



Silver Formaldehyde Plant ECS

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Preface

Dynea AS, Norway (DYNEA) was contacted by Synthite Ltd., UK (SYNTHITE) in January 2026 to advise on their per date flue gas emissions violating the requirements defined in the best available techniques (BAT) reference document (BREF) for the production of large volume organic chemicals (LVOC).

The primary concern is the formaldehyde component (FA) in the flue gas present post-combustion from the tail gas of SYNTHITE's silver formaldehyde plant (FA PLANT) in Mold, UK. The emission limit of FA set by BREF LVOC is 5.0 mg/Nm³ (dry). As of date, reported emission levels of FA exceed the limit by a two-digit fold.

A purchase order P64367 was signed between SYNTHITE and DYNEA on February 2, 2026, to include a study (presented in this report) with the objective of reducing the emission level of FA below the upper permissible limit. Assessments of the on-site related equipment, including the operational aspects of such equipment, shall be carried out to find answers to the elevated emissions. Furthermore, adequate measures to meet the FA emission requirement shall be proposed and include general process design specifications after the assessment.

Abstract

This report presents DYNEA's assessment of the elevated formaldehyde (FA) emissions from the thermal oxidizer/boiler system serving Synthite's silver formaldehyde plant in Mold, UK, with the objective of identifying the causes of non-compliance and defining measures required to achieve the applicable BAT/BREF/LVOC emission limit of 5.0 mg/Nm³ (dry) for FA. The assessment was based on process review, evaluation of reported operating and emissions data, and steady-state chemical process simulations of the existing boiler/thermal oxidizer arrangement.

The study shows that the current system is limited by three principal factors affecting destruction and removal efficiency (DRE): insufficient effective residence time, inadequate combustion temperature, and poor reactant mixing inside the combustion chambers. The present arrangement, where tail gas, foul air and ambient air are introduced separately with little or no controlled premixing or directing of the flows, results in weak turbulence, poor chamber volume utilization, and non-uniform operating conditions between the two combustion chambers. In addition, the lack of tight air-to-fuel ratio (AFR) control leads to excess oxygen and comparatively low combustion temperatures, which are detrimental to oxidation of formaldehyde and other volatile organic compounds (VOCs).

Based on the latest reported data and the simulation results, the as-is operation corresponds to emissions of approximately 33.3 mg/Nm³ (dry) for FA and 39.0 mg/Nm³ (dry) for TVOC, together with high CO emissions, whereas the target case demonstrates with conservative considerations that FA emissions at 5.0 mg/Nm³ (dry) and TVOC at 7.0 mg/Nm³ (dry) are achievable when combustion temperature is increased to more than 900 °C by significantly reducing the ambient air supply while assuming fair mixing of the reactants during combustion for improved oxidation conditions. The analysis therefore concludes that compliance can be achieved only through a revamp of the burner system, including proper feed directing and/or premixing, improved burner design, tighter combustion control, and measures to prevent condensation in the feed lines. DYNEA recommends installation of dedicated burner assemblies on each combustion chamber, supported by appropriate instrumentation, burner management and insulation/heat-tracing of relevant lines, in order to establish robust and controllable operating conditions for sustained compliance.

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Nomenclature

AFR	Air-to-fuel ratio
BAT	The best available techniques
BMS	Burner management system
BOILER	The steam boiler downstream the FA PLANT
BREF	BAT reference document
CFD	Computational fluid dynamics
CO	Carbon monoxide
CO ₂	Carbon dioxide
DRE	Destruction and removal efficiency
DYNEA	Dynea AS, Norway
EOS	Equation of state
FA	Formaldehyde
FA PLANT	SYNTHITE's silver formaldehyde plant in Mold, UK
H ₂	Hydrogen gas
LPG	Liquefied petroleum gas
LVOC	Large volume organic chemicals
MeOH	Methanol
MA	Methylal
MF	Methyl formate
MIMO	Multiple-input, multiple-output
N ₂	Nitrogen gas
NO _x	Nitrogen oxides
O ₂	Oxygen gas
SRK	Soave-Redlich-Kwong EOS
STP	Standard temperature and pressure i.e. 0 °C and 1 atm
SYNTHITE	Synthite Ltd., UK
TO	The thermal oxidizer integrated with the BOILER
TVOC	Total volatile organic compounds
UV	Ultraviolet
VOCs	Volatile organic compounds
fasil®	DYNEA's silver formaldehyde technology

Fluid reference conditions:

N*	Prefix implying STP where * is the unit of volume or volumetric flow rate
(actual)	Fluid unaltered
(dry)	Conditioned fluid: Free from water
(dry, 3% O ₂)	Conditioned fluid: Free from water and corrected the air equivalents to meet 3.0 % v/v O ₂ by assuming dry air

1 Introduction

Rigorous measurements of gas emissions to the atmosphere are increasingly important for the chemical process industry. Likewise, are the measures to comply with the contemporary directives becoming highly dependent on effective and sometimes complex emission handling systems. Non-compliant companies may be facing fines or penalties from legal actions. Clean operation is therefore paramount. Not only from a financial standpoint, but also to build and maintain a good industry reputation.

The tail gas downstream the FA PLANT is fed to a thermal oxidizer (TO) to oxidize volatile organic compounds (VOCs) like FA, methanol (MeOH), methyl formate (MF) and methylal (MA), which are the dominant chemical compounds commonly found in the tail gas of a formalin production facility. Also, as the tail gas consists of a fair amount of hydrogen gas (H₂) being the second greatest constituent behind nitrogen gas (N₂), the combustion process is self-driven without the need for extra fuel sources. Medium pressure steam is produced in the boiler, which is integrated with the TO as one unit (BOILER), to recover most of the heat produced. The thermal oxidizer part of the BOILER was never designed to have the tail gas as part of the feedstock but has nevertheless been remodeled to be able to burn it.

2 Assessment of the Current Process Performance

2.1 The Process

The tail gas is fed to the TO via a manifold (DN 375) that splits the gas stream into 4 feed pipes (DN 300) of which each has a control valve (DN 150) followed by a in-line flame arrestor (DN 225), before the final full-bore piece of pipe (DN 225) extending 350 mm into the combustion chamber. The control valves are not subject to control any variables other than passing gas through but will automatically close in the event of a trip e.g. flame flashback causing high temperature inside the feed pipe. In normal operation, 3 out of the 4 control valves are fully open, whereas one is fully closed. The tail gas flow rate, temperature and composition are fully determined by and dependent on the upstream FA PLANT load and conditions. The pressure is not controlled but indirectly set by the control valves in operation.

The tail gas is either free from oxygen, or the concentration of oxygen is limited to such an extent that it cannot burn by itself at the presence of an ignition source. This is an intrinsically safety feature of the fundamental process design. Oxygen gas is supplied separately in the form of foul air and ambient air. The former is fed to the TO by 2 full-bore feed pipes (DN 250) extending 470 mm into the combustion chamber, each having a separate in-line flame arrestor (DN 250) and connected to an upstream common line with a fan running at its rated load. The latter is drawn into the combustion chamber by an induced draft produced from the flue gas fan operating at fixed speed downstream the BOILER before the stack. The ambient air inlets are hand-operated ventilation dampers at the vicinity of the combustion chamber.

The foul air flow rate, temperature, pressure and composition are fully determined by and dependent on any upstream conditions like the foul air fan capacity and the upstream plant state making up the foul air. The ambient air feed rate on the other hand is to some extent controllable by manually adjusting the dampers by hand, but there is no other way to verify the flow rate other than back-calculating e.g. by measuring the total flue gas flow rate and deducting other feed flow rates, or by predicting from a model given one or more independent variables like combustion temperature and oxygen concentration in the flue gas.

The TO is a dual burner setup i.e. two combustion chambers, each being an unlined corrugated pipe of diameter 1 m and length 4.4 m. Each burner section serves 2 tail gas feed pipes, 1 foul air feed pipe, and 1 ambient air ventilation damper. There is no premixing of any feed streams prior to combustion, nor any directed introduction of the feeds into the chambers for well mixing. The developed flame is assured and stabilized by the flue gas fan that makes an induced convection draft through the BOILER.

