Reworld Tulsa
2122 South Yukon Ave
Tulsa, OK 74107

February 27, 2025

Ms. Hillary Young, PE
Chief Engineer
Land Protection Division
P.O. Box 1677
Oklahoma City, OK 73101-1677

Subject: Reworld Tulsa RMW Solid Waste Permit No. 3572033
Response to Land Protection Division Discussion on January 16, 2025 and email dated February 21, 2025

Dear Ms. Young:

Reworld Tulsa (formerly "Covanta") appreciates the Oklahoma Department of Environmental Quality's ("ODEQ" or "Division") review of Reworld's permit modification application for the addition of Regulated Medical Waste ("RMW") as an allowable fuel at the Tulsa facility. Per the discussion on January 16, 2025, and Ms. Daneshmand's email dated February 21, 2025, Reworld is providing this correspondence.

Specifically, Reworld is addressing the following requests:

- **Provide a clear breakdown of the equations, including coefficients and variables used in Martin's model.**

  See Response #7 below. Martin's updated report is attached in Attachment A.

- **Provide the basis for selecting Model A for destruction efficiency calculations but Model E was utilized to determine the flue gas temperature limit in the upper furnace.**

  See Response #5 below and the revised Martin report in Attachment A. Model B provides the most conservative results and will be used for monitoring the upper furnace temperature. A comparison of each model's minimum temperature at the IR to ensure 2000 °F at the grate is included in Response 5.

- **Provide the free radical concentrations utilized in the destruction efficiency calculations.**

  See Response #6 below.

- **Provide a revised (or submit a new) contingency plan for addressing actions to take in the event visual observation of incomplete combustion or in the event the interlock system is triggered.**

As noted in Response #4 below and in Appendix C of the Application, Reworld proposes any unburned material be returned to the units for reprocessing.

- **For the variance to periodic testing requirements, DEQ proposed periodic visual inspections. Reworld was to brainstorm options that would work for its operations and facility.**

  See Response #3 below. Reworld proposes visual inspections.

- **Reworld indicated they are still evaluating the flue gas temperature limit in the upper furnace and the frequency for monitoring.**

  See Reworld's discussion under Response #5 below.

- **Provide documentation that the fixed radiation monitors are in compliance with OAC 252:33-32(b).**

  See Response #1 below.

- **Provide variance justification from OAC 252:515-23-32(c). This rule requires an interlock system for radiation.**

  See Response #2 below.

- **Provide the size of the storage area where wastes will be segregated in the event radiation is detected.**

  Appendix F, Figure 1 of the Application identifies the area set aside for any wastes with detected radiation. The area is approximately 100 feet by 100 feet.

Detailed Responses

1. **Calibration Certificates for radiation monitors.**

   Per email dated 2/21/2025 from ODEQ, calibration data provided by the manufacturer is sufficient to demonstrate compliance with OAC 252:515-23-32(b). ODEQ will write the permit for Reworld to provide the calibration data for the unit(s) purchased once available.

2. **Variance justification from OAC 252:23-32(c).**

   As stated in Appendix G of the permit application, Reworld already monitors its incoming wastes for radioactivity to meet the requirement that no radioactive material be accepted.

For the RMW wastes, new radiation monitors will be co-located with the RMW receiving scales

Radiation monitors are set to alarm at two times the natural background radiation levels (4.5 micro-roentgens/hour).

By scanning the wastes on arrival, Reworld ensures accepted wastes comply with its Waste Exclusion Plan (WEP). Reworld already has its operating procedure for handling wastes which exceed radioactivity thresholds.

Although Reworld delivers waste to the combustion units via a conveyor system, the process is still a manual one with potential personnel exposure during unloading of trucks and loading to the conveyor belt. Thus, Reworld requests a variance from this redundant monitoring for radioactivity.

Monitoring at receipt ensures protection of employees and prevents any offloading or further handling of radioactive materials.

Radiation monitoring at receipt is more protective than waiting and scanning after unloading and handling.

A radiation monitor interlock is not necessary since the radiation monitor at the scale is sufficient and meets the radiation requirements. If the radiation monitor at the scale detects radiation, the truck will be isolated and rejected per current procedure. The radiation inspection as part of the receiving activities protects employees from possible radiation that would be associated with the unloading of wastes and allows an expedient return to the generator.

3. **Develop options for the periodic visual inspection of ash to determine the presence of unburned components of RMW.**

   Reworld Tulsa proposes to incorporate a monthly visual ash inspection while combusting RMW. Records of these visual inspections will be maintained at the facility offices.

4. **Develop an SOP for inspection of ash due to specific events that could pose a risk of unburned RMW present in the ash (e.g., sudden boiler shutdown due to boiler tube failure, prolonged low temperature event).**

   The proposed RMW Processing SOP included in the ODEQ Land Application (Appendix C) includes a procedure to address emergency shutdown scenarios during RMW processing.

Appendix O of the application further detailed the following action to be taken related to delivery of RMW to the combustors:

> Covanta Tulsa's air quality permit specifies the facility's start up and shut down procedures as well as limits the total time during which start up and shut down activities may take. Finally, as detailed in Appendix C of this permit application, RMW material is not delivered to the burners until the units are at full operating condition. RMW is delivered to the units via a containerized conveyor belt system. In the event Covanta Tulsa noted a concern [or the interlock system was triggered], the operator would turn off the RMW delivery system. Waste already in the burner would remain for its normal time.

The facility already monitors its ash for incomplete combustion. Any unburned RMW material visually observed in the ash would be returned to the combustion units for reprocessing.

5. **Determine the minimum 1-min temperature as measured by the IRs that correlates to a minimum temperature of 2,000 degrees at the grate.**

Reworld proposes to establish a minimum flue gas temperature in the upper furnace of each combustor which will serve as the basis for interlocking the RMW feed system at times when RMW is being processed, as was done at its Lake County and Marion County facilities (where Reworld also processes RMW). The minimum flue gas temperature will be correlated (based on the temperature studies conducted and the modeling performed) to a grate temperature of 2000°F. Compliance with the upper furnace temperature limit will be determined by continuous flue gas temperature monitoring at the elevation of the existing Infrared Pyrometers (70 feet, which is 40 feet above grate level). Reworld will install an electrical interlock system between that upper furnace temperature (monitored using the IR Pyrometers) and the RMW feed system so that in the event the upper furnace temperature falls below the minimum, the RMW feed system will cease operation until the upper furnace temperature is above the required temperature.

Reworld proposes a 1-minute average flue gas temperature of 1305˚F at elevation 70 feet as the minimum temperature below which the RMW feed system interlock will be activated. The proposed 1305˚F limit ensures a minimum temperature at the grate level of 2000˚F. The proposed limit is calculated based on the five (5) load condition models analyzed by Martin GmbH ("Martin"), the original equipment manufacturer, based on actual operating data collected at the Tulsa facility in 2024. The five (5) load conditions are defined in **Table 1** below and vary in terms of the HHV of the waste and feed rate to the MWC. These load conditions represent the range of normal operations of the unit.

