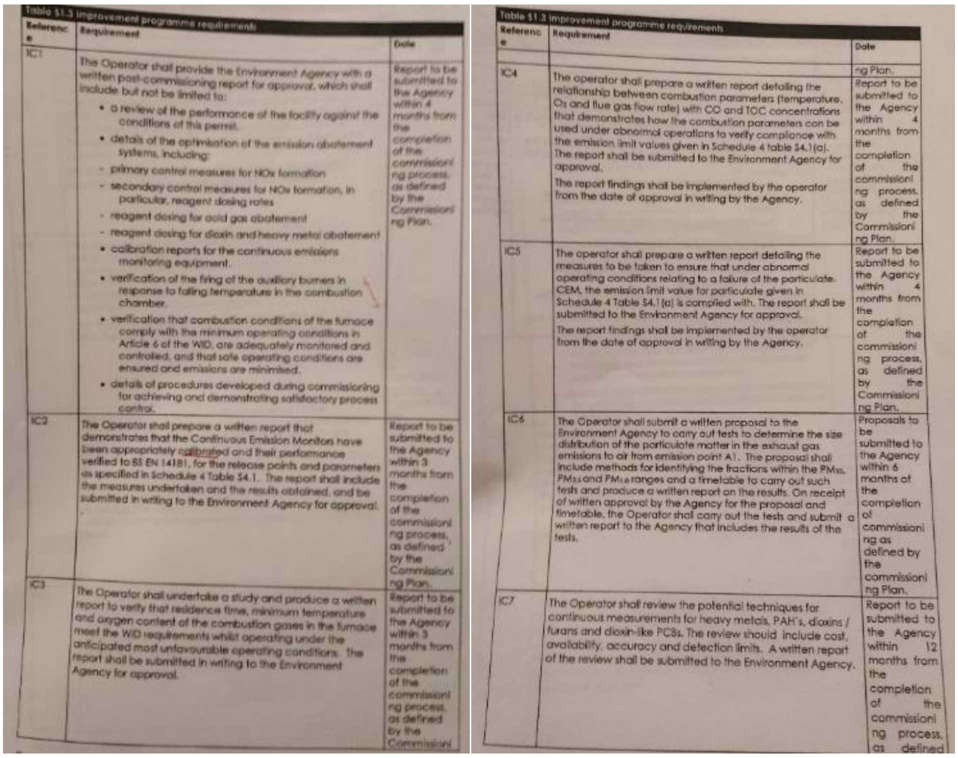


Table S1.3 Improvement programme requirements

Reference	Requirement	Date
IC1	The Operator shall provide the Environment Agency with a written post-commissioning report for approval, which shall include but not be limited to: • a review of the performance of the facility against the conditions of this permit. • details of the optimisation of the emission abatement systems, including: - primary control measures for NOx formation - secondary control measures for NOx formation, in particular, reagent dosing rates - reagent dosing for acid gas abatement - reagent dosing for dioxin and heavy metal abatement • calibration reports for the continuous emissions monitoring equipment. • verification of the firing of the auxiliary burners in response to falling temperature in the combustion chamber. • verification that combustion conditions of the furnace comply with the minimum operating conditions in Article 6 of the WID, are adequately monitored and controlled, and that safe operating conditions are ensured and emissions are minimised. • details of procedures developed during commissioning for achieving and demonstrating satisfactory process control.	Report to be submitted to the Agency within 4 months from the completion of the commissioning process, as defined by the Commissioning Plan.
IC2	The Operator shall prepare a written report that demonstrates that the Continuous Emission Monitors have been appropriately calibrated and their performance verified to BS EN 14181, for the release points and parameters as specified in Schedule 4 Table S4.1. The report shall include the measures undertaken and the results obtained, and be submitted in writing to the Environment Agency for approval.	Report to be submitted to the Agency within 3 months from the completion of the commissioning process, as defined by the Commissioning Plan.
IC3	The Operator shall undertake a study and produce a written report to verify that residence time, minimum temperature and oxygen content of the combustion gases in the furnace meet the WID requirements whilst operating under the anticipated most unfavourable operating conditions. The report shall be submitted in writing to the Environment Agency for approval.	Report to be submitted to the Agency within 3 months from the completion of the commissioning process, as defined by the Commissioni
		ng Plan.
IC4	The operator shall prepare a written report detailing the relationship between combustion parameters (temperature, O_2 and flue gas flow rate) with CO and TOC concentrations that demonstrates how the combustion parameters can be used under abnormal operations to verify compliance with the emission limit values given in Schedule 4 table S4.1(a). The report shall be submitted to the Environment Agency for approval. The report findings shall be implemented by the operator from the date of approval in writing by the Agency.	Report to be submitted to the Agency within 4 months from the completion of the commissioning process, as defined by the Commissioning Plan.
IC5	The operator shall prepare a written report detailing the measures to be taken to ensure that under abnormal operating conditions relating to a failure of the particulate CEM, the emission limit value for particulate given in Schedule 4 Table S4.1(a) is complied with. The report shall be submitted to the Environment Agency for approval. The report findings shall be implemented by the operator from the date of approval in writing by the Agency.	Report to be submitted to the Agency within 4 months from the completion of the commissioning process, as defined by the Commissioning Plan.
IC6	The Operator shall submit a written proposal to the Environment Agency to carry out tests to determine the size distribution of the particulate matter in the exhaust gas emissions to air from emission point A1. The proposal shall include methods for identifying the fractions within the PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ ranges and a timetable to carry out such tests and produce a written report on the results. On receipt of written approval by the Agency for the proposal and timetable, the Operator shall carry out the tests and submit a written report to the Agency that includes the results of the tests.	Proposals to be submitted to the Agency within 6 months of the completion of commissioning as defined by the commissioning Plan.
IC7	The Operator shall review the potential techniques for continuous measurements for heavy metals, PAH's, dioxins / furans and dioxin-like PCBs. The review should include cost, availability, accuracy and detection limits. A written report of the review shall be submitted to the Environment Agency.	Report to be submitted to the Agency within 12 months from the completion of the commissioning process, as defined

Figure 7 D *Improvement Conditions set under the Environmental Permit*.

Figure 8A *A view inside the Tipping hall area encompassing a Traffic Management System linked to appropriate unloading bays with raised kerbs. The unloading of waste is assisted by the traffic controller system thereby instructing drivers when and where to unload waste. Vehicles are directed to the appropriate bay using traffic light indicators.*