The tail gas piping is insulated until the manifold inlet, from where everything else onwards is uninsulated. The foul air pipes are also uninsulated, as well as the burner rings with the dampers.

Please refer to the piping and instrumentation diagram (P&ID) in appendix A – Boiler P&ID for a visual understanding of the BOILER. For a visual understanding of the feed streams to the TO, including the combustion chamber and internals, please refer to appendix B – Thermal Oxidizer Feed Streams Arrangement and appendix C – Combustion Chamber and Internals of the Thermal Oxidizer, respectively.

2.2 Performance Data

The first issued reported flue gas emissions with respect to FA, total volatile organic compounds (TVOC) and nitrogen oxides (NOx) are shown in Table 2.1 and Table 2.2. The former table also includes residual oxygen gas (O2) and carbon dioxide (CO2) in the flue gas for reference. Further, the latest reported flue gas emissions with respect to FA, TVOC, NOx and carbon monoxide (CO) are shown in Table 2.3, Table 2.4 and Table 2.5. Water vapor and residual O2 are included in the two former tables, respectively. The reported tail gas VOCs shown in Table 2.6, and the reported foul air data shown in Table 2.7 and Table 2.8, serve as basis for the TO performance. Please note the caption of each individual table which declares the reference conditions (noted in round brackets if any) of the presented data; (dry) means free from water, whereas (dry, 3% O2) means free from water and corrected the air equivalents to meet 3.0 % v/v O2. Units of volumes with prefix N implies the reference condition; standard temperature and pressure (STP), i.e. 0 °C and 1 atm.

Table 2.1: Reported flue gas emission data – first issued

Date	Flue Gas [m3/h]	FA [g/h]	TVOC (as carbon) [g/h]	NOx (as NO2) [g/h]	O2 [% v/v]	CO2 [% v/v]
03.08.2023	17,983	563	473	14.9	16.9 ± 0.44	N/A ± N/A
24.04.2024	16,310	647	287	17.6	13.9 ± 0.49	2.1 ± 0.072
19.11.2024	16,610	641	677	19.0	14.3 ± 0.48	2.2 ± 0.064
17.01.2025	17,243	130	662	35.3	14.1 ± 0.44	2.9 ± 0.100
10.07.2025	15,281	1,919	1,316	31.5	11.3 ± 0.29	3.3 ± 0.088

Table 2.2: Reported flue gas emission data by reference conditions (dry, 3% O₂) – first issued

Date	Flue Gas [Nm ³ /h]	FA [mg/Nm ³]	TVOC (as carbon) [mg/Nm ³]	NO _x (as NO ₂) [mg/Nm ³]
03.08.2023	2,402	191.0	179.0	5.7
24.04.2024	3,717	71.7	31.8	4.9
19.11.2024	3,462	68.0	72.4	5.4
17.01.2025	3,613	13.9	70.4	6.9
10.07.2025	6,086	170.0	117.0	5.3

Table 2.3: Reported flue gas emission data – latest

Date	Flue Gas [m ³ /h]	FA [g/h]	TVOC (as carbon) [g/h]	NO _x (as NO ₂) [g/h]	CO [g/h]	Water [% v/v]
20.02.2026	18,453 ± 896	344 ± 69.8	402 ± 28.8	48.3 ± 2.7	2,341 ± 137	5.3 ± 0.16
20.02.2026 ⁽¹⁾	18,601 ± 894	103 ± 20.9	63.5 ± 4.5	47.7 ± 2.7	1,619 ± 94.1	4.6 ± 0.16

Table 2.4: Reported flue gas emission data by reference conditions (dry) – latest

Date	Flue Gas [Nm ³ /h]	FA [mg/Nm ³]	TVOC (as carbon) [mg/Nm ³]	O ₂ [% v/v]
20.02.2026	10,295 ± 500	33.3 ± 6.6	39.0 ± 2.1	11.6 ± 0.35
20.02.2026 ⁽¹⁾	10,724 ± 515	9.6 ± 1.9	5.9 ± 0.31	11.7 ± 0.36

Table 2.5: Reported flue gas emission data by reference conditions (dry, 3% O₂) – latest

Date	Flue Gas [Nm ³ /h]	NO _x (as NO ₂) [mg/Nm ³]	CO [mg/Nm ³]
20.02.2026	5,394 ± 262	8.8 ± 0.52	427 ± 26.3
20.02.2026 ⁽¹⁾	5,540 ± 266	8.6 ± 0.52	291 ± 18.2

¹ Foul air fan OFF

Table 2.6: Reported tail gas VOCs

Date	Tail Gas [Nm ³ /h]	FA [mg/Nm ³]	TVOC (as carbon) [mg/Nm ³]
30.10.2023	1,901	1,017	1,463

Table 2.7: Reported foul air data – latest

Date	Foul Air [m ³ /h]	Foul Air [Nm ³ /h]	FA [g/h]	TVOC (as carbon) [g/h]	Water [% v/v]
20.02.2026	2,311 ± 111	2,167 ± 104	2,191 ± 443	1,014 ± 72.7	1.9 ± 0.080

Table 2.8: Reported foul air data by reference conditions (dry) – latest

Date	Foul Air [Nm ³ /h]	FA [mg/Nm ³]	TVOC (as carbon) [mg/Nm ³]
20.02.2026	2,125 ± 102	1,030 ± 202	477 ± 25.4

2.3 Data Basis

The data used as basis for benchmarking, calculations and discussions refers hereinafter to Table 2.9 for the feed streams. The tail gas is close to the limit of saturation with water vapor, whereas the ambient air has a relative humidity of 90 %. The foul air humidity reflects the reported water concentration from Table 2.7 which makes the dew point only 0.13 °C below the stream temperature of 17.0 °C. The composition of the tail gas and the foul air with respect to FA, MeOH, MF and MA reflect the reported VOCs from Table 2.6 and Table 2.8, respectively. Same distribution ratios between MeOH, MF and MA are assumed for the tail gas and the foul air streams. Residual composition of components in the tail gas is estimated from DYNEA's database of tail gas analysis from comparable silver formaldehyde plants. Residual composition of components in the foul air stream is assumed to consist of the same dry air composition as of the ambient air stream. The pressure of the feed streams reflects the negative gauge pressure expected inside the combustion chamber induced by the flue gas fan. Moreover, the pressure drop in the BOILER (from the feed streams inlet till the flue gas fan) is estimated to 7.0 mbar, and further from the flue gas fan up till the stack outlet being 0.5 mbar. The total heat loss of the BOILER is estimated to 1.0 %, and the flue gas temperature out of the BOILER is in the range 200 – 250 °C.

Following the process description, the feed stream data are presented as velocities in Table 2.10 while assuming equal flow distribution. Note that ambient air velocities cannot be determined, but the distribution between either section of the TO is denoted assuming equal combustion conditions i.e. indifferent oxygen excess post-combustion and matching combustion temperature.

The combustion temperature is measured to 650 °C at the center of the flame which is on par with the preliminary chemical process simulations performed for verification.