Table 1 Tulsa Modeled Operating Scenarios and Minimum Temperature Calculations

		Model A	Model B	Model C	Model D	Model E
1	**Thermal Load (%)**	97	97	97	87	87
2	**HHV (kBTU/lb)**	5.7	5.2	6.2	5.2	6.2
3	**Feed Rate (tons/hr)**	13.9	15.3	12.5	13.8	11.3
4	**Grate Temperature (°F)**	2584	2544	2630	2594	2680
5	**Average Modeled IR Temperature (°F)**	1858	1849	1865	1795	1810
6	**Grate Temperature Minus 2000 °F (°F) (Line 5 - 2000 °F)**	584	544	630	594	680
7	**Min Temp to ensure 2000 F at the grate (°F) Grate Temperature Minus 2000 °F (Line 5 - Line 6)**	1274	1305	1235	1201	1130

The monitored temperature at the IR Pyrometer elevation for each load condition was correlated to temperatures in the furnace. Of the five (5) load conditions analyzed by Martin, Model load condition B was used to establish the proposed minimum temperature because it reflects the most conservative conditions. As shown in Table 1 above and on page 21 of the final Martin report provided in **Attachment A**, the grate level temperature for Model B is calculated at 2544°F, and the predicted temperature at the IR-level for Model B is 1849°F. The temperature difference between the grate level temperature of 2544°F and the referenced 2000°F is 544°F. Subtracting this difference (544°F) from the predicted IR-level temperature of 1849°F yields a temperature of 1305°F at the IR-level. Calculated in the same manner as shown in **Table 1**, the IR-level temperatures to verify a grate-level temperature of 2000°F for each of the other four (4) load condition models analyzed by Martin were less than 1305°F. Therefore, the 1305°F minimum 1-minute average temperature was conservatively chosen as the temperature limit for triggering the feed system interlock.

6. **Provide the free radical concentrations utilized in the destruction efficiency calculations.**

   Dr. Philip Taylor's report, submitted by Reworld to ODEQ on December 13, 2024, demonstrated a DRE of 99.9999% for monochlorobenzene. His thermal kinetic modeling of the Tulsa municipal waste combustor is based on time and temperature profiles of the municipal waste combustor completed by Martim GmbH, the designer of the MWC units at the Tulsa Facility.

   Free radical concentrations of 0.8 parts per million for hydrogen atoms (H) and 12 parts per billion for hydroxyl radicals (OH) were developed by Dr. Taylor for use in the DRE calculations based on the waste composition and stoichiometry for load condition Model A in the Martin report.

   Dr. Taylor determined the free radical concentrations by using the chemical equilibrium program STANJAN, developed at Stanford University and widely used to determine concentrations of chemical constituents in complex reactions. Dr. Taylor used the version of STANJAN available online from the Bioanalytical Microfluidics Program in the Department of Chemical and Biological at Colorado State University (https://navier.engr.colostate.edu/research/). Input parameters to the model include temperature, pressure, reactant (fuel) chemical constituent concentrations based on waste analysis, and expected flue gas composition representing the product of the reactions. The waste composition and waste-to-air ratio from the Martin model were used to define the reactants. The output gas composition -- including CO, CO_2, H_2O, H_2, O_2, N_2, NO, CH_2O – was used to define the product of the combustion reactions. The expected CO_2, H_2O and N_2 concentrations were validated with the data from the Martin profile.

7. **Provide a clear breakdown of the equations, including coefficients and variables used in Martin's model.**

   In preparing the application for RMW processing at Reworld Tulsa, the facility recognized the need to better understand the relationship between time and temperature from the furnace grate to the exit of the first pass of the boiler. Of course, the extremely elevated temperatures at the grate preclude direct continuous measurement, so to understand the dynamic environment within the municipal waste combustor required a combination of flue gas temperature measurements in the upper furnace and modeling of various operating load conditions.

As a result, in late 2024 and at Reworld's request, Martin GmbH ("Martin"), the designer of the MWCs at the Tulsa Facility, conducted a temperature profile study of one of the units at the Tulsa facility using design data, temperature measurements of the flue gas in the upper furnace using Infrared Pyrometer technology ("IR technology"), and overfire and underfire air flow data along with other operating data including the oxygen concentrations of the flue gas. The study provided calculated temperatures at grate level for different thermal load conditions representing a range of normal operation of the unit. The calculated temperature at grate level for each load condition was then used for predicting the elevations at which specific flue gas temperatures targets were achieved which also allowed a determination of residence time. A report of the Martin GmbH study was originally included with Reworld's response dated November 27, 2024, to ODEQ's Air and Land Division Notices of Deficiency. A final version of the Martin GmbH report with additional information as noted below is in **Attachment A**.

As noted in Response No. 5 above, Martin correlated the time and temperature at five (5) different boiler thermal load condition points (Models A-E) that reflect an expected range of waste feed rates and higher heating values of the waste. The design and operating data allowed Martin to determine the temperature at grate level for each of the five (5) operating scenarios. See Table 1 above for a comparison of the five models. Martin's analyses were used to establish a proposed minimum grate temperature as measured in the upper furnace to verify that RMW is being introduced to the furnace when the grate temperature is 2000°F or greater.

In response to ODEQ's request for additional information concerning Martin GmbH's temperature profile study, Martin revised its previously submitted report with clarifying information. **Attachment A** contains the final Martin report as well as a summary of Martin's expertise in engineering and construction of thermal waste treatment plants and a description of their approach in creating the model for evaluating the municipal waste combustion unit at the Tulsa Facility. As noted, the description of Martin's approach references the page numbers of the study.

As described by Martin in **Attachment A**, the steps in the development of the model included the following:

1. Monthly data on the higher heating value of the waste processed at Tulsa in 2024 provided by Reworld (p. 4) were used by Martin to calculate a waste composition for the analysis.
2. The next step used the waste composition and an average waste throughput rate of 13.9 tons per hour (average throughput from Reworld data) to calculate the stoichiometric air volume required to combust the waste. Note the units on the waste throughput rates in the original Martin report were in error and have been corrected from "lbs/hr" to "kg/hr" on pages 7 and 8 in the final report attached to this response

document. The actual excess air at the end of the boiler was determined based on oxygen measurements at the end of the boiler and overfire air flow measurements provided by Reworld. The results of the combustion calculation included determinations of the flue gas composition in the combustion chamber and at the end boiler as shown on page 8 of the report. The results of the combustion air calculations for the average waste processing rates in April and August of 2024 are provided on page 9 of the report.

3. To validate the calculations and models described above, Martin performed an energy and mass balance around the entire boiler. The results of the balance are provided on page 10 and show that the inlet and outlet enthalpy flows are within 2% of each other. On this basis, the quality of the operating data was deemed acceptable and that the model was an accurate representation of the system.

4. The next step in the application of the model involved using a local energy and mass balance to calculate the adiabatic combustion temperature in the combustion chamber. The equations for calculating the adiabatic combustion temperature are provided on page 12 of the report along with the sources of information used in the calculation. A new page 13 has been added to the report which contains a glossary of the terms used in the equations.

5. The last step in the model's development was calculating the temperature profile. The equations used in this process are shown on page 14 of the report and a new page 15 has been added to the report which contains a glossary of the terms used in the equations. As noted by Martin, the approach is described in the literature at "Warmetechnische Berechnung der Wasserohrkessel," a reference book on boilers and steam power. The temperature profile within the furnace is affected by the heat transferred via thermal radiation to the furnace walls.