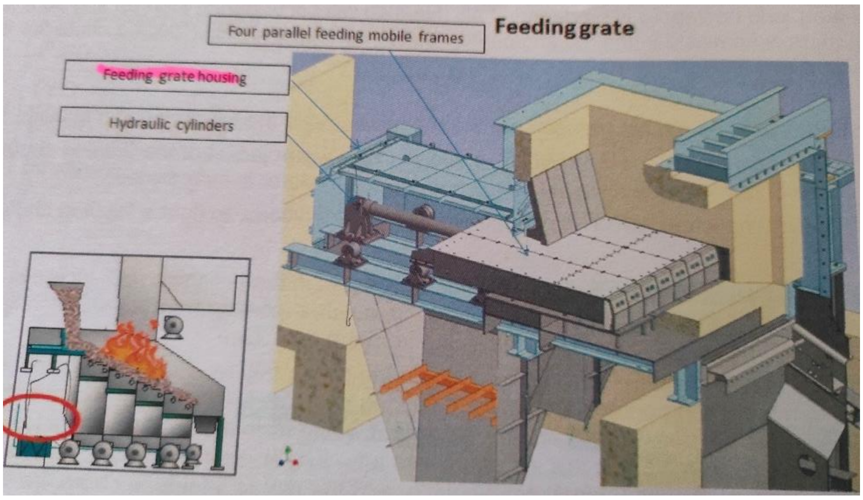


Figure 8B *Feeding table parts*

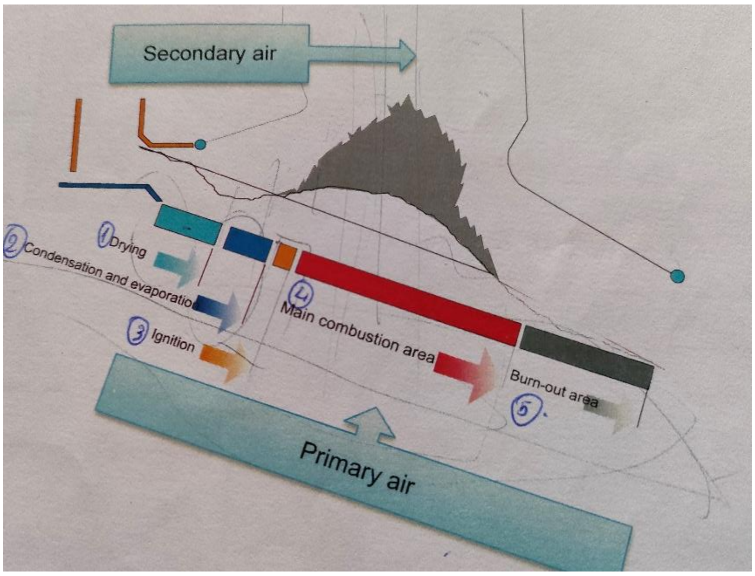


Figure 8C *Combustion process at different zones*

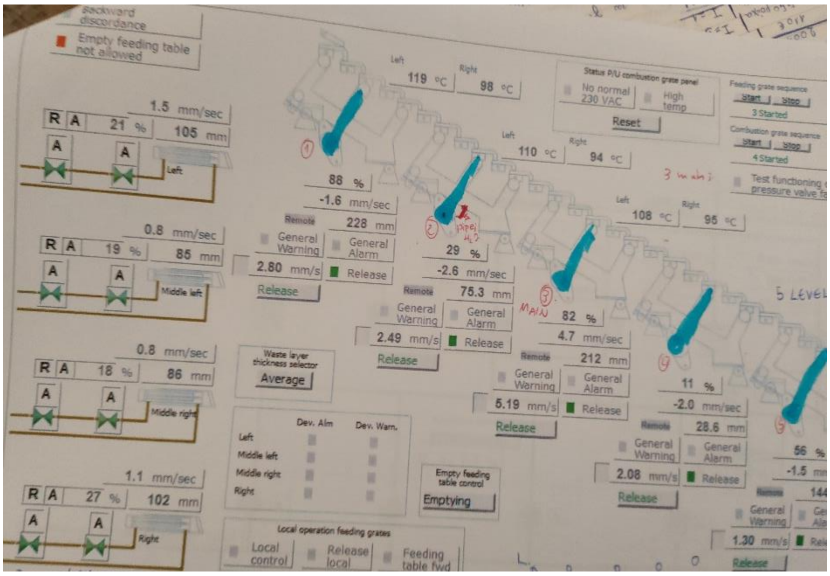


Figure 8D *DCS interfaces of grate movement*

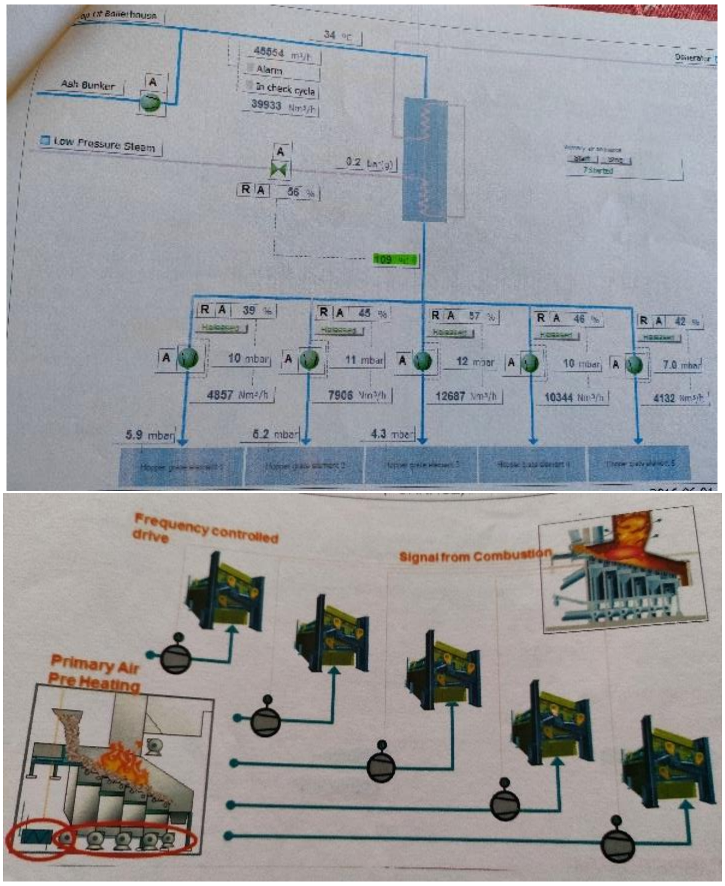


Figure 8 E1 *Feeding grate primary air supply and DCS screen*

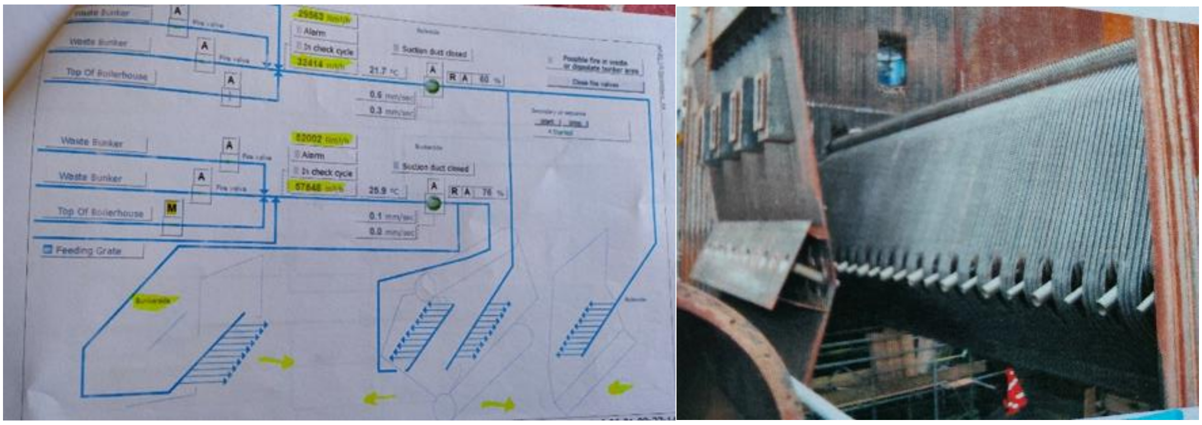


Figure 8 E2 *Feeding grate secondary air supply and DCS screen*

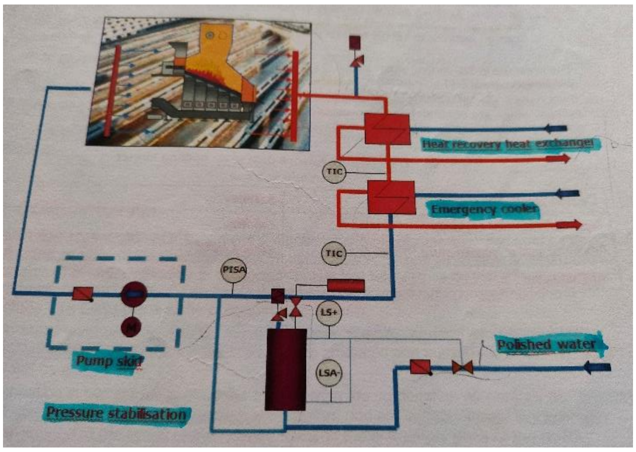


Figure 8 F *Water Cooling system*

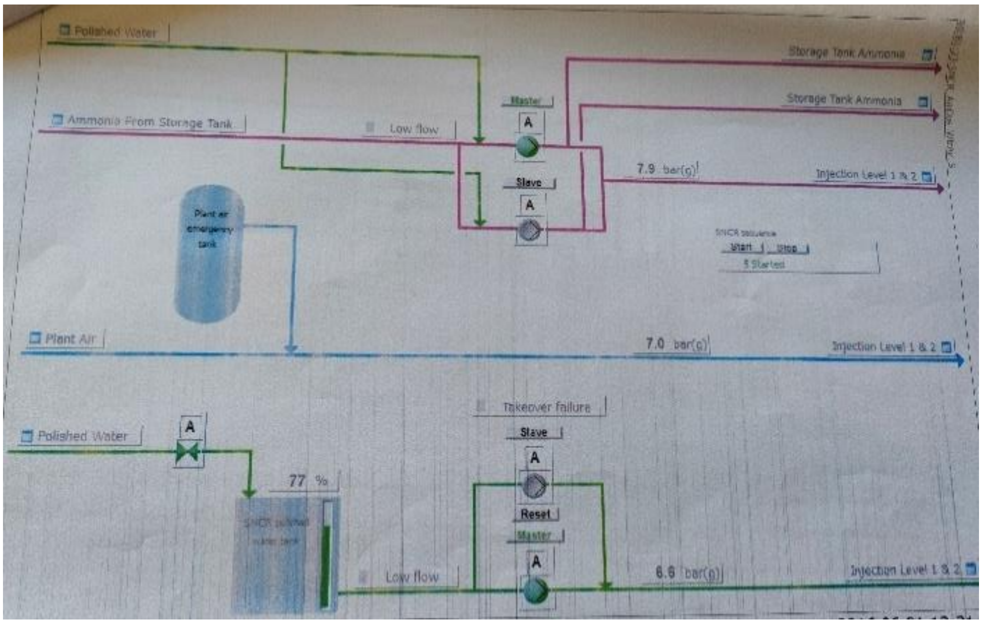


Figure 9 *Master and slave function of NOx abatement SNCR system*

Auxiliary Burners are in place to ensure the smooth plant operation. Figure 10 highlights the use of Auxiliary Burner. Their operation particularly when starting, stopping and in case of malfunctioning ensures that the plant shall stay compliant with the rule of 850C for 2 seconds according to 2010/75/EU. The waste on the grate is moved in a way that allows the waste homogenization, at the appropriate speed, thereby monitoring the thickness of layer adjusting speed. The waste will be excelling to the different zones of drying on the top, ending up burned out at the bottom of the grate where the ashes are disposed. The conditions of complete combustion are achieved with the supply of preheated air in excess. This is ensured by the addition of preheated air below the grates (Primary Air) and above the boiler prism (Secondary/Tertiary Air). This system ensures the avoidance of formation of potent gases including Carbon monoxide, dioxins, furans. By means of a non-catalytic SNCR reactor present at 2 levels of the Boiler area and with the use of appropriate features encompassing adequate lances, ammonia or urea is injected. In this way, NOx formation is inactivated to form Nitrogen within the appropriate temperature range before the 1st pass of the steam boiler. Figures 11 A, B and C present the SNCR system process.