Table 2.9: Basis data for thermal oxidizer feed streams

		Tail Gas	Foul Air	Ambient Air
Temperature	[°C]	18.0	17.0	10.0
Pressure	[mbarg]	-1.0	-1.0	-1.0
Total Flow Rate	[kg/h]	5,500.0	3,000.0	7,100.0
	[Nm ³ /h]	5,191.4	2,337.9	5,516.8
Composition:	[% v/v]			
FA	"	0.075916	0.075421	-
Water	"	1.935205	1.900008	1.101786
MeOH	"	0.023746	0.001433	-
N ₂	"	73.395932	76.533073	77.220380
Argon	"	0.877923	0.915482	0.923703
O ₂	"	-	20.528258	20.712599
H ₂	"	18.728651	-	-
CO ₂	"	4.123732	0.041167	0.041536
CO	"	0.753409	-	-
NO ₂	"	-	-	-
NO	"	-	-	-
MF	"	0.083111	0.005015	-
MA	"	0.002375	0.000143	-

Table 2.10: Stream velocities of thermal oxidizer feeds excl. ambient air

		TO Section of the BOILER				
		Total	Left		Right	
			Pipe #1	Pipe #2	Pipe #3	Pipe #4
Tail Gas:	[m/s]					
Manifold (DN 375)	"	13.9				
Branch (DN 300)	"		7.3	7.3	-	7.3
Control Valve (DN 150)	"		29.0	29.0	-	29.0
Feed Pipe (DN 225)	"		12.9	12.9	-	12.9
			Pipe #1		Pipe #2	
Foul Air:	[m/s]					
Feed Pipe (DN 250)	"			7.0		7.0
			Damper #1		Damper #2	
Ambient Air:	[-]					
Distribution	"		73.6 %		26.4 %	

2.4 Chemical Process Simulations

Steady-state simulations for modelling, design and optimization of the chemical engineering processes are performed with the software suite CHEMCAD (version 8.1.2 build 18002, module CC-STEADY STATE). The Soave-Redlich-Kwong (SRK) equation of state (EOS) is used as the global fluid package for both the K-value model and the enthalpy model. Residual FA, TVOC, NO_x and CO after combustion is set by adjusting the conversion factors of the reactants, whilst the NO/NO₂-ratio is determined by minimizing the Gibbs energy of the system.

The latest flue gas emission data from Table 2.4 and Table 2.5 are presented in Table 2.11, and serve as basis for analyzing the current performance of the BOILER. The same table includes the expected emissions as targets after a revamp or a new installation, though being somewhat conservative for FA, TVOC and NO_x emissions, and shall therefore be perceived and treated as the worst-case performance during normal operation for those components. Especially the target emission of NO_x is considerably high compared to DYNEA's experience with thermal oxidation of tail gas at high temperatures (900 – 1,000 °C). Though being high, the NO_x target emission is calculated by maintaining the same extent of reaction percentage as of the as-is run case (22.4 %), by assuming the minimized Gibbs energy of the system represents 100 % of the possible conversion to NO_x. The target emissions of CO, on the other hand, are set quite rigorously to expectations and hence, that number (3.0 mg/Nm³ at ref. cond. dry, 3% O₂) might become elevated depending on final remodel solution of the BOILER and the operating conditions. Dry air composition is used when calculating the air flow rate equivalents for correction (deduction or addition) from the dry flue gas stream in the process of targeting the reference O₂ concentration of 3.0 %.

Table 2.11: Data basis for the performance of the BOILER as-is and target by reference conditions; (dry) for FA and TVOC, whereas (dry, 3% O₂) for NO_x and CO

Simulation Run	FA [mg/Nm ³]	TVOC (as carbon) [mg/Nm ³]	NO _x (as NO ₂) [mg/Nm ³]	CO [mg/Nm ³]
As-is	33.3	39.0	8.8	427.0
Target	5.0	7.0	46.4	3.0
Emission Limit	5.0	40.0	50.0	N/A

The as-is performance of the BOILER is presented in Table 2.12. The flue gas data are presented as wet (actual), and with reference to the conditions (dry) and (dry, 3% O₂). Likewise, the target performance data are presented in Table 2.13. Here, the air-to-fuel ratio (AFR) has been reduced to more likely achieve the listed emission targets. The tail gas stream and the foul air stream are both considered as fuels, and hence remain unchanged, whereas the ambient air flow rate is reduced by 69.6 % on a total basis. By following the same equal flow distribution as denoted before with only 3 out of 4 tail gas control valves opened, the reduced AFR causes an even more skewed distribution of the ambient air feed between the two combustion chambers i.e. 89.5 % and 10.5 % for the left and right side, respectively. The elevated combustion temperature from the as-is to the target run case of the BOILER shows at least 12.2 % increased steam production solely due to the reduced AFR. The destruction and removal efficiency (DRE) of each emission component is presented in Table 2.14.

Table 2.12: Performance of the BOILER as-is

Simulation Run		As-is		
Combustion Temperature	[°C]	658.0		
Heat Duty (at Flue Gas 200 °C)	[kW]	2,251.7		
Actual vs. Ref. Conditions		(actual)	(dry)	(dry, 3% O ₂)
Flue Gas Total Flow Rate	[kg/h]	15,600.0	14,639.7	9,155.7
	[Nm ³ /h]	12,546.6	11,351.9	7,108.5
Composition:	[% v/v]			
FA	"	0.002249	0.002486	0.003970
Water	"	9.522173	-	-
MeOH	"	0.000038	0.000042	0.000067
N ₂	"	78.583646	86.854041	92.091262
Argon	"	0.939999	1.038927	1.101562
O ₂	"	8.782955	9.707301	3.000046
H ₂	"	-	-	-
CO ₂	"	2.147232	2.373214	3.764809
CO	"	0.019359	0.021397	0.034169
NO ₂	"	0.000014	0.000015	0.000024
NO	"	0.000229	0.000253	0.000404
MF	"	0.002005	0.002216	0.003539
MA	"	0.000095	0.000106	0.000169

Table 2.13: Performance of the BOILER target

Simulation Run		Target		
Combustion Temperature	[°C]	913.1		
Heat Duty (at Flue Gas 200 °C)	[kW]	2,527.4		
Actual vs. Ref. Conditions		(actual)	(dry)	(dry, 3% O2)
Flue Gas Total Flow Rate	[kg/h]	10,658.8	9,731.9	9,169.3
	[Nm3/h]	8,706.3	7,553.1	7,117.8
Composition:	[% v/v]			
FA	"	0.000324	0.000373	0.000396
Water	"	13.245022	-	-
MeOH	"	0.000018	0.000020	0.000022
N2	"	79.192781	91.283274	92.090851
Argon	"	0.947289	1.091913	1.101572
O2	"	3.500016	4.034370	3.000080
H2	"	-	-	-
CO2	"	3.112111	3.587242	3.804098
CO	"	0.000196	0.000226	0.000240
NO2	"	0.000014	0.000016	0.000017
NO	"	0.001834	0.002114	0.002244
MF	"	0.000370	0.000426	0.000452
MA	"	0.000018	0.000020	0.000022

Table 2.14: The performance of the BOILER presented as component-wise DREs

Simulation Run	FA	TVOC (as carbon)	NOx (as NO2)	CO
	[%]	[%]	[%]	[%]
As-is	95.05	94.90	-	93.79
Target	99.51	99.39	-	99.96

2.5 DRE Impact Parameter 1: Residence Time

Residence time is the first and the most fundamental parameter to assure sufficient DRE. Without enough volume for the rate-determining reaction step to advance within acceptable tolerances at optimal combustion conditions in terms of air/fuel-mixture composition, temperature and fluid dynamics, there is hardly any way to tweak operation variables or revamp the TO to achieve the minimum DRE. At suboptimal combustion conditions, the residence time requirement increases, while also in case of poor mixing or premature temperature drop during combustion, the effective chamber volume becomes smaller. Nevertheless, for any specific combustion condition, there is a cut-off where any more volume inside the combustion chamber will not significantly improve the DRE.

The residence time calculation for the BOILER relies on rough estimates as there are two combustion chambers in which normally operate at different load, and possibly different AFR, causing uncertainties itself, but also uncertainties to the effective chamber volume due to missing computational fluid dynamics (CFD) representing the applicable run cases.

From the given dimensions of the TO, the physical volume of each chamber is calculated to be 3.46 m³. Given the data basis of this study and the BOILER as-is performance data, the total flue gas flow rate is 12,547 Nm³/h split roughly 2/3 to the left chamber, and 1/3 to the right chamber. The corresponding total actual flow rate is 42,445 m³/h at 650 °C which yields a residence time of 0.44 s and 0.88 s for the left and right chamber, respectively, given adiabatic conditions and uncompromised volume utilization. A mean temperature drop of 50 °C during combustion, caused by the chamber being unlined, yields a marginal greater residence time of 0.47 s and 0.93 s, respectively, due to the lower total actual flow rate of 40,146 m³/h. Further, as the feeds enter the chamber without any sort of mixing, the effective volume is drastically reduced from the physical volume, e.g. a volume utilization of 40 % yields the residence time becoming 0.19 s and 0.37 s, respectively.