6. The temperature profile is next adjusted based on the measured flue gas temperatures measured by Reworld at 70-feet elevation using the IR pyrometer. The specific volume and velocity of the flue gas for many small increments of height were calculated which allows the flue gas temperature to be calculated at each height. The temperature of the flue gas at each incremental height was then determined as described on page 18 of the report. The flue gas temperature at each of the incremental heights above the grate was then plotted to shape the final temperature profile and allow for the determination of residence times and temperatures at distinct levels. The plot for Model A, based on data from April 2024 provided by Reworld, is presented on page 19 of the report.

7. Four (4) additional unit operating load condition scenarios (Models B through E as specified on page 20 of the Martin report contained in **Attachment A**) based on

varying higher heating values of waste, waste charging rates and thermal loads were analyzed by Martin. Models A through E cover the full range of typical operations. Like Model A, Models B and C were based on 97% thermal load of the unit. Models D and E were based on 87% thermal load. For each load condition, the temperature profile was modeled and then refined as described above. **Figure 1** contained in **Attachment B** is a diagram of a combustion unit showing the key input parameters used in the development of the temperature profile models. The plotted profiles of the analyses for Models A and Models B through E are presented on pages 19 and pages 21-24 of the final Martin report, respectively. The 1-second flue gas residence time heights above the grate along with flue gas temperature at those heights and the calculated grate level and IR level flue gas temperatures for each of the five (5) Models have also been incorporated into the final report.

8. Sources of literature used in developing the model are provided on page 25 of the report.

We look forward to your review. Please contact us with any questions.

Yours,

SAllois

Stephanie Allois
Director, Regional Environmental
South Region

Reworld

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Attachment A: Revised Martin Report

February 2025

WASTE TO ENERGY – INNOVATION AUS TRADITION

TULSA

Temperature profile furnace/1. pass

AGENDA

1. Tasks and Aims

Calculation adiabatic combustion temperature

- Creation of a model for the combustion chamber and 1st pass
- Determination of the temperature at grate level
- Determination of the elevation of 1800 °F
- Calculation of the temperature at a residence time of 2 s. Is 2000 °F/ 2 s feasible?

2. Input Data

HHV Data Summary – Jan 2024

DATA INPUTS	UNITS	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24	Oct-24	Nov-24	Dec-24	Tot/Avg
Refuse Processed	Tons	28,121.1	10,394.0	23,126.3	28,696.1	22,619.5	28,154.1	26,933.5	29,072.8	26,113.7	26,630.7	21,592.3		**271,454.1**
Total Operating Time - All Units	Hours	2,018.5	772.2	1,831.6	2,062.5	1,638.2	2,031.6	1,981.3	2,092.9	1,854.0	1,899.2	1,625.6		**19,807.5**
Boiler 1 Steam Production	klbs	64,857.8	0.0	54,738.6	63,200.1	63,673.0	68,295.7	60,194.1	67,101.0	49,040.9	60,735.0	58,789.7		**610,625.9**
Boiler 2 Steam Production	klbs	59,064.7	36,787.1	50,017.1	65,164.2	44,983.6	62,657.8	70,442.7	69,663.2	65,906.0	58,238.5	57,504.7		**640,429.5**
Boiler 3 Steam Production	klbs	70,112.3	34,933.9	54,818.0	69,656.1	47,418.3	63,305.7	55,235.7	63,835.6	65,238.1	64,779.1	37,894.0		**627,226.8**
Boiler 1 Stm Temp	deg F	694.5	0.0	523.0	643.6	669.1	693.0	697.2	683.6	668.9	690.6	708.0		**669.0**
Boiler 2 Stm Temp	deg F	684.9	589.7	519.4	633.0	618.1	621.3	650.9	684.9	669.3	651.7	692.7		**642.6**
Boiler 3 Stm Temp	deg F	645.1	653.1	527.5	668.3	670.3	618.3	696.9	646.5	655.8	669.9	637.8		**645.0**
Boiler 1 Stm Press	psig	689.1	0.0	512.1	637.9	632.4	640.0	637.9	645.8	642.6	638.2	637.1		**632.9**
Boiler 2 Stm Press	psig	640.0	607.2	496.2	637.1	631.7	639.9	635.2	645.4	637.8	637.4	636.5		**625.3**
Boiler 3 Stm Press	psig	644.6	613.3	464.4	642.3	640.9	644.5	643.0	649.3	640.6	640.1	646.9		**626.2**
Boiler Feedwater Temperature (Avg)	deg F	231.8	241.9	234.6	216.4	222.8	220.0	212.4	230.5	209.9	203.6	181.7		**217.8**
Blr 1 Econ Exit Gas Temp (Avg)	deg F	404.0	0.0	336.0	400.0	397.0	393.0	405.0	426.0	423.0	410.0	429.0		**402.6**
Blr 2 Econ Exit Gas Temp (Avg)	deg F	426.5	388.8	326.3	405.0	387.1	381.4	397.3	424.5	408.8	382.0	429.1		**398.1**
Blr 3 Econ Exit Gas Temp (Avg)	deg F	381.5	382.0	347.1	395.9	407.5	406.4	413.5	428.8	438.5	439.7	428.0		**407.0**
Blr 1 Heated Comb Air Temp	deg F	59.0	0.0	70.0	78.8	84.2	97.3	99.6	100.7	98.0	86.0	70.8		**84.5**
Blr 2 Heated Comb Air Temp	deg F	58.4	48.3	70.2	76.9	83.0	94.4	96.8	98.4	95.8	81.7	69.9		**81.5**
Blr 3 Heated Comb Air Temp	deg F	58.8	47.5	70.0	78.6	83.0	96.1	98.3	100.4	97.0	84.9	71.8		**82.1**
Ambient Air Temp (Avg)	deg F	40.0	31.3	55.7	59.6	66.5	78.9	81.1	83.1	79.0	65.8	51.9		**65.2**
Blr 1 Econ Exit Wet O2 (Avg)	%	9.07	0.00	13.13	10.33	10.72	12.53	9.91	10.07	10.66	9.85	9.46		**10.56**
Blr 2 Econ Exit Wet O2 (Avg)	%	10.51	11.08	12.30	10.28	10.49	9.92	9.56	9.51	9.20	9.66	9.75		**10.11**
Blr 3 Econ Exit Wet O2 (Avg)	%	11.96	12.51	12.99	11.21	11.30	11.54	11.28	11.45	11.19	11.03	11.57		**11.59**
Aux Fuel Usage - Natural Gas	kcuft	6,397.00	0.00	4,642.00	2,096.00	2,966.00	5,896.00	8,980.00	6,499.00	3,708.00	5,257.00	4,122.00		**50,563.0**
HHV Raw Database Curve	Btu/lb	5,445.5	5,327.2	5,059.6	5,495.3	5,467.8	5,429.8	5,528.2	5,451.9	5,548.9	5,581.6	5,910.7		**5,482.8**