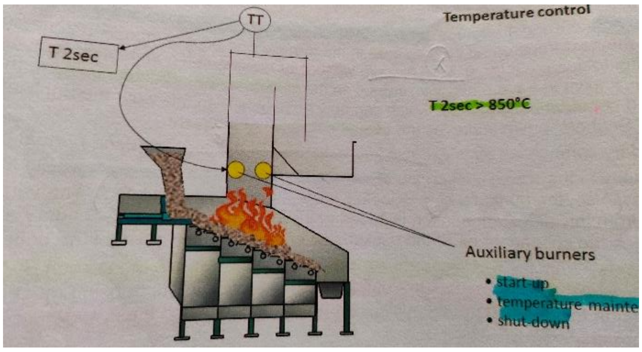


Figure 10 *Auxiliary Burners location*

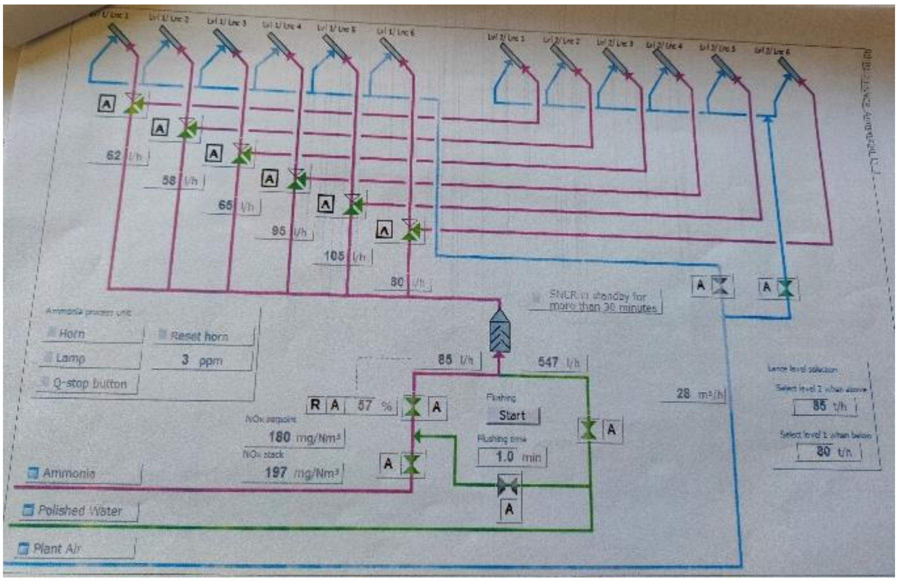


Figure 11A *DCS SNCR dosing system layout*

Figure 11B *SNCR dosing system, lances and associated features*

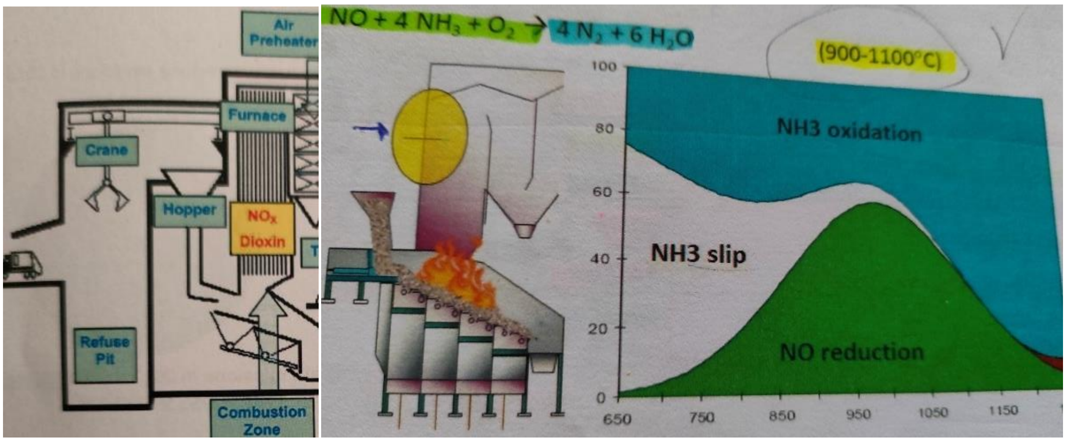


Figure 11 C *NOx formation***,** *SNCR System tackling NOx emissions at the appropriate Temperature and with the right dosage to be verified by CEMS monitoring performance*

The steam boiler (ie 87MWt) is designed in such a way that by the flue gas turbulent motion and subsequent movement inside the empty passes; from the 1st to the 3rd passage, changing gas direction, heavier particles of fly ash are expelled while on the same time the flue gas Temperatures decreases to protect the heat exchanging parts. The flue gas passes on the 4th pass exchanging heat, with the heating tubes in the convective part section at the right Temperature range. The water and steam separation takes place inside the boiler drum where levels of water are monitored and triggered by alarms. Water level normally stays in the middle. The water and steam fractions are continuously recirculated inside the Boiler in a way that impurities are removed by a Blow Down valve to the mud drum and renewed demineralised water is fed into the system. Figures 12 A till D depict main Boiler parts and their functions.