By doing the same calculation exercise for the BOILER target performance data, the total flue gas flow rate is 8,706 Nm³/h split roughly 2/3 to the left chamber, and 1/3 to the right chamber. The corresponding total actual flow rate is 37,430 m³/h at 900 °C which yields a residence time of 0.50 s and 1.00 s for the left and right chamber, respectively, given adiabatic conditions and uncompromised volume utilization. A mean temperature drop of 100 °C during combustion, caused by the chamber being unlined, yields a marginal greater residence time of 0.55 s and 1.09 s, respectively, due to the lower total actual flow rate of 34,239 m³/h. Further, as the feeds enter the chamber without any sort of mixing, the effective volume is drastically reduced from the physical volume, e.g. a volume utilization of 40 % yields the residence time becoming 0.22 s and 0.44 s, respectively.

From DYNEA's experience, in past thermal oxidizer commissioning activities, but also follow-ups on thermal oxidizers in operation both on site in Lillestrøm, Norway, and at fasil®-licensee sites, the residence time even down to 0.5 s has proved high enough DRE to meet the regulatory emission requirements given sufficient combustion temperature and mixing prior and during combustion which is being pointed out in the following two subsections about the two remaining DRE impact parameters.

2.6 DRE Impact Parameter 2: Combustion Temperature

Sufficiently high combustion temperature is decisive for the DRE. As the TO is integrated inside the BOILER, the temperature dispersion throughout the spatial dimensions (axial, radial and lateral) is susceptible to high gradients causing a rapid drop in combustion temperature at which a minimum DRE cannot be met. While H₂ is easily oxidized to the level of 100 % DRE and self-sustaining once ignited at the concentrations seen in the tail gas of a silver formaldehyde plant, the VOCs on the other hand require persistent high temperature throughout the course of reaction to conduct a reasonable DRE.

All thermal oxidizers in connection with DYNEA's silver formaldehyde technology (fasil®) are instructed by the vendor to not run lower than 850 °C to ensure the minimum DRE requirement. That does not mean that the FA emissions can't be reduced below the emission threshold with a lower temperature than 850 °C as an increased effective chamber volume and/or more effective mixing of the feeds will compensate for that. However, putting numbers to each effect on the DRE is not practical as it requires high fidelity models of the exact processes.

In practical terms, DYNEA typically aims for a minimum combustion temperature of 900 °C for the fasil® tail gas to assure a high DRE even for the hardest combustible VOCs like MA.

Higher combustion temperatures come, however, at the expense of increased NO_x emissions, but are limited by lowering the peak flame temperature by assuring high degree of turbulence (reactant mixing), and by limiting the residence time of which the flue gas stays at elevated temperatures after completed combustion. By no means have DYNEA had any problems with regards to NO_x from any of the thermal oxidizers in operation to date.

2.7 DRE Impact Parameter 3: Turbulence

Sufficient mixing of the reactants is the third critical parameter for the DRE. Turbulence per se is not important, but turbulence is typically a precursor to form decent mixing. Suboptimal mixing makes the effective combustion chamber volume become smaller, as mentioned earlier. While on the opposite end, efficient mixing drastically reduces the required residence time given the combustion temperature being effective for oxidation of the combustibles.

The combustion temperature being effective is an absolute criterion that cannot be emphasized enough. However, well mixing during combustion at elevated temperatures is crucial to maximize the DRE of VOCs as rapid and thorough mixing promotes near complete combustion of VOCs due to the countless and vital reaction mechanisms that happens in the presence of a flame, while simultaneously minimizing the formation of NO_x due to the reduction of flame temperature peaks. Theoretically, the effective chamber volume and the mixing efficiency have some degrees of freedom for give and take to achieve the same high DRE, but the combustion temperature flexibility is a lot more rigorous as there comes to a point where the most efficient mixing combined with a decent and effective chamber volume cannot make up for any lower temperature to keep up the same high DRE.

The turbulence of the combustion in the BOILER is rather scarce primarily due to the lack of reactant inmixing. The feeds come into the combustion chamber separately with no proper alignment in terms of dictation of flow direction, flame stabilization, mixing efficiency and volume utilization. Hence, the achieved mixing is inherently induced by the flame developed and by the draft through the TO.

DYNEA have primarily experience with two types of thermal oxidizers; one that may be either separated from or integrated with the boiler, where full flow directing of the feed streams occur initially at the burner side in front of the pre-combustion chamber; and one that is solely integrated with the boiler, where the burner facilitates near-wall introduction of the feed streams into the pre-combustion chamber perpendicular to the axial direction, creating a swirl for maximum chamber volume utilization and turbulence for optimal reactant mixing. The burner is connected to the pre-combustion chamber (the burner assembly where the majority of the fuel is oxidized) which further is attached externally to the boiler/combustion chamber (where the slower reactions are finalized). The pre-combustion chamber is lined with refractory material for heat conservation, as well as the combustion chamber itself incl. piping in cases where the thermal oxidizer is separated from the boiler, whereas the combustion chamber is unlined in cases where the thermal oxidizer is integrated with the boiler.

3 Discussion

3.1 Tail gas and foul air VOCs

Analyses has shown, from DYNEA's database of tail gas compositions from comparable silver formaldehyde plants, that FA typically lies within the range 100 – 200 mg/Nm³, and rarely exceeds 300 mg/Nm³ even for plants with moderate absorption design in terms of top section internals and absorbent cooling. As the reported FA concentrations in the tail gas and the foul air of the FA PLANT are 1,017 mg/Nm³ (wet) and 1,030 mg/Nm³ (dry), respectively, there are surely potential for improving the figures by revamping the absorption sections and/or including new scrubber facilities prior the streams entering the BOILER.

While MF is highly volatile, and hence the dominant VOC of the tail gas, the TVOC concentration cannot improve considerably even if the FA absorption improves. Still, it's the FA component which is of concern in this study, meaning that any improvement in reducing the concentration of FA being fed to the BOILER is an overall enhancement even though modifications to the TO is probably inevitable to manage the permissible emission limit.

3.2 Validity of the data basis

When comparing the process simulation results (Table 2.12) and the latest reported emissions (Table 2.3 and Table 2.4) with regards to O₂ and water, there seem to be an underreporting of water and an overreporting of O₂ in the flue gas by the assumption that the data basis for the process simulations are correct. By looking from the other way, assuming the reported data are correct, there should be remarkably less H₂ in the tail gas to balance out the discrepancies of both O₂ and water. However, such a reduction of the H₂ content in the tail gas is not feasible from a conventional silver formaldehyde plant.

When comparing the process simulation results (Table 2.12) and the first reported emissions (Table 2.1) with regards to CO₂, there are indications that the tail gas should contain more CO₂ than assumed and used in the data basis. This is to some extent achievable but implies a low yield on the reactor of the formaldehyde plant. Moreover, the CO₂ content of the foul air is not explicitly known as it is only assumed to be VOC contaminated air.

3.3 Revamp recommendations – general perspectives

DYNEA see 3 main issues to solve to manage the permissible emission limits:

1. Premixing/directing of the feed streams
2. Uniform operating conditions between left and right combustion chamber
3. AFR control (including excess O₂ and inside chamber flue gas temperature monitoring)

The positive effects of directing the feed streams for well mixing during the combustion phase are quite obvious just by comparing the reported VOC emissions from Table 2.4 where the flue gas analyzes were performed twice the same day with a few hours apart only to compare the results of having the foul air fan running vs. not running. If the inmixing of foul air had been comparable to the inmixing of tail gas, the numbers would look like 13.9 mg/Nm³ (not like 33.3 mg/Nm³ as in table) and 6.7 mg/Nm³ (not like 39.0 mg/Nm³ as in table) for the FA and TVOC (as carbon), respectively, when the foul air fan was ON. The hypothetical numbers are calculated assuming a proportional increase in FA and TVOC emissions from the reported numbers when the foul air fan was OFF, given the change in total FA and TVOC flow rates of the applicable feed streams (tail gas + foul air vs. tail gas only).