2. Input Data

MARTIN

Process Data from 10/14/2024

10/13/2024 23:34:45.803 | 2 Hours | 10/14/2024 01:34:45.803

Object Tree	Scale	Engineerin...	Tag	Raw Scale	Minimum	Maximum	Average	Std Deviation	Cursor1	Cursor1 Time
Pane1										
B1 Main Steam Flow PV	0.00 - 115.00	klbs	TulDAS.TUL_B1FT112_PV	0.000000 - 115.000000	89.0	101.0	94.0	2.3	95.5	10/14/2024 1:29:44 AM
B1 Boiler Feedwater PV	0.00 - 115.00	klbs	TulDAS.TUL_B1FI114_PV	0.000000 - 115.000000	64.9	111.6	87.6	9.6	95.9	10/14/2024 1:29:44 AM
B1 Steam Header Press PV	500.00 - 700.00	psi	TulDAS.TUL_B1PT118_PV	0.000000 - 1000.000000	618	626	621	1	620	10/14/2024 1:29:44 AM
B1 Sec SH Out Steam Temp PV	0.00 - 1,000.00	DegF	TulDAS.TUL_B1TT117_PV	0.000000 - 1000.000000	1,000	1,000	1,000	0	1,000	10/14/2024 1:29:44 AM
B1 ECON WATER INLET TEMP	0.00 - 300.00	-	TulDAS.TUL_B1TT124_PV	-	-	-	-	-	n/a	10/14/2024 1:29:44 AM
B1_CC_Temperature_PV	1,000.00 - 2,000.00	DegF	TulDAS.TUL_B1_CC_Temperatur...	0.000000 - 2000.000000	1,741	1,991	1,865	47	1,900	10/14/2024 1:29:44 AM
B1 O2 CEMS SDA Inlet Dry Vol	5.00 - 20.00	%	TulDAS.TU_1AE126_PV	0.000000 - 25.000000	9.3	12.2	10.9	0.5	11.1	10/14/2024 1:29:44 AM
B1 Total Air Flow PV	0.00 - 200,000.00	lbs/hr	TulDAS.TUL_B1FI101_PV	0.000000 - 200000.000...	145,112	173,855	157,908	5,749	154,043	10/14/2024 1:29:44 AM
B1 IR Temp Probe PV	1,000.00 - 2,000.00	DegF	TulDAS.TUL_B1TIT_1001_PV	250.000000 - 3000.000...	1,740	1,997	1,865	47	1,900	10/14/2024 1:29:44 AM
B1 FIREBOX AVG TEMP	1,000.00 - 2,000.00	DEGF	TulDAS.TU_1TT130A_PV	0.000000 - 3000.000000	1,728	1,820	1,773	19	1,781	10/14/2024 1:29:44 AM
B1 PRI SH OUTLET GAS TEMP	1,000.00 - 2,000.00	DEGF	TulDAS.TU_1TE127E_PV	-454.000000 - 2498.00...	594	595	595	-	n/a	10/14/2024 1:29:44 AM
B1 GEN BANK INLET GAS TEMP	0.00 - 2,000.00	DEGF	TulDAS.TU_1TE127G_PV	-454.000000 - 2498.00...	1,257	1,259	1,258	-	n/a	10/14/2024 1:29:44 AM
B1 FIREBOX SIDEWALL GAS TEMP	0.00 - 2,000.00	DEGF	TulDAS.TU_1TE127I_PV	-454.000000 - 2498.00...	-	-	-	-	n/a	10/14/2024 1:29:44 AM
B1 PRI SH INLET GAS TEMP	0.00 - 2,000.00	DEGF	TulDAS.TU_1TE127K_PV	-454.000000 - 2498.00...	738	739	739	-	n/a	10/14/2024 1:29:44 AM
B1 Preheater Out Temp PV	0.00 - 300.00	DegF	TulDAS.TUL_B1TT103_PV	0.000000 - 300.000000	92	97	95	1	92	10/14/2024 1:29:44 AM
B1 Drum Press PV	500.00 - 900.00	psi	TulDAS.TUL_B1PT110_PV	0.000000 - 1000.000000	671	684	677	3	677	10/14/2024 1:29:44 AM
B1 ECON OUTLET GAS TEMP	0.00 - 500.00	-	TulDAS.TUL_B1TE123A_PV	-	-	-	-	-	n/a	10/14/2024 1:29:44 AM
B1 Side Wall Temp PV	0.00 - 3,000.00	DegF	TulDAS.TUL_B1TT130_PV	0.000000 - 3000.000000	1,728	1,820	1,773	19	1,781	10/14/2024 1:29:44 AM
B1_OFA_Front_Press_PV	0.00 - 20.00	inwc	TulDAS.TUL_B1_OFA_Front_Pre...	0.000000 - 99.000000	10.1	10.3	10.2	0.0	10.2	10/14/2024 1:29:44 AM
B1_OFA_Rear_Press_PV	0.00 - 20.00	inwc	TulDAS.TUL_B1_OFA_Rear_Pre...	0.000000 - 99.000000	11.7	11.8	11.7	0.0	11.7	10/14/2024 1:29:44 AM
B1 SDA INLET TEMP AVG	200.00 - 500.00	DEGF	TulDAS.TU_1TR7000_PV	100.000000 - 600.0000...	466	479	473	3	474	10/14/2024 1:29:44 AM
B1 PRI SH INLET STEAM TEMP	0.00 - 1,000.00	DEGF	TulDAS.TU_1TE136A_PV	0.000000 - 1000.000000	582	595	589	3	589	10/14/2024 1:29:44 AM
B1 Prim SH Steam Outlet Temp PV	0.00 - 1,000.00	DegF	TulDAS.TUL_B1TT115_PV	0.000000 - 1000.000000	0	0	0	0	0	10/14/2024 1:29:44 AM
B1 Prim SH Steam Outlet Temp PV	0.00 - 1,000.00	DegF	TulDAS.TUL_B1TT116_PV	0.000000 - 1000.000000	582	595	589	3	589	10/14/2024 1:29:44 AM
B1 Sec SH Out Steam Temp PV	0.00 - 1,000.00	DegF	TulDAS.TUL_B1TT117_PV	0.000000 - 1000.000000	1,000	1,000	1,000	0	1,000	10/14/2024 1:29:44 AM

2. Input Data

Additional Information

Pitot measurements:

- 38 – 39,000 lb/hr (~8,000 scfm) in the front duct, rear OFA header press was 9.8 inwc.
- 22 – 23,000 lb/hr (~5,000 scfm) in the rear duct, front OFA header press was 11.7 inwc.