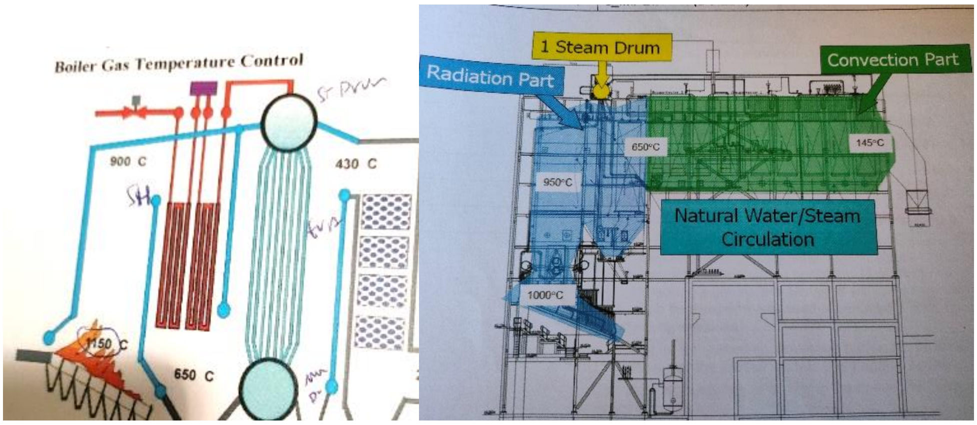


Figure 12 A *Indicative Temperature operational ranges within the Boiler.*

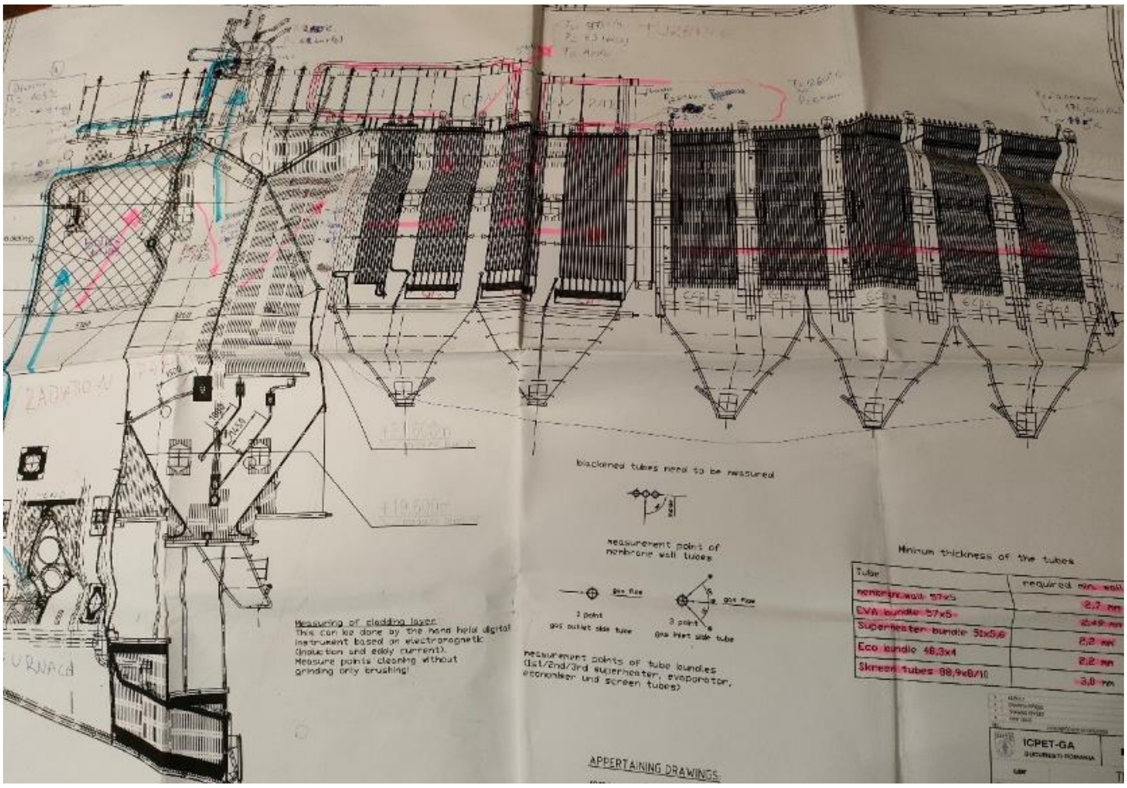


Figure 12 B *Main parts and sections of the Boiler*

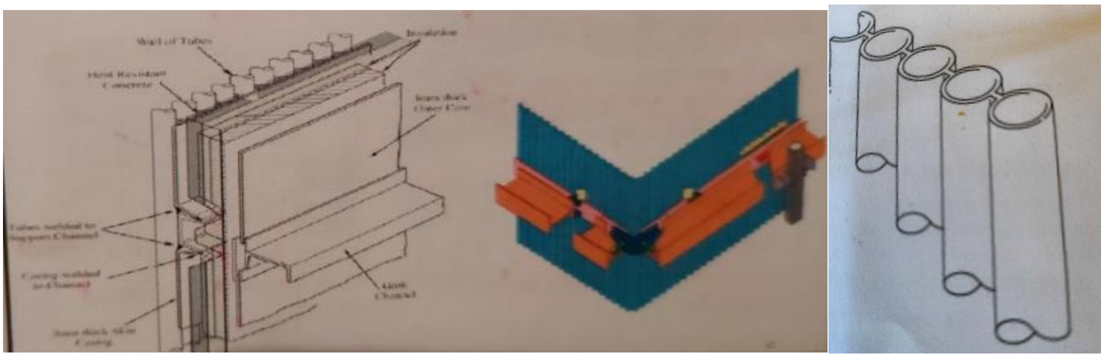
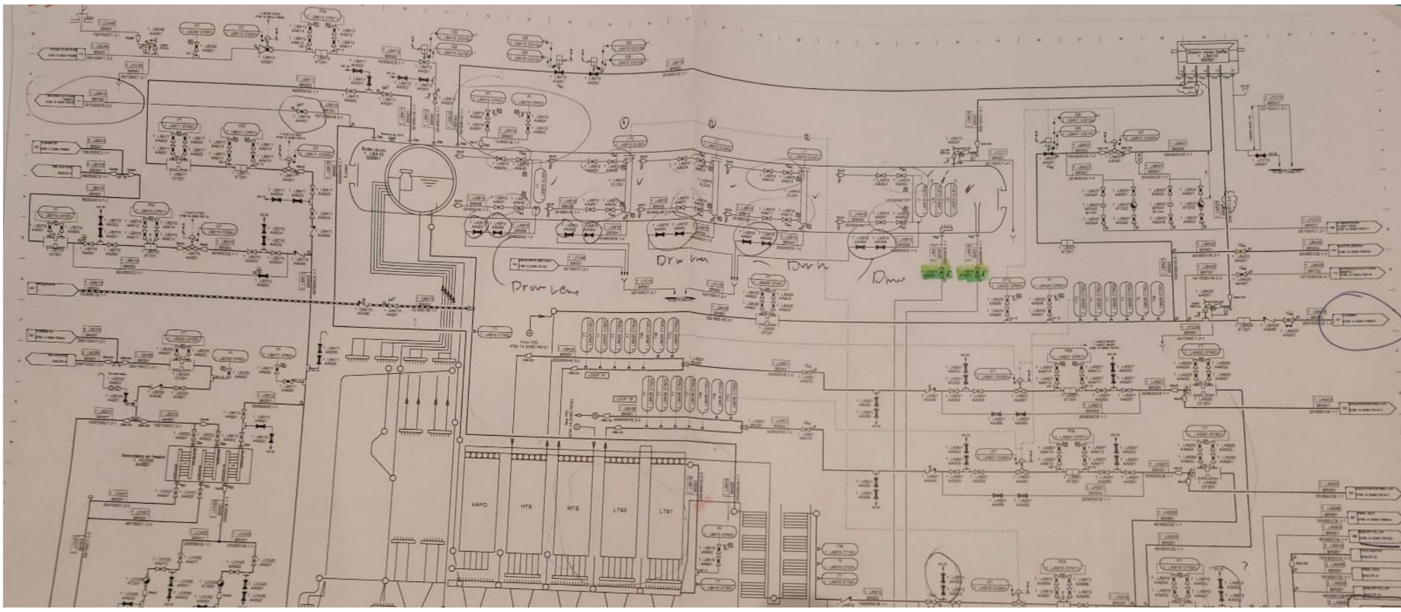


Figure 12 C *Boiler membrane wall tubes*



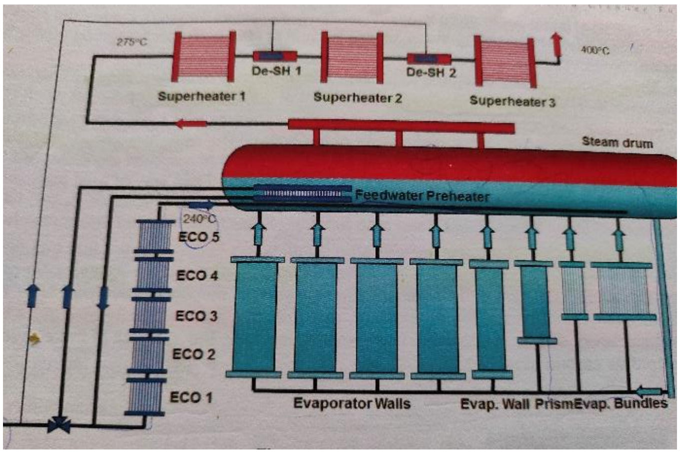


Figure 12 D *Boiler steam separation fed to Superheaters*

The wastewater is reused to cool the ash. Figure 13 presents the ash conveying system. Water quality is monitored continuously in sample stations to ensure compliance at different stages of the plant so that it meets compliance thresholds with EN 12952-12 ie to be free of salts having suitable conductivity, pH, to be free from dissolved gases such as O2. Treatment is carried out at different stages of the plant to reach the appropriate quality protocols with various means including but not limited to activated carbon filters, ion exchange resins, with chemical addition including ammonia, trisodium phosphate dosage and the use of a deaerator for the separation of dissolved gases. Figures 14A to C shows areas of the water treatment process.

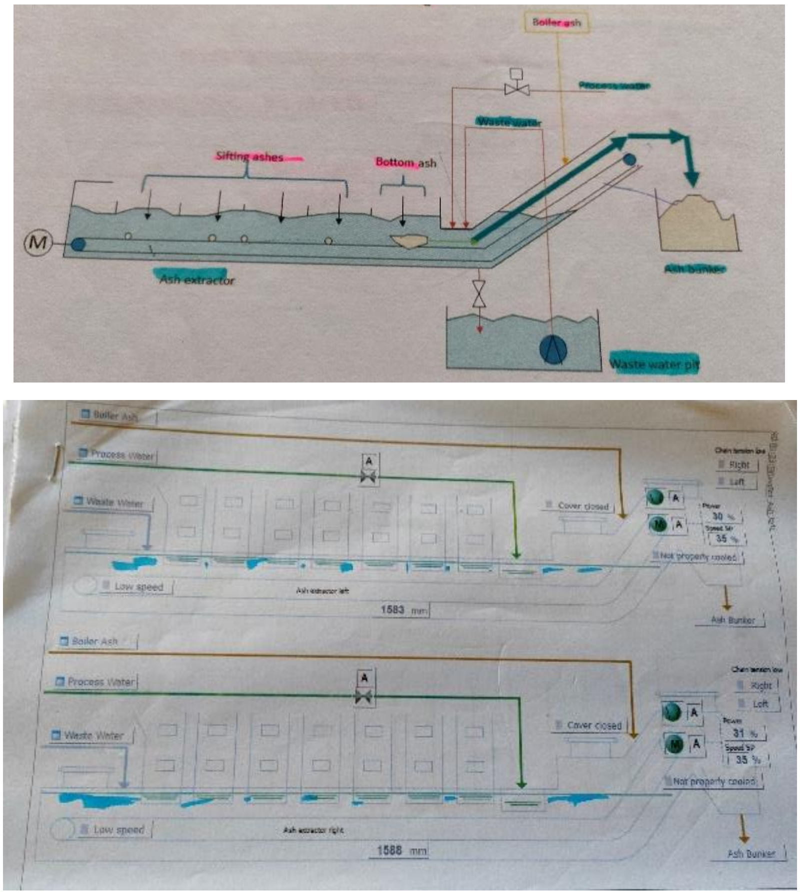


Figure 13 *Ash conveyor system*

Figure 14A *Areas of wastewater treatment process*

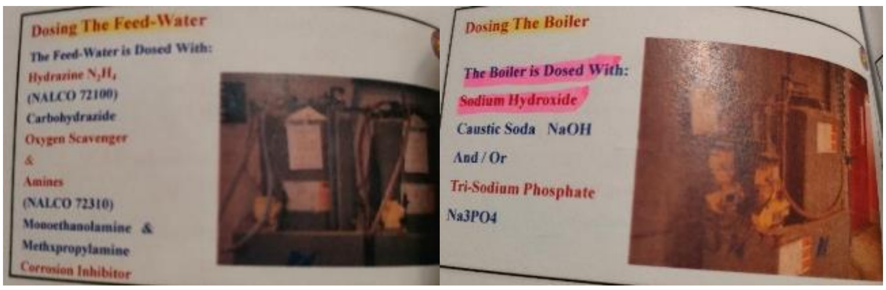


Figure 14B *Water dosing chemical treatment*

Figure 14C *Boiler Cleaning of dissolved gases with the use of deaerator*

The superheated steam ie approximately 100 t/hr per boiler from the 2 steam boilers is delivered from the superheater tube bundles. In the Superheaters section the steam reaches in optimal conditions (52 bar, 400C) and fed to the Turbine. The Superheaters are supported by attemperators which are been used to cool down Temperatures as well as to protect the lifespan of Superheater bundles. The superheated steam in the turbine expands and drives the generator to produce electricity of roughly 25% of the total energy load in an ERF plant. The rest of the usable steam is extracted from the Turbine via pipework to nearby facilities or for purposes of district heating and the remaining usable steam to cover the internal operation requirements. Figures 15 A to C highlight the Turbine operation.

The steam gets condensed and driven to cool down by means of cooling such as cooling towers where steam is condensed, water is processed and returned to the feeding system. The entire system works in an optimum energy efficiency manner using steam recirculation. Figures 16 A and B focus on the steam cooling system. Figure 17A pinpoints the Turbine steam extraction parts while Figure 17B demonstrates how the whole steam cycle works.