The revamp must ensure adequate directing or partial premixing of air (parts of foul air and/or ambient air feed) into the tail gas feed for flame stabilization and direct the remaining air (which would be the majority of the total foul air and ambient air) into the flame. By doing so, the feed streams become well mixed during combustion, creating turbulence, and together with the flame, which is an essential driver for fast and easy oxidation (primarily due to the formation of the highly reactive radicals) of components that would otherwise be hard to decompose and oxidize, satisfactory oxidation conditions are established for in the end assuring conformity with the emission regulations.

One side note is that all feed pipes should ideally be insulated and possibly heat traced, for multiple reasons. One is clearly to assure well mixing and a homogeneous vapor phase for combustion. The feed streams connected with pipes are all close to or at saturation, causing a high likelihood of condensation/droplets which ultimately may impair the DRE. An alternative for heat tracing of the pipes is to have the feed streams superheated. Nevertheless, insulation is inevitable in either case.

As the distribution of the incoming tail gas flow is 2/3 to the left chamber and 1/3 to the right chamber, while the incoming foul air flow is not following the same split ratio but rather distributed equally between the chambers, there becomes a significant skewed demand for ambient air inmixing in order to equalize the AFR. Not only is the difference in residence time consequently becoming a factor of 2, but also the correct feed flow rate of ambient air becomes hard to control as the flue gas fan is common for both chambers, and the only applicable manipulated variable is the individual opening position of the dampers. Adjusting these dampers by hand for control is impractical and almost impossible in practice as they are coupled in this multiple-input, multiple-output (MIMO) system, e.g. a single change in the damper opening of one side of the TO will inherently impact the operating conditions of both sides like flame stability, dispersion, combustion temperature, DREs and excess O₂.

High combustion temperature is required to minimize the emissions of VOCs. Hence, tight AFR control is required to keep the excess O₂ at adequate levels (typical target concentration range of O₂ in the flue gas is 1.5 – 2.5 % v/v from DYNEA's experience). The revamp must ensure uniform operating conditions between the two sides of the TO, that being a mirrored-like installation of the feed streams and the burner assemblies with common control valves for a true equalized parallel setup, or an independent installation of the left and right burner assemblies with individual control valves for more operation flexibility. The latter, however, is more reliant on flue gas temperature monitoring inside the chamber of each side to verify the oxidation conditions as an O₂-concentration analyzer installed on the flue gas duct cannot verify the individual chambers' oxidation conditions, particularly if the loads are different between the two sides.

3.4 Revamp recommendations – detailed perspectives

DYNEA have as mentioned experience with primarily two types of burners for oxidation of tail gas from silver formaldehyde plants:

1. Conventional forward flame type burner (Fives North American Magna-Flame™ Series)
2. Swirl flame type burner (Saacke SSB Series)

The latter type is quite sophisticated, highly customizable in terms of fuel connections and fuel types, while securing high DREs. However, the expense of installing such a burner assembly is considerably higher compared to a conventional forward flame type burner that is just as capable of oxidizing FA with ease, which is the primary concern of this study. DYNEA's recommendation is therefore to install two burners of the type Fives North American Magna-Flame™ Series, one connected to each combustion chamber of the BOILER.

The Fives North American burner should facilitate the tail gas coming in via the gas fuel connection, whereas the foul air including the additional ambient air coming in via the air connection. All the feed streams must be free from condensate, and hence, insulation, superheating and/or heat tracing must be in place. As far as the turndown ratio is concerned, the feed steam arrangement should be mirrored between the two burners and have all control and degradation elements on the common lines, if possible, e.g. control valves, fans and filters. A fan for supply of the ambient air must potentially (but not necessarily) be installed. Whereas any existing fans for the tail gas and the foul air, including the flue gas fan, are subject to (but not limited to) replacement. The burner must be equipped with a gas-boosted pilot and a UV-scanner for flame supervision. The AFR must be tightly controlled by the burner management system (BMS) to assure the correct combustion conditions. The BMS shall also manage start-up, operation and supervision of the burner. All safety functions shall be handled by the BMS. Support functions, controls and communications which are not in relation to safety can be handled by other control systems.

Typical required instrumentation would be pressure monitoring and control of the feed streams to ensure proper AFR control (particularly if based on control valve opening positions rather than mass flow meters) and min./max. operating pressure, and O₂-analyzer on the tail gas stream to prevent flashbacks (typically dual fast closing isolation valves in series are required for compliance with EN ISO 13577-2:2023). Highly advocated instrumentation would typically be O₂-analyzer on the flue gas stream, and temperature monitoring somewhere inside the combustion chamber (possibly on the brickwork of the refractory lining in the pre-combustion chamber which has a longer time constant for smoother temperature readings and lower readings overall, offset from the actual combustion temperature to enhance the thermocouple lifespan and mitigate drift with time). Flow measurements of the feed streams which are based on dP-measuring principles are typically optional and may be used for information but cannot be used for control.

Required utilities are instrument air, LPG or natural gas for the pilot burner, and cooling air for the UV-scanner and the pilot burner (may be substituted by instrument air if desired and if the supply is satisfactory). For Ex-zoned areas, N₂ is typically required for performing the leakage test of the dual shut-off valves on the tail gas line, as well as for flushing the tail gas feed pipe to the burner.

4 Conclusion

The assessment confirms that the current thermal oxidizer/boiler arrangement is not capable of consistently meeting the formaldehyde emission requirement in its present configuration. Although the existing system provides substantial oxidation of combustible components, the achieved destruction and removal efficiency is insufficient for reliable compliance with the formaldehyde limit of 5.0 mg/Nm³ (dry), primarily because the combustion process is constrained by inadequate mixing, insufficient effective residence time and too low combustion temperature under high-excess-air operation.

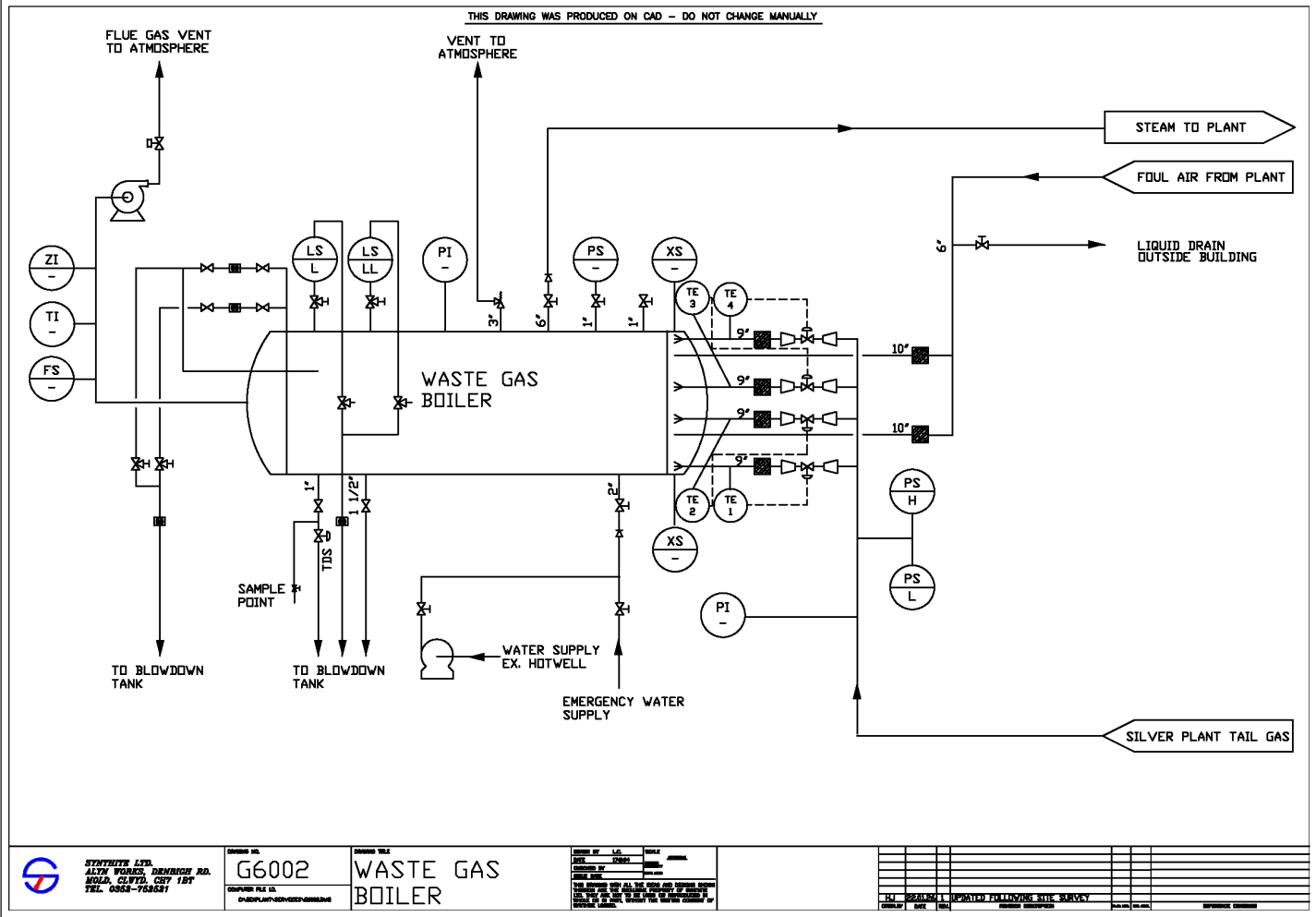
The study further shows that the present feed arrangement causes uneven operating conditions between the two combustion chambers and makes proper AFR control impractical. Tail gas, foul air and ambient air enter the combustion chamber separately and without adequate flow direction, which limits turbulence and reduces effective chamber volume utilization. In addition, the current manual handling of ambient air and the non-uniform distribution of tail gas and foul air create a highly skewed combustion pattern that weakens flame stabilization and oxidation efficiency.