The calculation is based on the input data of Reworld

Reworld is responsible for the quality of the input data

3. Combustion Calculation

Waste Properties

		April 2024	August 2024
Fuel throughput	kg/hr	12,622	12,602
Fuel throughput	lbs/hr	27,827	27,782
High Heating value	Btu/lb	5659	5575
Water	% by wt.	20.69	20.90
Non-combustible matter	% by wt.	26.67	27.13
Carbon	% by wt.	29.579	29.188
Hydrogen	% by wt.	4.054	3.987
Oxygen	% by wt.	17.685	17.491
Nitrogen	% by wt.	0.621	0.614
Chlorine	% by wt.	0.550	0.542
Sulphur	% by wt.	0.141	0.139
Fluorine	% by wt.	0.009	0.009

- Heating value and throughput by input of Covanta Data
- Fuel composition determined by correction curves of Martin

3. Combustion Calculation

Calculation of combustion air

		April 2024	August 2024
Input			
Fuel throughput	kg/hr	12,622	12,602
Fuel throughput	lbs/hr	27,827	27,782
High heating value	Btu/lb	5,659	5,575
Oxygen at boiler end	%, dry	10.0	10.0
Total air as input	lbs/hr	157,927	157,898
Air necessary to achieve oxygen at boiler end	lbs/hr	210,692	207,227
Output			
Leakage air	lbs/hr	52,765	49,329
Oxygen at furnace	%, dry	6.3	6.5

- Total air flow by PLS value
- Oxygen of 10 % as assumed long time median (average is to influenced by disturbances in operation)

4. Combustion Calculation

Calculation of combustion air

		April 2024	August 2024
Input			
Fuel throughput	kg/hr	12,622	12,602
Fuel throughput	lbs/hr	27,827	27,782
High Heating value	Btu/lb	5,659	5,575
Underfired Air	lbs/hr	96,926	96,897
Overfired Air	lbs/hr	61,001	61,000
Flue gas in furnace	lbs/hr	183,798	183,741
Oxygen in furnace	%, dry	6.264	6.508
Flue gas at boiler end	lbs/hr	236,563	233,070
Oxygen at boiler end	%, dry	10	10

4. Combustion Calculation

Validation with a boiler balance, Data of April 2024

	Mass Flow [lbs/hr]	Enthalpy [BTU/lb]	Enthalpy flow [BTU/hr]
		Input	
Fuel	27,827	4,995	138,990
Underfired Air	96,926	4	421
Overfired Air	61,001	1	53
Leakage Air	52,765	0	0
Feed Water	94,644	186	17,560
Sum			**157,025**
		Output	
Flue gas (Boiler Outlet)	232,502	110	25,548
Life steam	93,917	1,339	125,763
Blow- down	728	490	357
Heat loss in the grate	-	-	2,086
Radiation loss	-	-	921
Sum	-		**154,674**

4. Combustion Calculation

Validation with a boiler balance

Additional information and assumptions:

- Reference temperature for enthalpies is 77 °F (25°C)
- Heating value of waste is the net calorific value (low heating value)
- The blow down rate of 0,75 %
- Flue gas outlet temperature is 18 °F higher than SDA Inlet temperature
- Feed water flow is the sum of steam flow and blowdown

Conclusion:

- Difference between input and output is 2351 kBTU/hr (2 % error)
- Data quality is acceptable

5. Thermal calculation

Calculation adiabatic combustion temperature

Adiabatic combustion temperature in the furnace:

$$h_{\mathrm{ad}} = (\dot{Q}_{\mathrm{Waste}} - \dot{Q}_{\mathrm{Heat\ loss}} + \dot{Q}_{\mathrm{Underfired\ air}} + \dot{Q}_{\mathrm{Overfired\ air}}) \,/\, \dot{m}_{\mathrm{Flue\ gas,Furnace}}$$

$$= (\dot{m}_{\mathrm{Waste}} h_{u,Waste}\,(1 - \epsilon_{loss}) + \dot{m}_{\mathrm{Underfired\ air}} h_{\mathrm{Underfired\ air}} + \dot{m}_{\mathrm{Overfired\ air}} h_{\mathrm{Overfired\ air}}) \,/\, \dot{m}_{\mathrm{Flue\ gas,Furnace}}$$

$$h_{\mathrm{ad}} = f(T_{\mathrm{ad}}) = h_{\mathrm{fluegas}}(y = 0) = f(T_{\mathrm{ad}})$$

- Water / steam data according to IAPWS R7-97(2012) [1]
- Flue gas data according to FDBR, VAIS-Handbuch Wärme- und Strömungstechnik- VAIS [2]

5. Thermal calculation

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Calculation adiabatic combustion temperature

$\dot{Q}_{\mathrm{Waste}}$	Heat input of fuel [BTU/hr]	T_{ad}	Adiabatic furnace temperature [°F]
$\dot{m}_{\mathrm{Waste}}$	Fuel mass flow [lbs/hr]	h_{ad}	Specific adiabtic enthalpy of the flue gas [BTU/lb]
$h_{u,Waste}$	Net calorific value of fuel [BTU/lb]	$\dot{m}_{\mathrm{Flue\ gas,Furnac}}$	Mass flow of flue gas in the furnace [lbs/hr]
$\dot{Q}_{\mathrm{Heat\ loss}}$	Sum of losses due to radiation, grate ash, fly ash, incomplete combustion [BTU/hr]	h_{fluegas}	Specific enthalpy of underfired air [BTU/lb]
ϵ_{loss}	Loss factor related to the total heat input [-]	y	Height above the grate [ft]
$\dot{Q}_{\mathrm{Overfired\ air}}$	Heat input of overfired air [BTU/hr]		
$\dot{m}_{\mathrm{Overfired\ air}}$	Mass flow of overfired air [lbs/hr]		
$h_{\mathrm{Overfired\ air}}$	Specific enthalpy of overfired air [BTU/lb]		
$\dot{Q}_{\mathrm{Underfired\ air}}$	Heat input of underfired air [BTU/hr]		
$\dot{m}_{\mathrm{Underfired\ air}}$	Mass flow of underfired air [lbs/hr]		
$h_{\mathrm{Underfired\ air}}$	Specific enthalpy of underfired air [BTU/lb]		

5. Thermal calculation

Simplified calculation of the temperature profile

The following approach is described in literature : “Wärmetechnische Berechnung der Wasserrohrkessel” [3]

Assumptions:

- Main heat transfer in the furnace as function of the height is radiation
- Ideal plug flow
- Idealized wall temperature

$$\dot{Q}_{\mathrm{Transfer}}(y) = C_{1,2}\mathrm{A(y)}\,(T^4_{Flue\ gas}(y) - T^4_{Wall})$$

$$\dot{H}_{\mathrm{Flue\ gas}}\,(y) = \dot{H}_{\mathrm{Fluegas}}\,(y = 0) - \dot{Q}_{\mathrm{Transfer}}(y)$$

$$v_{Flue\ gas}(y) = \frac{\dot{m}_{Flue\ gas}}{A_{\mathrm{cross\ section}}\,\rho\,(T_{\mathrm{Flue\ gas}}(y))}$$