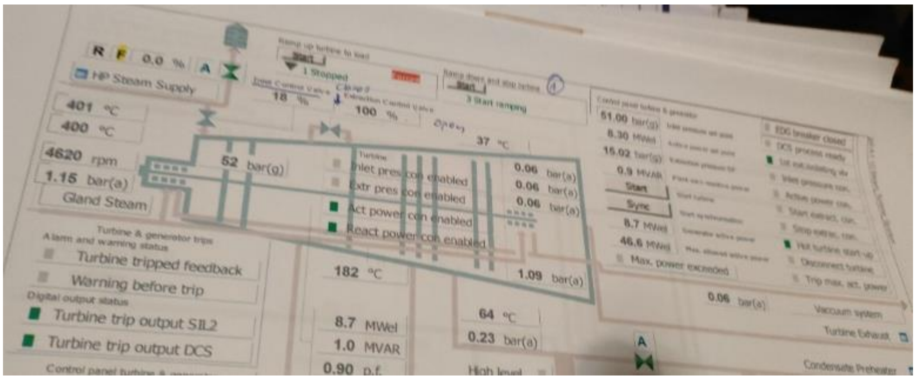


Figure 15A *DCS layout of Turbine functions and alarms*

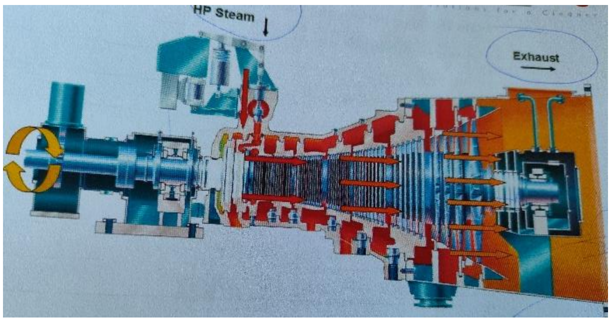


Figure 15 B *Steam expansion inside the Turbine*

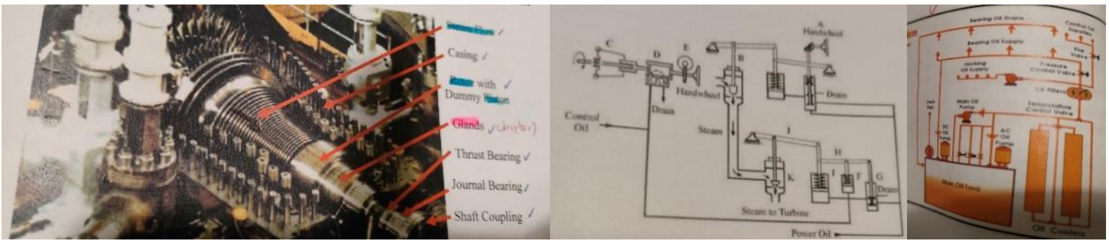


Figure 15 C *Turbine main parts and supporting features*

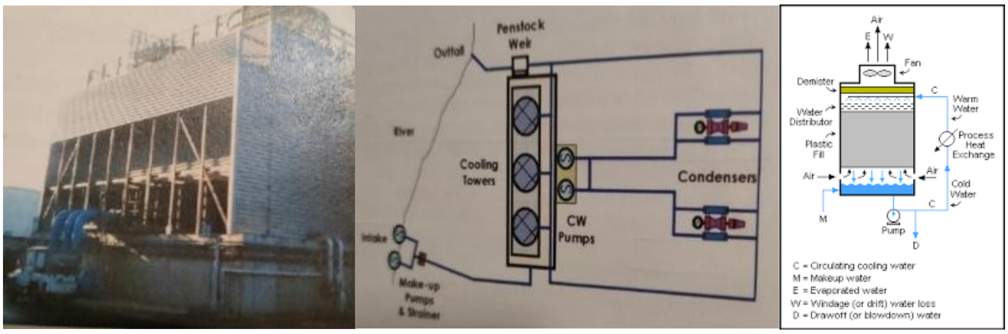


Figure 16A *Cooling Tower working principle and cooling process*

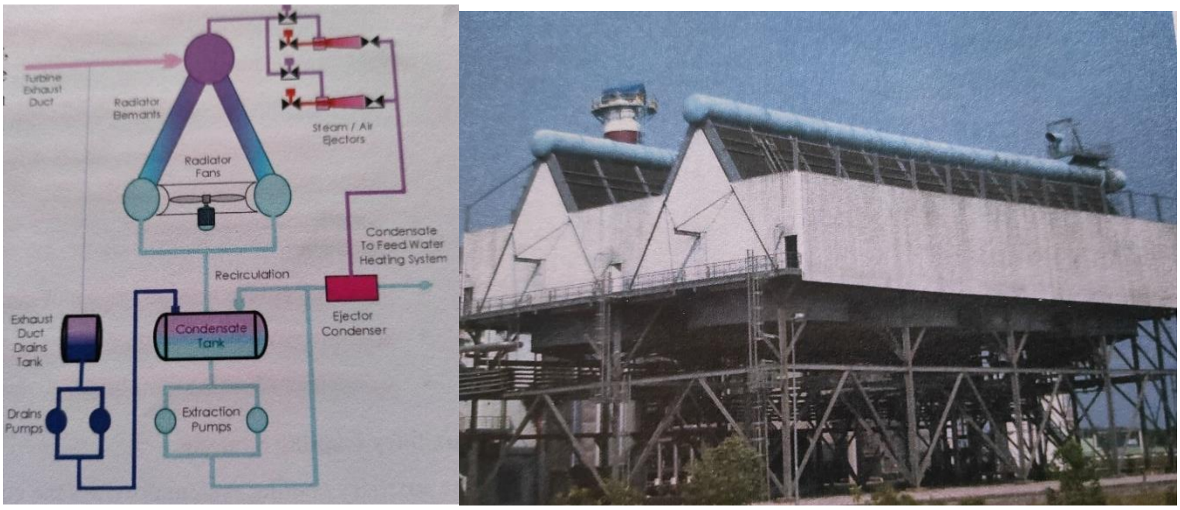


Figure 16 B *Air Cool Condenser working principle and cooling process*

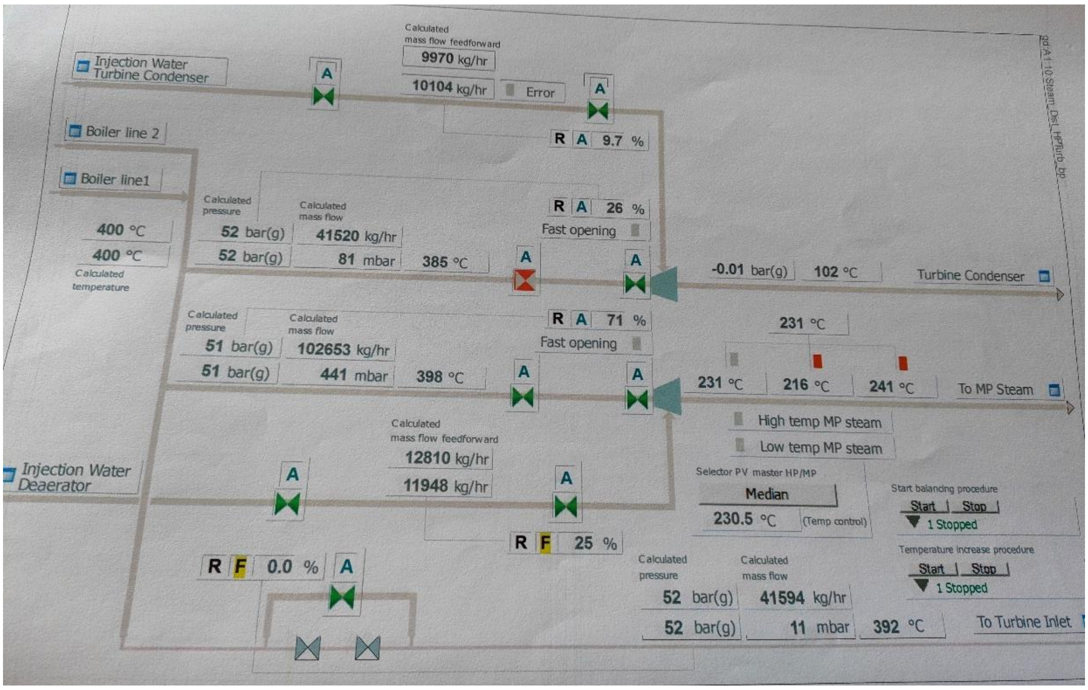


Figure 17A *Turbine extraction parts*

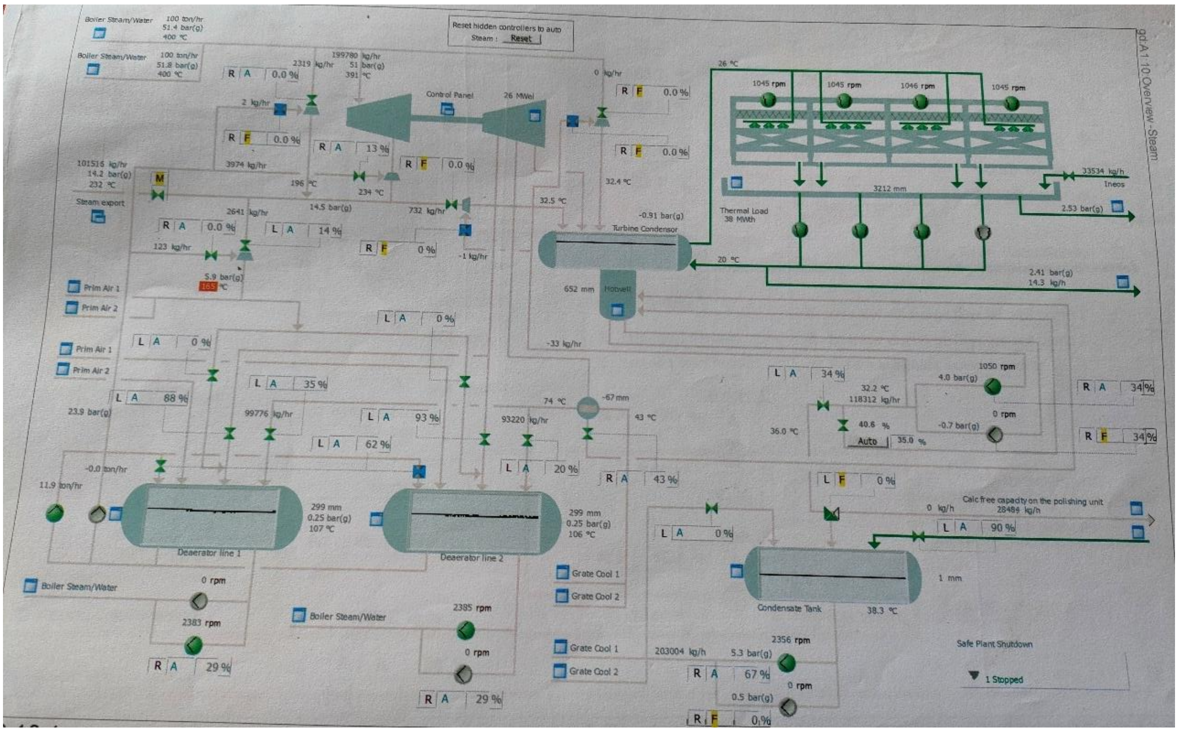


Figure 17 B *DCS illustrating main parts of the steam cycle process*

The formation of soot is driven mainly by the high operating Temperatures from combustion and the acidic environment by the acid gases formed inside the boiler. Figures 18A to C indicate the mechanisms that cause boiler tube failures and their associated effects. Frequent cleaning of steam boiler with the means of shower cleaning cycles in the 2nd/3rd passage or rapping cycles on the heat exchangers horizontal part, sometimes are not on their own sufficient. Figures 19A to C highlight the means of boiler cleaning.