Simulation results demonstrate that the required emission performance is achievable if the combustion system is redesigned to operate at substantially improved oxidation conditions. A conservative target case with reduced ambient air supply and higher combustion temperature indicates that formaldehyde emissions can be reduced from approximately 33.3 mg/Nm³ (dry) to 5.0 mg/Nm³ (dry), while TVOC can be lowered from approximately 39.0 mg/Nm³ (dry) to 7.0 mg/Nm³ (dry) and CO reduced dramatically, all while keeping NO_x within an acceptable range. This confirms that the principal route to compliance is not merely operational adjustment, but a technical revamp of the burner and feed introduction concept.

DYNEA therefore recommends that SYNTHITE implement a revamp centered on dedicated burner assemblies for each combustion chamber, with proper directing and/or partial premixing of the fuel and air streams, tight AFR control, and improved monitoring of oxygen and combustion temperature. The proposed solution should also include insulation and, where required, heat tracing or superheating of the feed lines to prevent condensation and maintain homogeneous vapor-phase combustion conditions. In addition, suitable burner management and safety systems, together with the required process instrumentation, are necessary to ensure reliable operation and regulatory compliance.

In summary, the elevated formaldehyde emissions are assessed to be a consequence of fundamental design and control limitations in the current combustion arrangement rather than an isolated operating deviation. With the recommended revamp measures in place, SYNTHITE should be able to establish stable combustion conditions, significantly improve VOC destruction efficiency, and achieve sustained compliance with the applicable emission requirements.