5. Thermal calculation

Calculation adiabatic combustion temperature

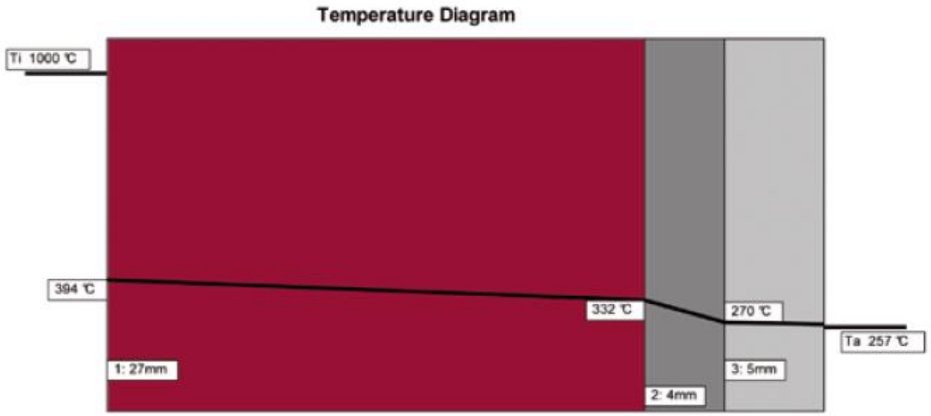
$C_{1,2}$	Radiation exchange factor of matter visible flame and membrane walls [BTU/hr/ft^2/R^4]
A(y)	Sum of membrane wall surface up to the level of y [in^2]
$T_{Flue\ gas}$(y)	Temperature of the flue gas at the height y [R]
T_{Wall}	Wall surface temperature [R]
$\dot{H}_{\mathrm{Fluegas}}$ (y)	Enthalpy flow [BTU/hr]
$\dot{Q}_{\mathrm{Transfer}}$(y)	Transferred heat [BTU/hr]
$v_{Flue\ gas}$(y)	Flue gas velocity at the height y [ft/s]
$\dot{m}_{Flue\ gas}$	Mass flow of flue gas in the furnace [lbs/hr]
$A_{\mathrm{cross\ section}}$	Flow cross section [in^2]
$\rho\ (\dot{T}_{Flue\ gas}(y))$	Density of flue gas at a specific temperature and height [lb/in^3]
y	Height above the grate [ft]

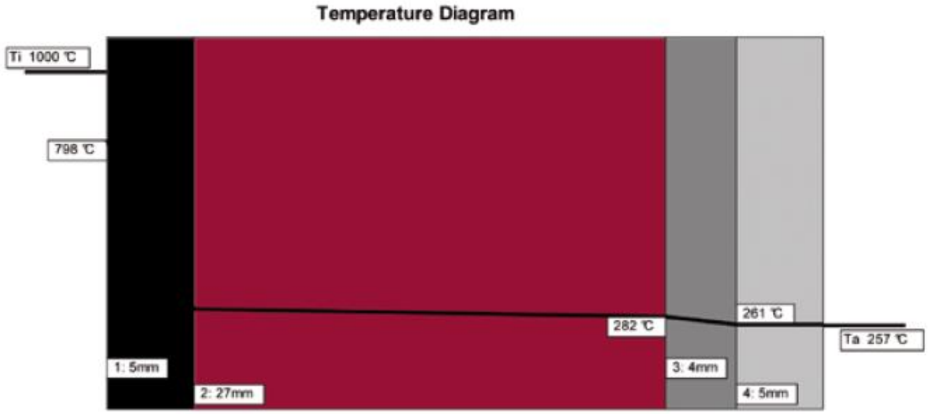
5. Thermal calculation

Influence of fouling on the wall temperature (example calculation [4])

Wall Construction		Cond. Factor	Thickn.	Cond.	Temperature of Layers	
Material			mm	W/(mK)	Face °C	Mean °C
1: +SI107C	SiC brick		27	26,300	394,0	362,9
2: +MK100P	refractory mastic		4	3,951	331,8	301,1
3: +ST0425	steel		5	41,332	270,4	266,7
			36		263,1	

Wall Construction		Cond. Factor	Thickn.	Cond.	Temperature of Layers	
Material			mm	W/(mK)	Face °C	Mean °C
1: +MK597A	contamination		5	0,204	797,5	555,6
2: +SI107C	SiC brick		27	26,300	302,8	292,4
3: +MK100P	refractory mastic		4	3,936	282,0	271,8
4: +ST0425	steel		5	41,494	261,5	260,2
			41		259,0	





- The fouling is the main heat resistance and significantly determines the wall temperature
- Boiler walls are fouled very fast
- Influence of type of refractory is low in comparison to the fouling

5. Thermal calculation

Influence of fouling on the wall temperature (example measurements [5])

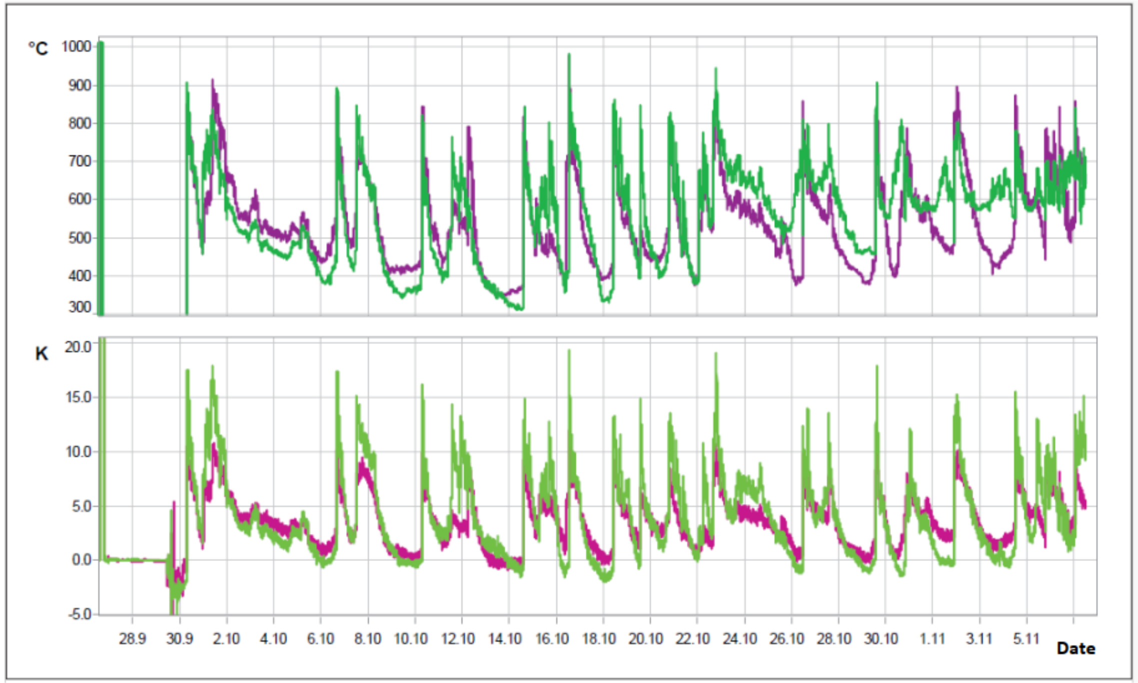
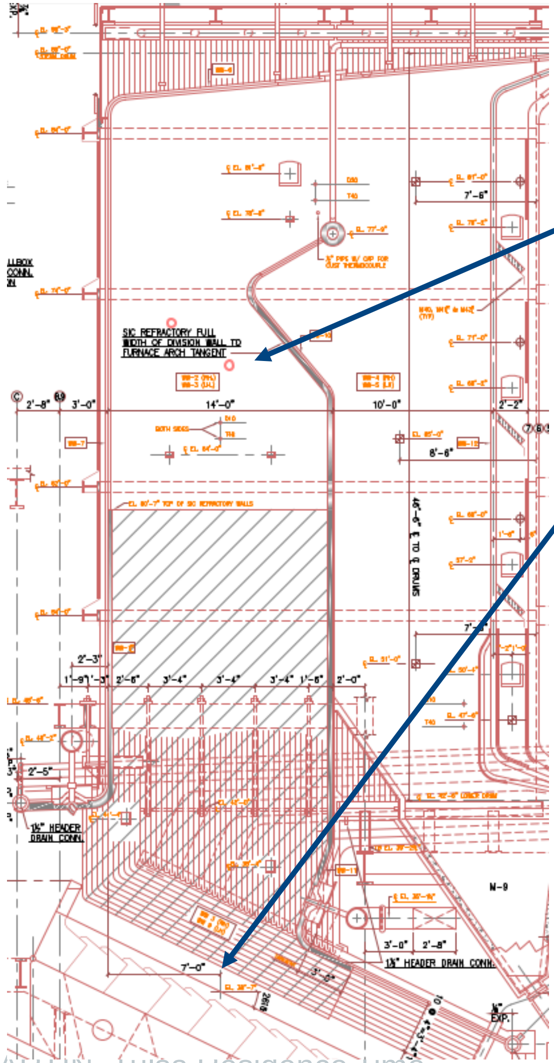