The constant monitoring of performance including the flue gas path, monitoring Temperatures including the convective part in combination with the steam production flow is vital. It sometimes requires rigorous response by the operator unblocking ash bridges with the use of pressurized equipment especially on the 2/3 pass of the boiler. The ash deposits end up through a closed circuit ie double flap valves and rotary valves system, on the ash extractor and meet with the bottom ash at the bottom side of the grate and from there in the IBA ash storage bunker. Figure 20 shows how the ash is transported to the ash extractor and to the ash bunker. From the bunker with the use of slag handling cranes ash is loaded to trucks. The ash accounts for approximately 20 to 25% of the total waste throughput. The ash is regularly sampled as part of its disposal and is subject to regular laboratory analysis monitoring.

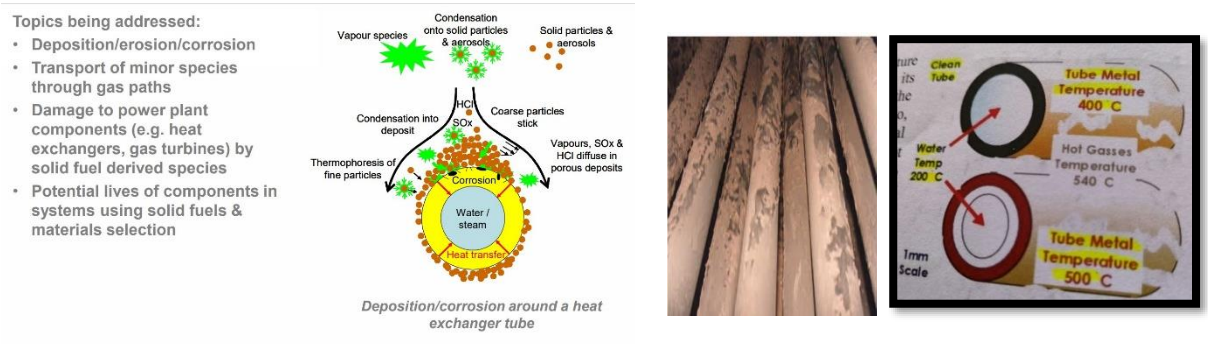


Figure 18A *Root causes of boiler tubes failures including scale inside the heat exchanger and deposits condensation around the heat exchanger tube*

Figure 18B *Boiler tubes thinning, scabbing, O2 attack, pitting, Flow Accelarated Corrossion and cracking*