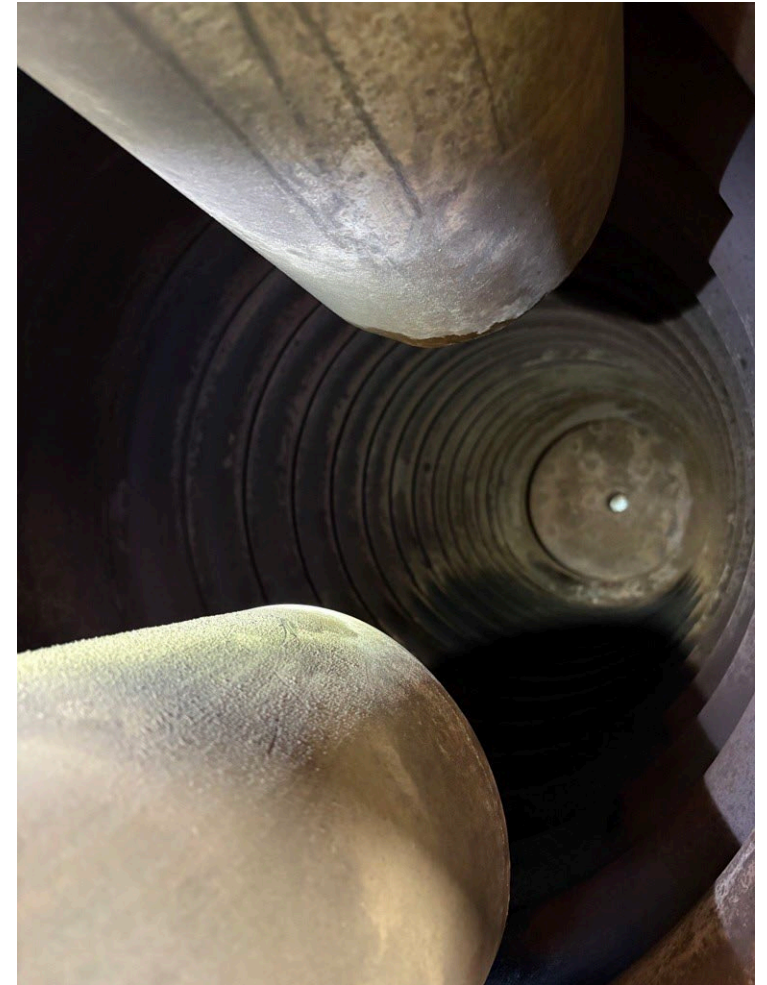
A Boiler P&ID



B Thermal Oxidizer Feed Streams Arrangement



C Combustion Chamber and Internals of the Thermal Oxidizer



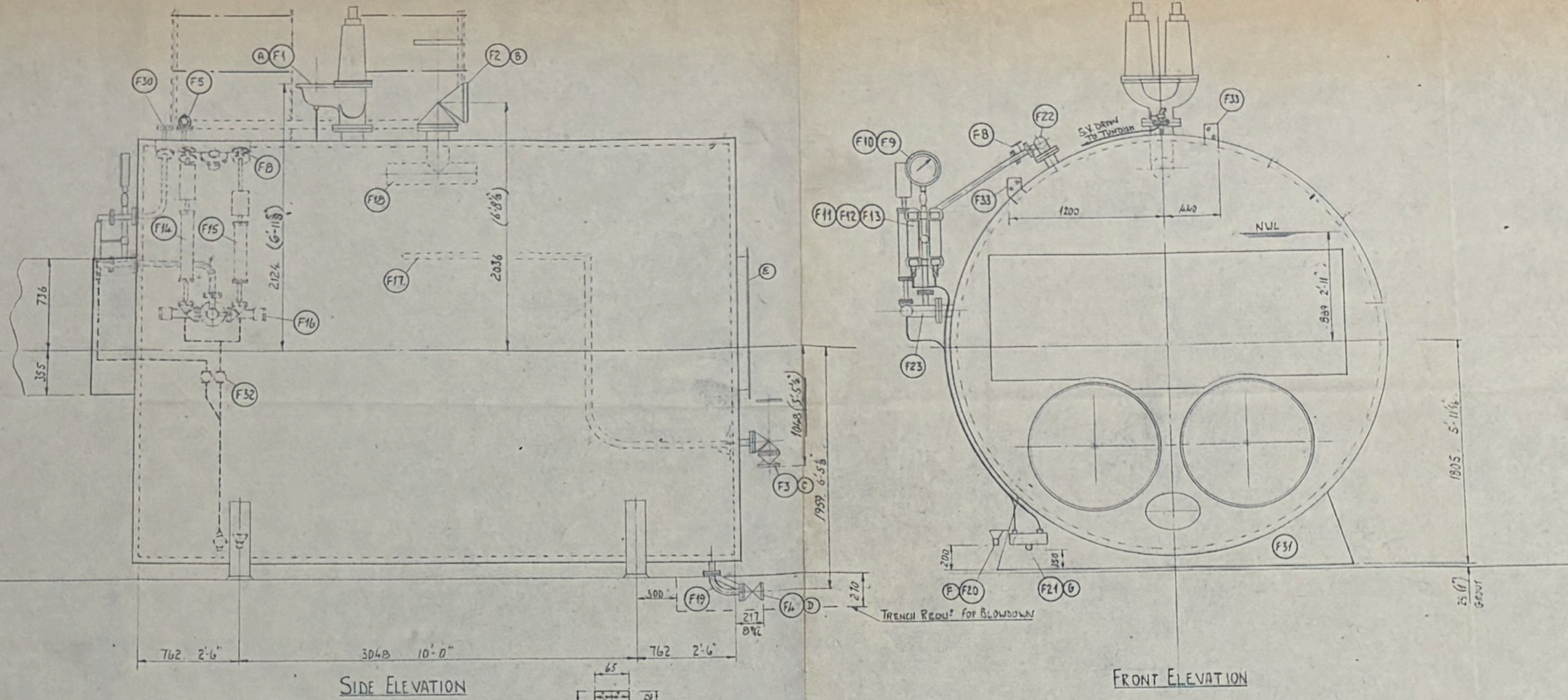
D Boiler Arrangement



Boiler
Arrangement.jpeg

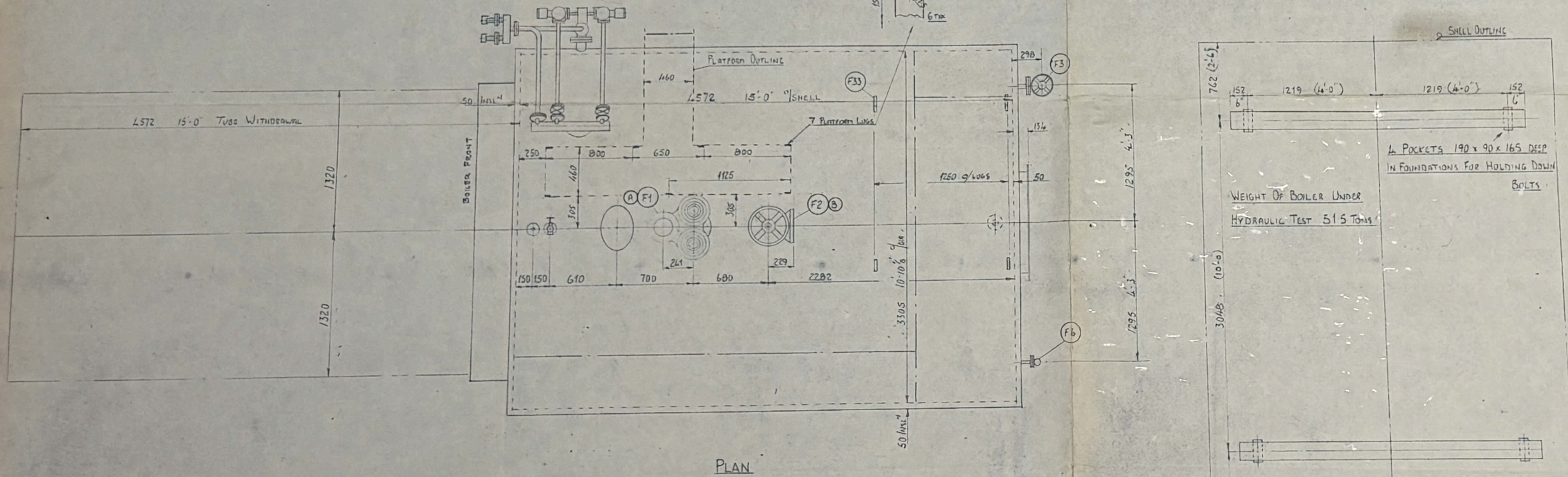
Standard Ladder & Platform Supplied
At Extra Cost If Required