figure 7: curves for temperature (top) and temperature difference measurements (bottom) in rear-ventilated (green) and back-filled (purple) tile areas over time, measuring position 1 on left side wall; severely fluctuating and very high thermal load on refractory lining in this area is clearly recognisable

- The fouling is the main heat resistance and determines the wall temperature
- Boiler walls are fouled very fast
- Influence of type of refractory is low

5. Thermal calculation

Model fit to experimental data



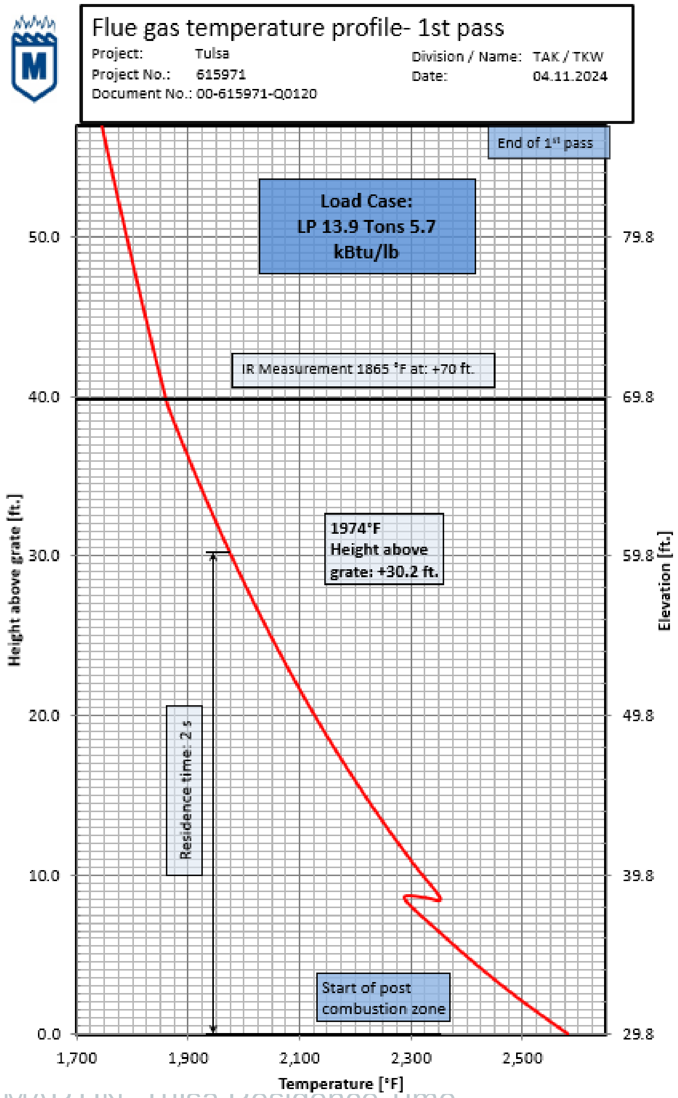
IR-Measurement

Adiabatic combustion temperature

- T_{Wall} is varied until the temperature profile matches the IR measurement at an elevation of 70 ft.
- $\dot{Q}_{\text{Transfer}}(y) \sim (T_{Flue\ gas}^4(y) - T_{Wall}^4)$ determines the characteristic of the curve
- $T_{Flue\ gas}(y)$ is calculated for several small increments
- $v_{Flue\ gas}(y)$ is calculated for several small increments

6. Results

Results for April 2024



- The residence time of two seconds ends 30.2 ft. above the grate
- At this height, the temperature is 1974 °F
- The residence time of one second ends 15.9 ft. above the grate
- At this height, the temperature is 2200 °F
- At a temperature of 2000 °F, the residence time is 1,9 s
- At a temperature of 1975 °F, the residence time is 2,0 s
- At a temperature of 1800 °F, the residence time is 3,4 s
- Temperature at grate level is 2584 °F

6. Results

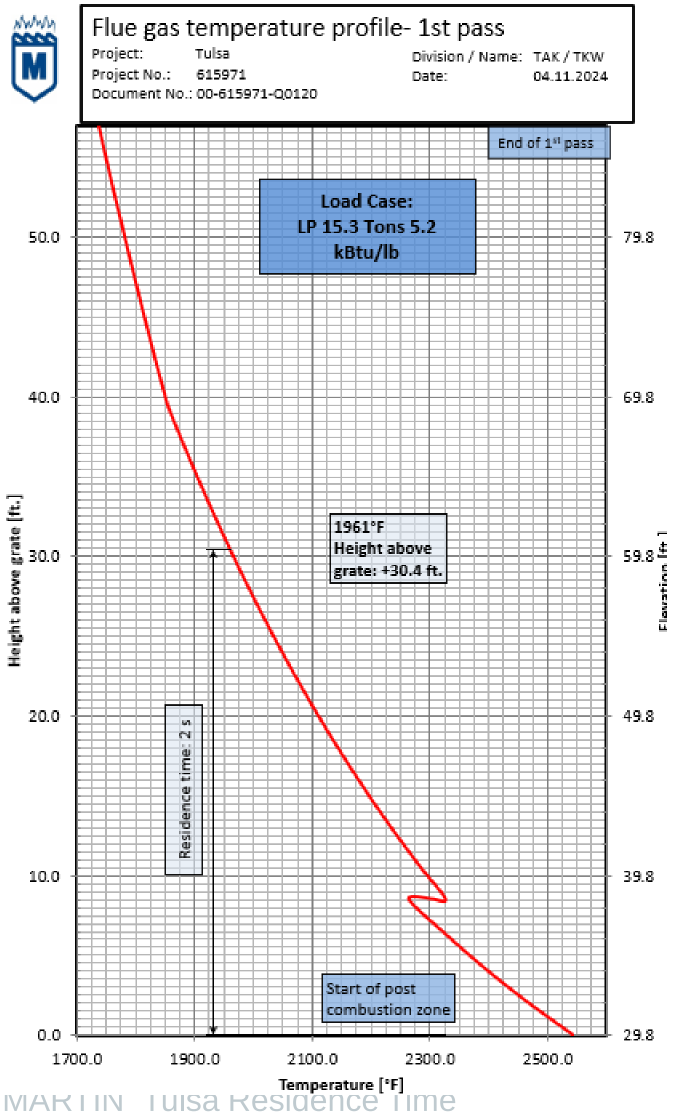
Additional load points

- Model A: Base is April 2024: 13.9 Tons, 5.7 kBtu/lb, 97 % thermal load
- Model B: 10 % more waste, heating value is reduced by 10 %: 15.3 Tons, 5.2 kBtu/lb, 97 % thermal load
- Model C: 10 % less waste, heating value is increased by 10 %: 12.5 Tons, 6.2 kBtu/lb, 97 % thermal load
- Model D: 10 % less waste than B, same heating value as B: 13.8 Tons, 5.2 kBtu/lb, 87 % thermal load
- Model E: 10 % less waste than C, same heating value as C: 11.3 Tons, 6.2 kBtu/lb, 87 % thermal load