Figure 18 C *2nd and 3rd part boiler ash formation causing blockages*

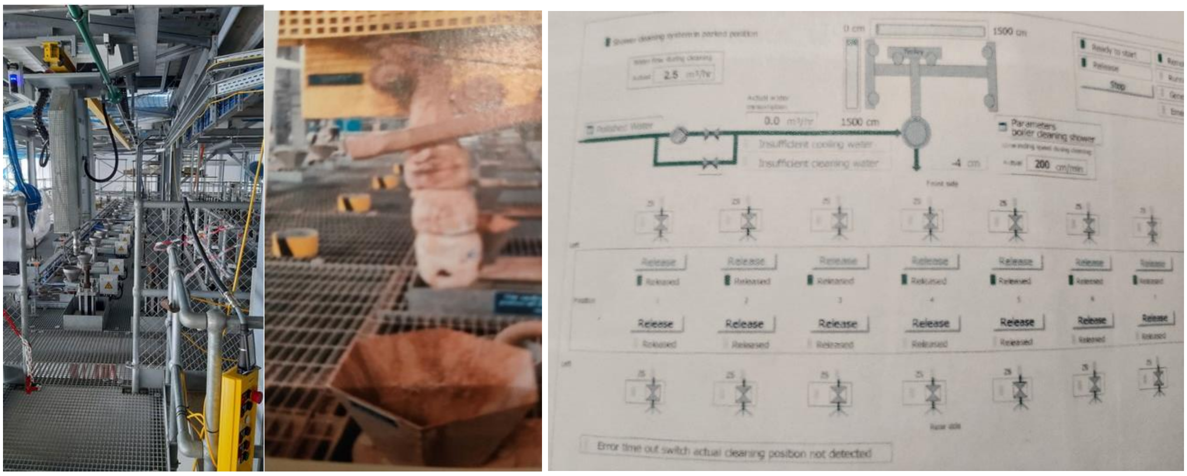


Figure 19A *Boiler shower cleaning process and DCS layout screen*

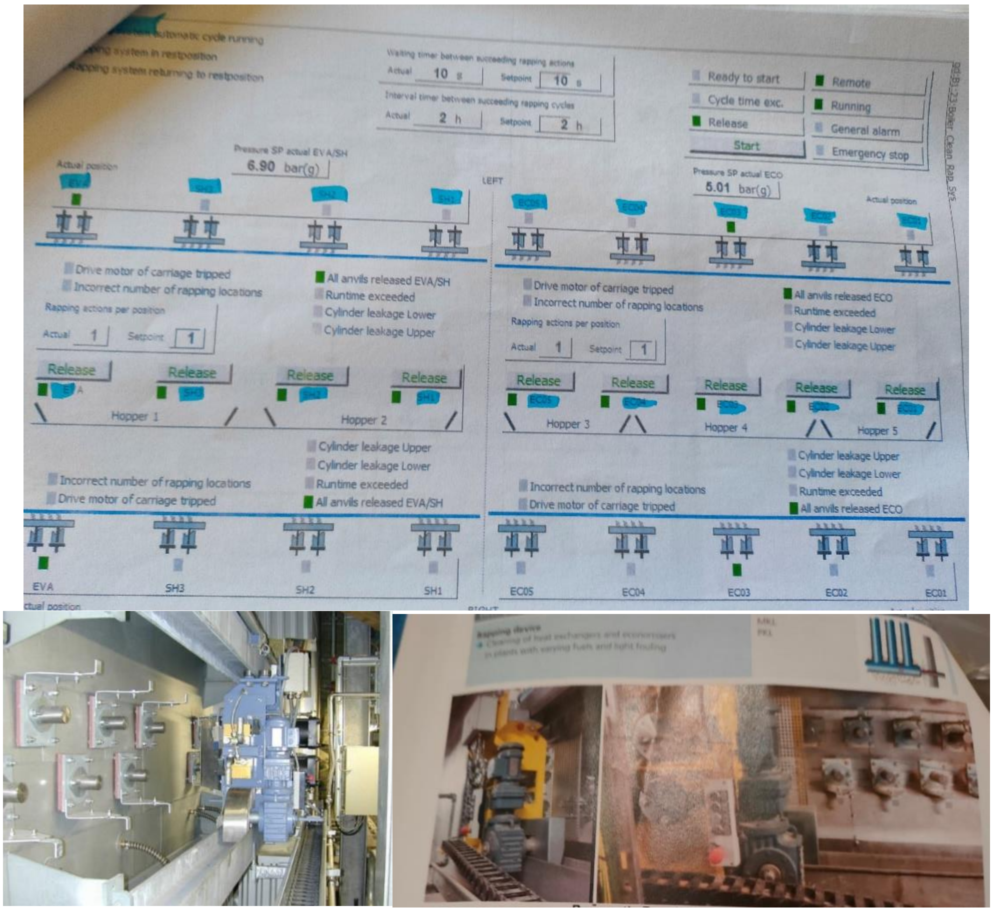


Figure 19B *Boiler rapping system and DCS layout screen*

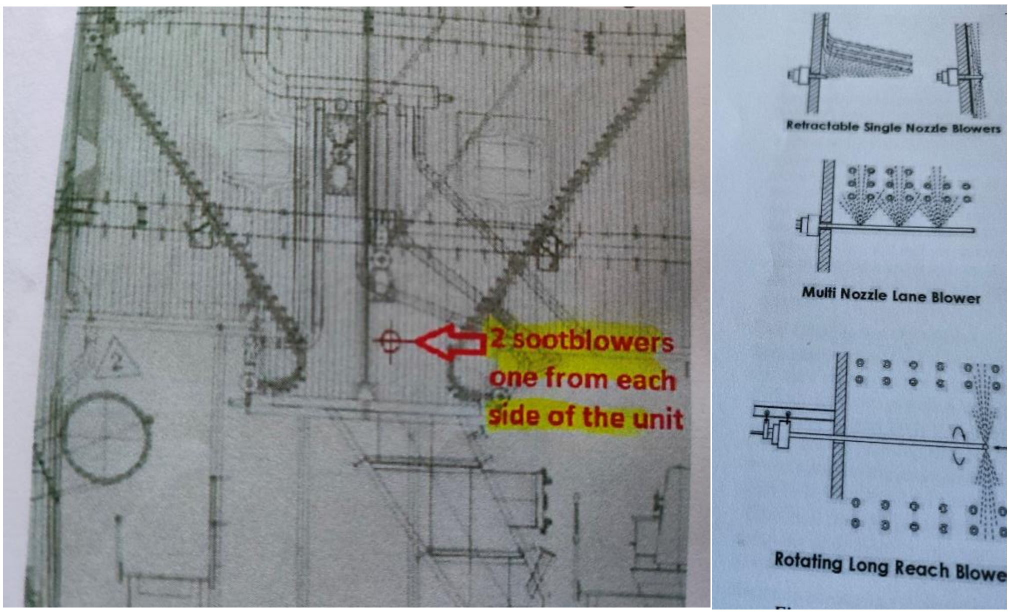


Figure 19 C *Sootblower system*

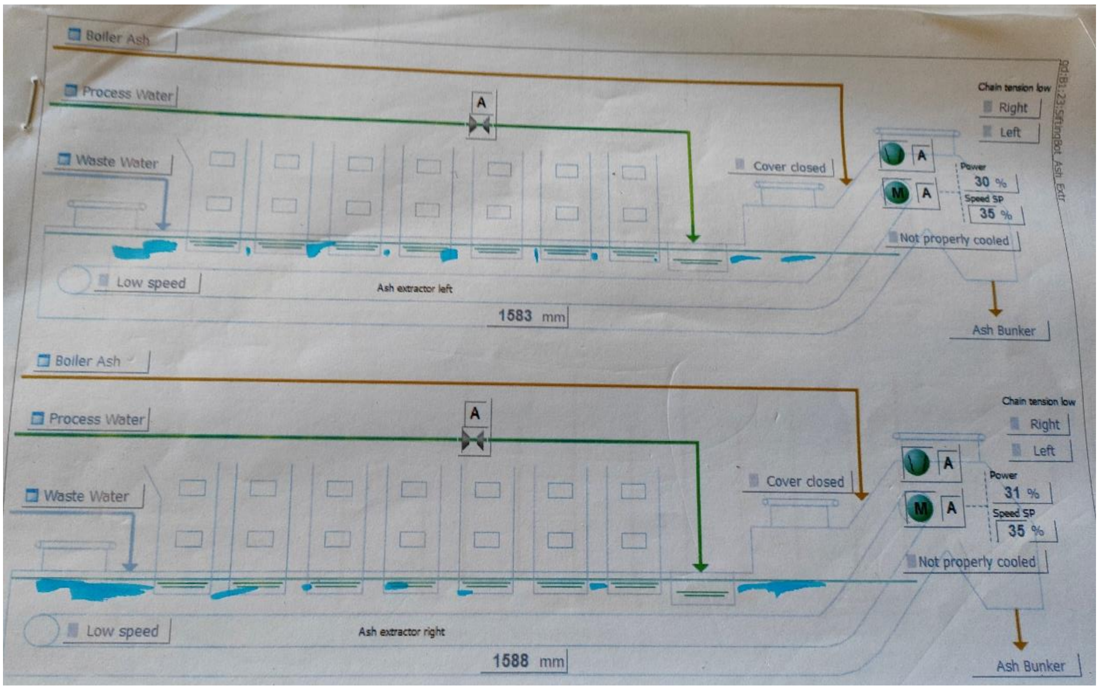


Figure 20 *Fly ash from the 2nd and 3rd pass and the horizontal heat exchangers part is extracted to the ash extractor*

The flue gas after leaving the economiser bundles where it receives heat to heat up the water, the gas exits from the boiler tail end to a system called Flue Gas Treatment (FGT) with the assistance of an ID Fan under slight negative pressure. The FGT system is insulated by lagging and trace heated to avoid Temperature drop. Each FGT Line system could consist of 2 venturi scrubbers with 2 lime silos, 1 Pulverised Active Carbon (PAC) silo in two stages and a bag filters system encompassing a compressed air pulse cleaning system and a screw conveyor for the Air Pollution Control residue (APCr) removal. In the venturi scrubber section, hydrated lime is fed with hoses in both stages and is recirculated and reused to deal with acid gases such as HCl, HF, SOx. Additionally, PAC is fed to a stage reactor for the reduction primarily dioxins and furans that could be reformed from flue gas cooling, but also other contaminants including heavy metals ie Hg. The purified flue gas is continuously monitored by CEMS operation to stay well below thresholds and comes of the stack at dispersion speed flow, while the APCr disposal is subject to legal monitoring surveillance as it contains potential hazardous and toxic compounds. The APCr leaves the plant in enclosed vehicles. The APCr fraction accounts for roughly 3% of the total waste throughput. Figure 21 highlights the working conditions of the ID Fan, while Figure 22 the various options for acid emissions neutralisation using alkaline chemicals. Figures 23 A to F depicts the main FGT parts and their functions.

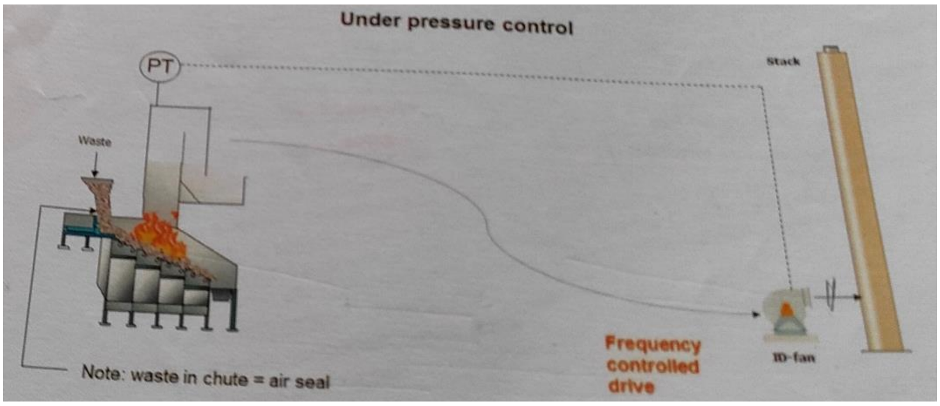


Figure 21 *ID Fan working under slight negative Pressure to extract flue gas*

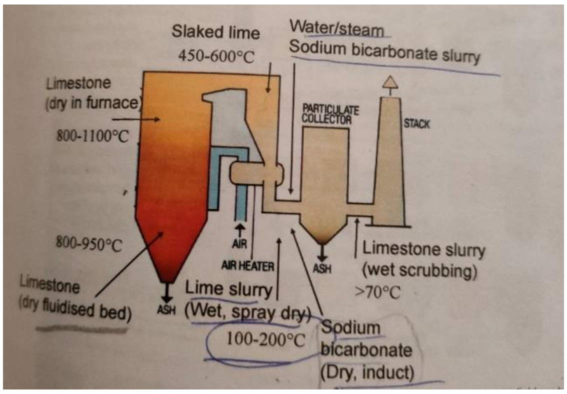


Figure 22 *Different options to tackle acid gases*

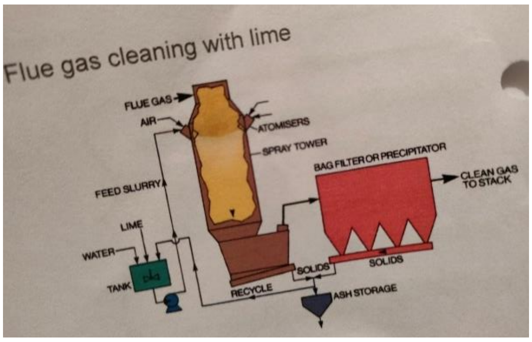


Figure 23A *Hydrated lime spent is recirculated in the 2 stages Scrubber Reactor*

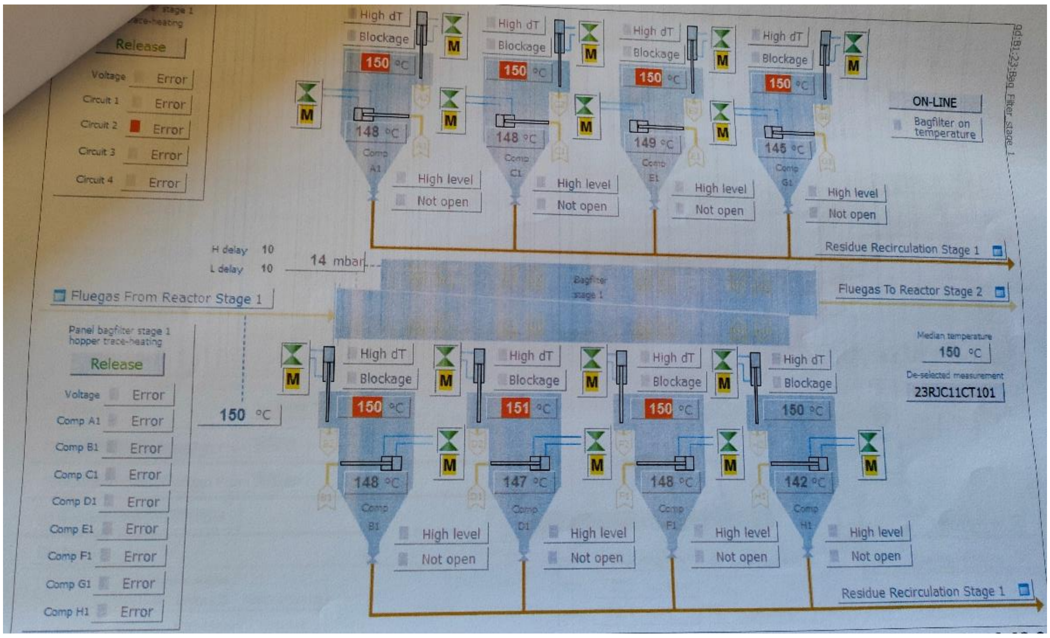
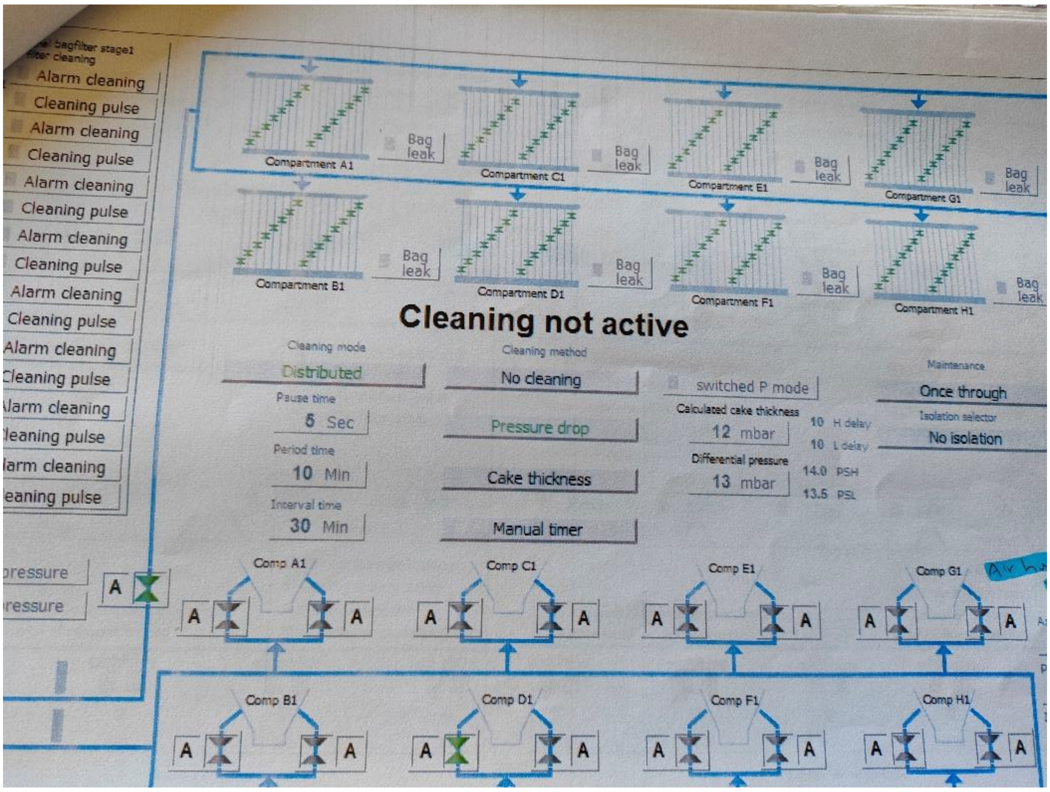