6 7/8" Diameter Cleared Area
Tubed Up @ Sides To Form
Kickerplate



SIDE ELEVATION

FRONT ELEVATION

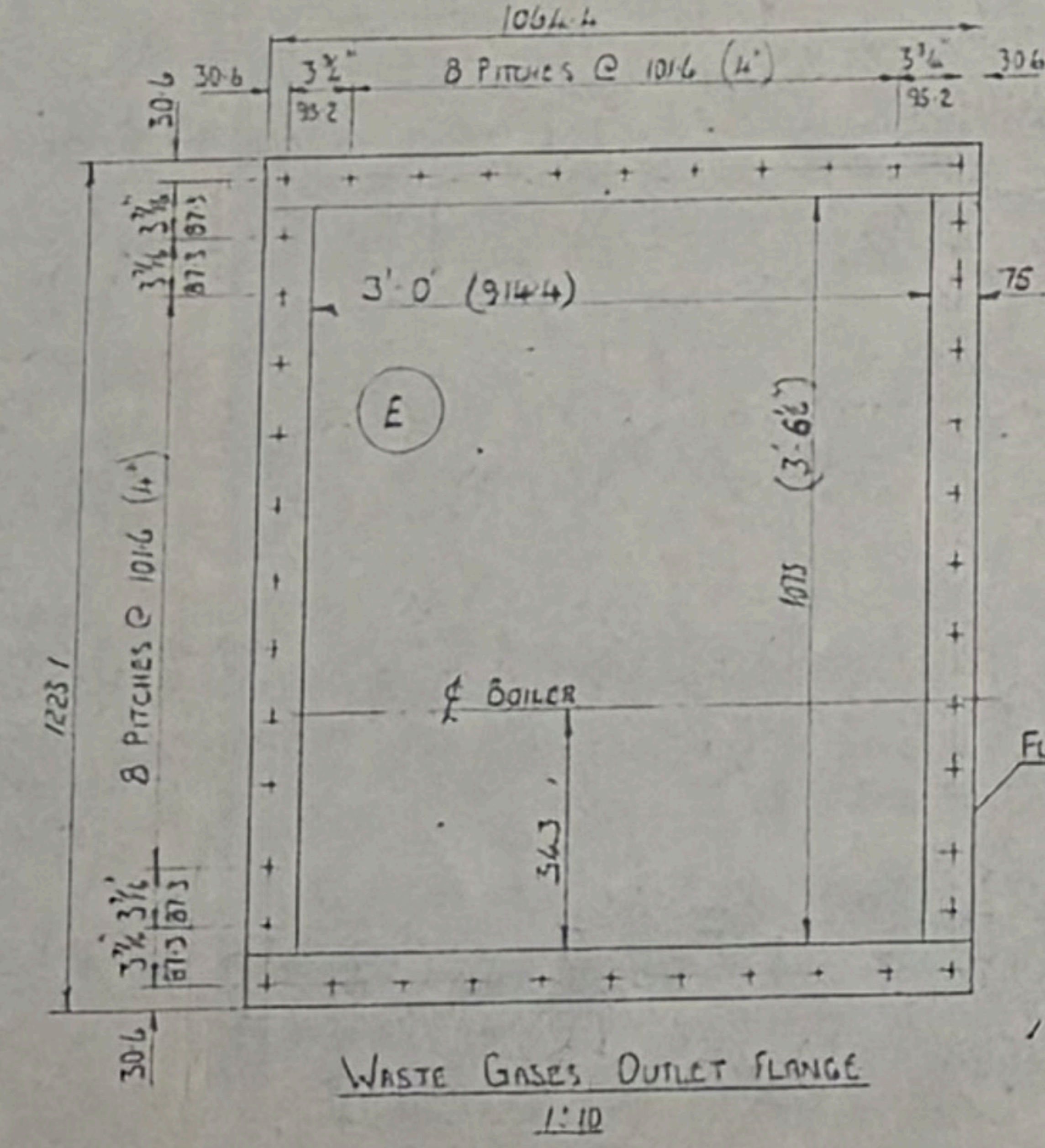


PLAN

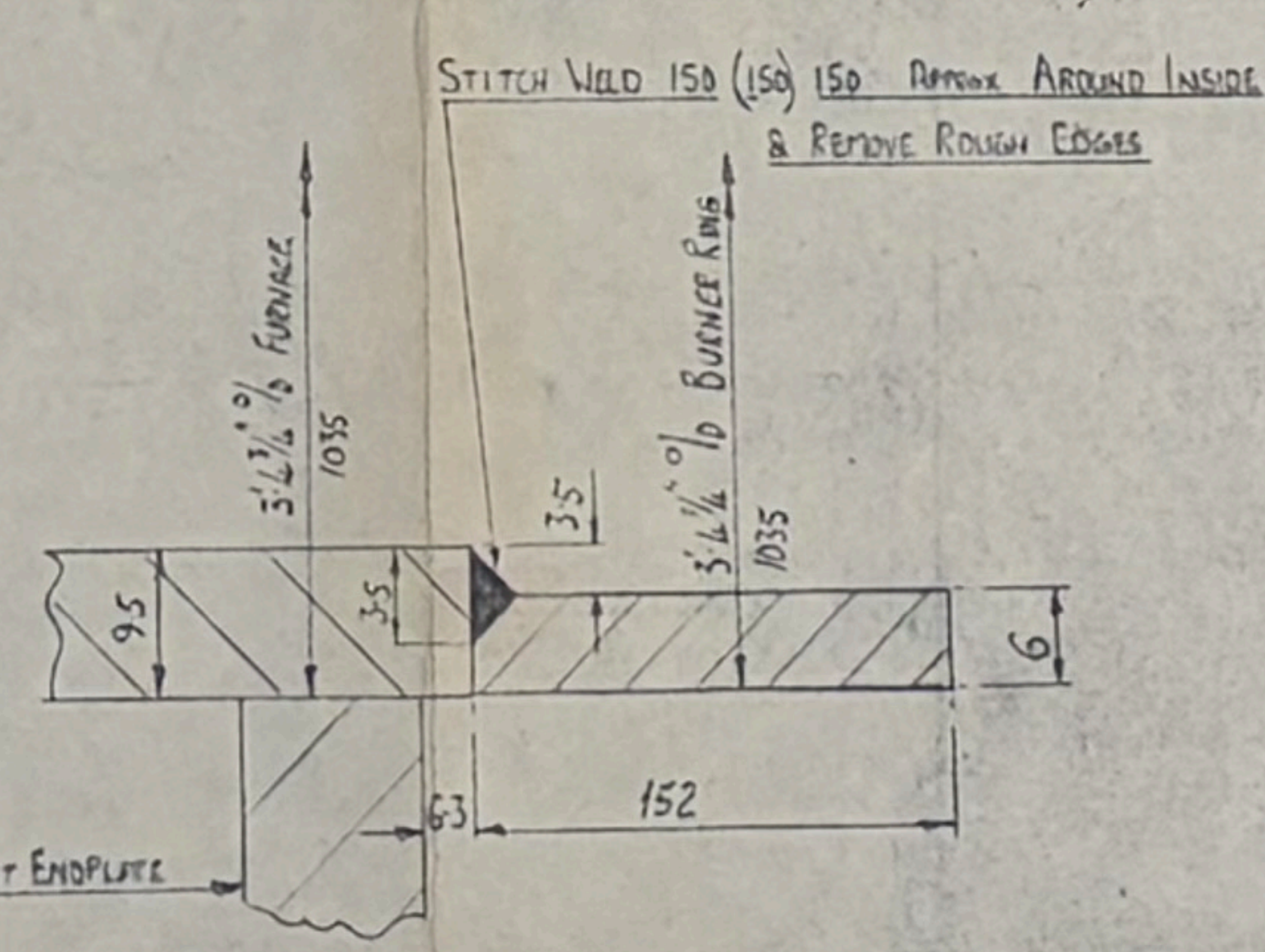
FIG No	REV	DESCRIPTION	MATERIAL	REMARKS
1021	F1	Double Spring Safety Valve 3"		SHAW
5041	F2	Main Stop Valve 6"		"
5041	F3	Free Check Valve 2"		"
220	F4	PS Blowdown Valve 1 1/2" (Key Fig 243)		"
4170	F5	Vent Valve		"
4170	F6	Water Sample Valve 1/2"		"
F7	F7	Spring To W.L. Controls - 1"		"
1133	F8	Pressure Limiter 10 Dia		SHAW
6321	F9	" " " " " "		"
1174	F10	Water Gauge Valve 1 1/2" (Key Fig 243)		"
1250	F11	" " " " " "		"
1250	F12	" " " " " "		"
1250	F13	Water Gauge 1 1/2" (Key Fig 243)		"
F14	F14	Hi-Low Alarm (Key Fig 243)		R TEST
F15	F15	Down Controls (Key Fig 243)		"
1250	F16	Spring To W.L. Controls - 1"		"
F17	F17	Internal Free Pipe (Key Fig 243)	Sp. Steel	G.C. 11/11
F18	F18	Drainage	"	"
F19	F19	Blowdown Pipe	"	"
F20	F20	Drainage	"	"
F21	F21	Hi-Low	"	"
F22	F22	Steam Main Valve (Left Hand)	"	"
F23	F23	Water	"	"
F24	F24	Set Pipe for W.L. Controls, W.L. Controls & Drains	"	"
F25	F25	Flanges Nameplate	"	"
F26	F26	Manhole Door 24" dia x 16 1/2" x 1/2" Tar	"	"
F27	F27	" " " " " "	"	"
F28	F28	Tube Supports T11 & T12	STD Y1	"
F29	F29	" " " " " "	"	"
F30	F30	Bundy Flange To 1/2" dia BS10 - Flange H	"	"
F31	F31	Stools	"	"
F32	F32	Supports for W.L. & Steam Main Drains	"	"
F33	F33	L.D. Fan Lugs	Disc 727216	"

Ref	Qty	Description	CONNECTION
A	1	Safety Valve Head - Off	Flange 4 1/2" dia BS10 Table D
B	1	Main Stop Valve Discharge	6 3/4" dia BS10 Table E
C	1	Free Check Valve	2" dia " " F
D	1	Blowdown Valve	1 1/2" " " F
E	1	Water Gauge Outlet Flange	See Detail
F	1	Drain Through	1" BSP. Female
G	1	HEADER	"

NOTE: WASTE GASES OUTLET DUCT AREA = 490 sq. in. (316128 mm²)
Minimum



WASTE GASES OUTLET FLANGE
1:10



DETAIL OF BURNER RING N.T.S.

ISSUE NO	DRAWN	CHECKED	APPROVED	DATE
4	KP	LA	15/15	BURNER RING DETAIL MODIFIED
3	KP	LA	6/11	ESS PIPES & POSITION OF PLATFORM LUGS INDICATED
2	KP	LA	4/11	MODIFIED TO CLIENTS REQUIREMENTS & PARTS LIST SUPPLIERS CHANGED
1	KP	LA	11/11	FIRST ISSUE

CONTRACT No 20/00661
FOR SYNTHITE LTD.

MACHINING TOLERANCES	SURFACE FINISH	BRITISH RANGE
EXCEPT WHERE OTHERWISE STATED -	CONTINENTAL	100/1000
NICHES	▽	ROUGH - MACHINE MARKS VISIBLE
0 - 1/16	▽▽	SMOOTH - MACHINE MARKS JUST VISIBLE
ABOVE 1/16 - 1/8	▽▽▽	FINE SMOOTH - MACHINE MARKS NOT VISIBLE
ABOVE 1/8 - 1/4	▽▽▽▽	HARSH FINISH

BOILER ARRANGEMENT

SCALE 1:20
ISSUED BY WALLSEND D.O.
DRG. No. 727220/4

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