Figure 23 B *DCS layout of Bag filters*



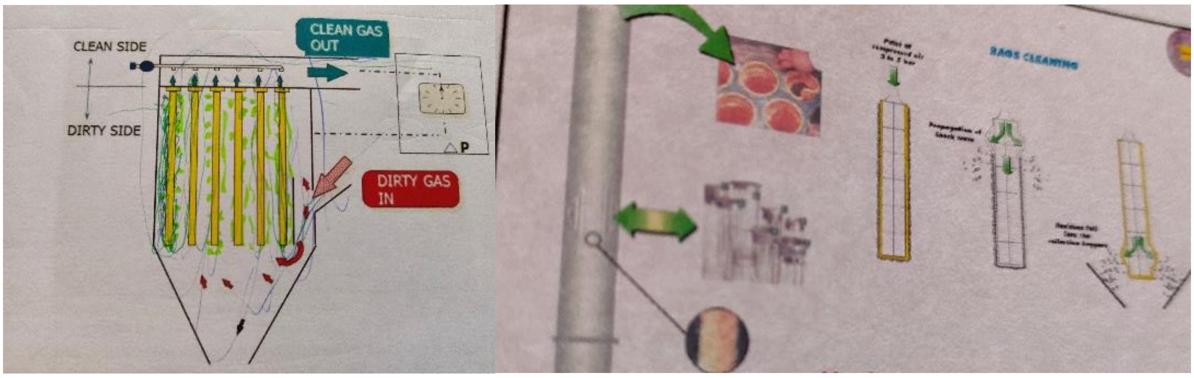


Figure 23 C *Bag filters cleaning detected by Pressure difference with compressed air flush*

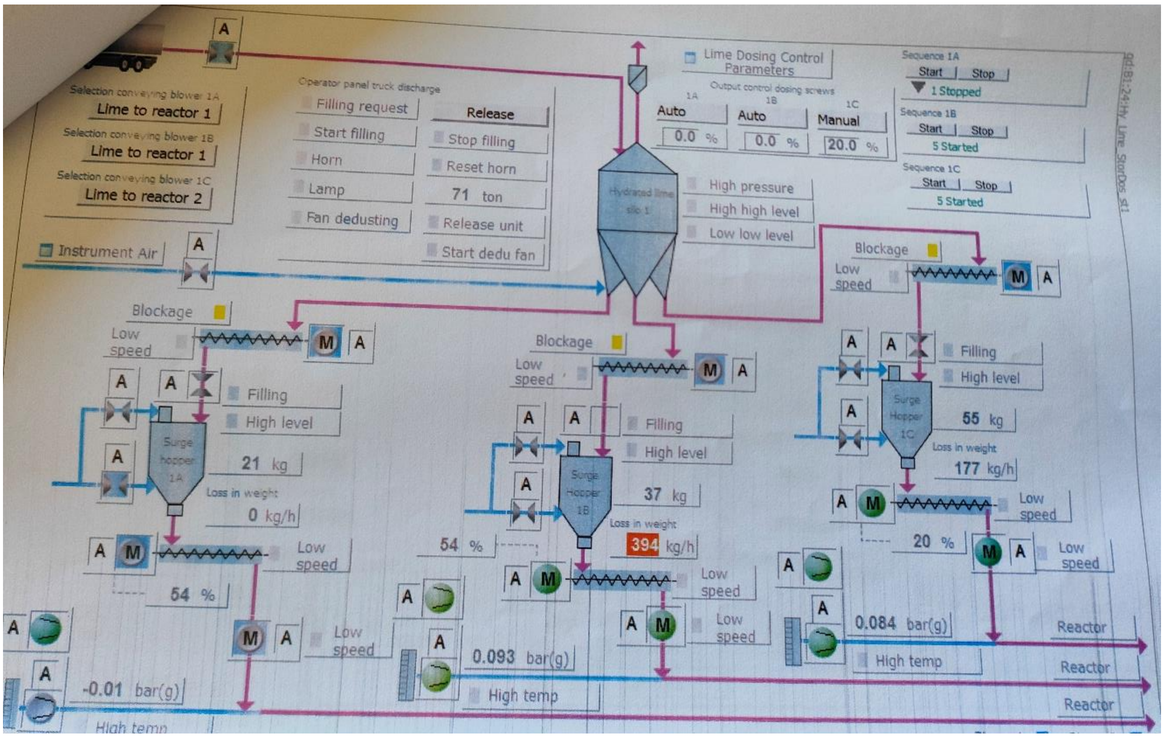


Figure 23 D *DCS layout demonstrating the Lime dosing to the Scrubber reactor*

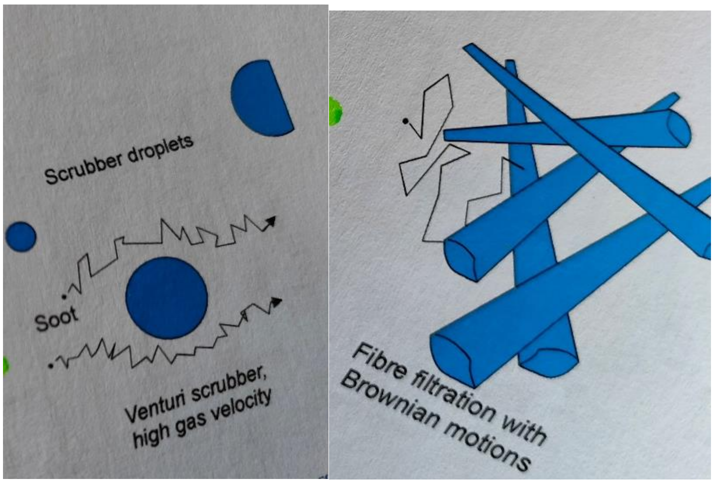


Figure 23 E *Removing partices with the use of Scrubber on the left hand side and Bag Filters system on the righthand side*

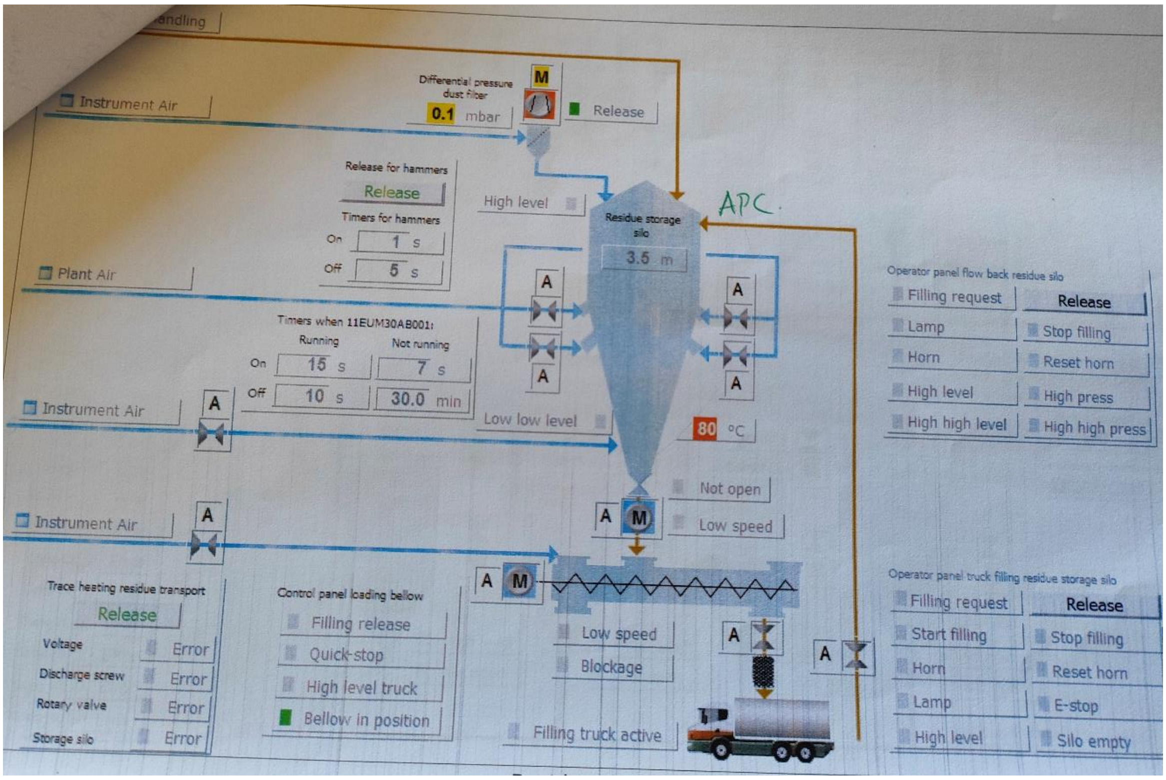


Figure 23F *DCS layout unloading of APCr*