The total combustion air is equal for 100 % load, the combustion air is reduced by 10 % for 87 % thermal loads

6. Results

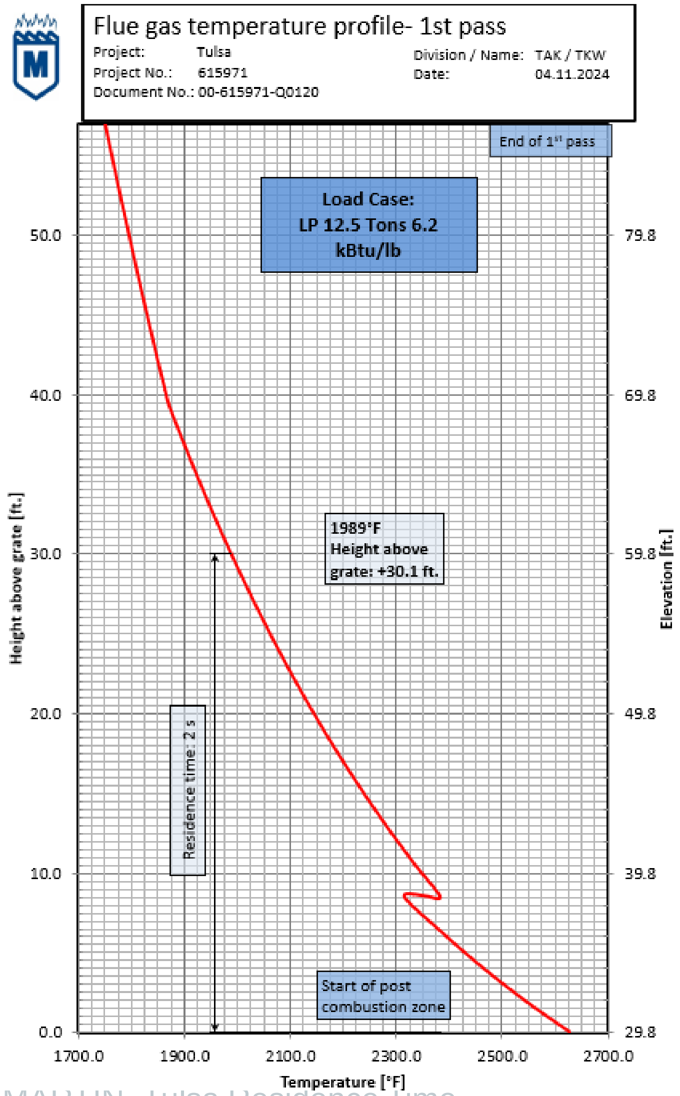
Results for Model B



- The residence time of two seconds ends 30.4 ft. over the grate
- At this height, the temperature is 1961 °F
- The residence time of one second ends 15.9 ft. above the grate
- At this height, the temperature is 2180 °F
- Temperature at 70 ft. is 1849 °F
- At a temperature of 2000 °F, the residence time is 1.8 s
- At a temperature of 1975 °F, the residence time is 1.9 s
- At a temperature of 1800 °F, the residence time is 3.3 s
- Temperature at grate level is 2544 °F

6. Results

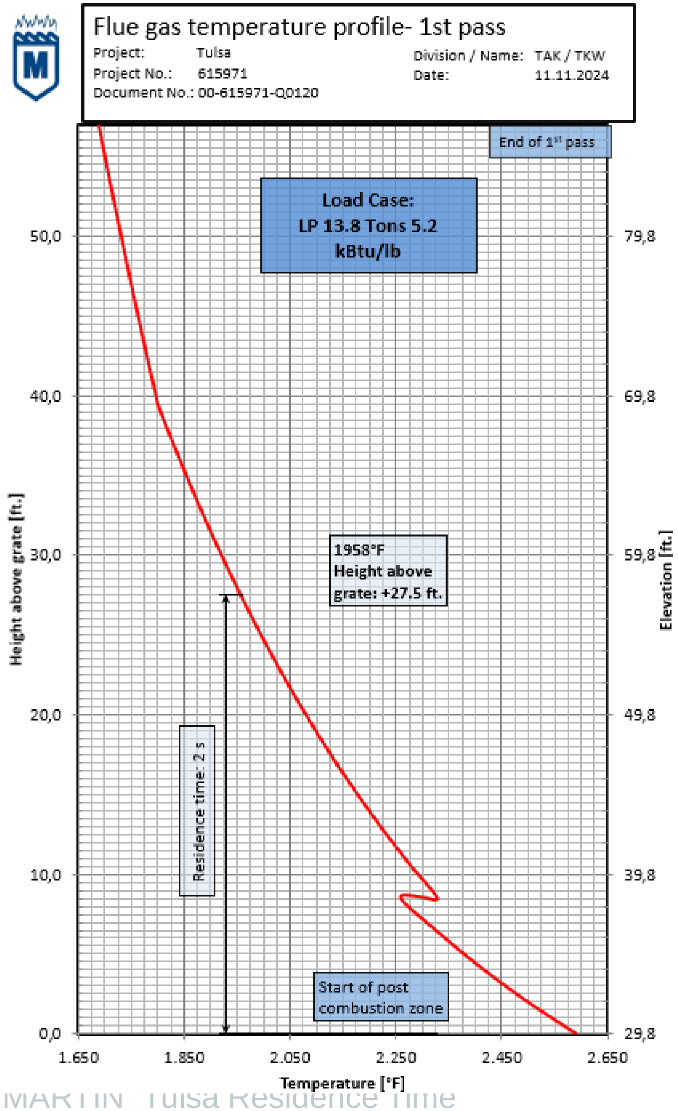
Results for Model C



- The residence time of two seconds ends 30.1 ft. over the grate
- At this height, the temperature is 1989 °F
- The residence time of one second ends 15.8 ft. above the grate
- At this height, the temperature is 2223 °F
- Temperature at 70 ft. is 1865 °F
- At a temperature of 2000 °F, the residence time is 1.9 s
- At a temperature of 1975 °F, the residence time is 2.1 s
- At a temperature of 1800 °F, the residence time is 3.5 s
- Temperature at grate level is 2630 °F

6. Results

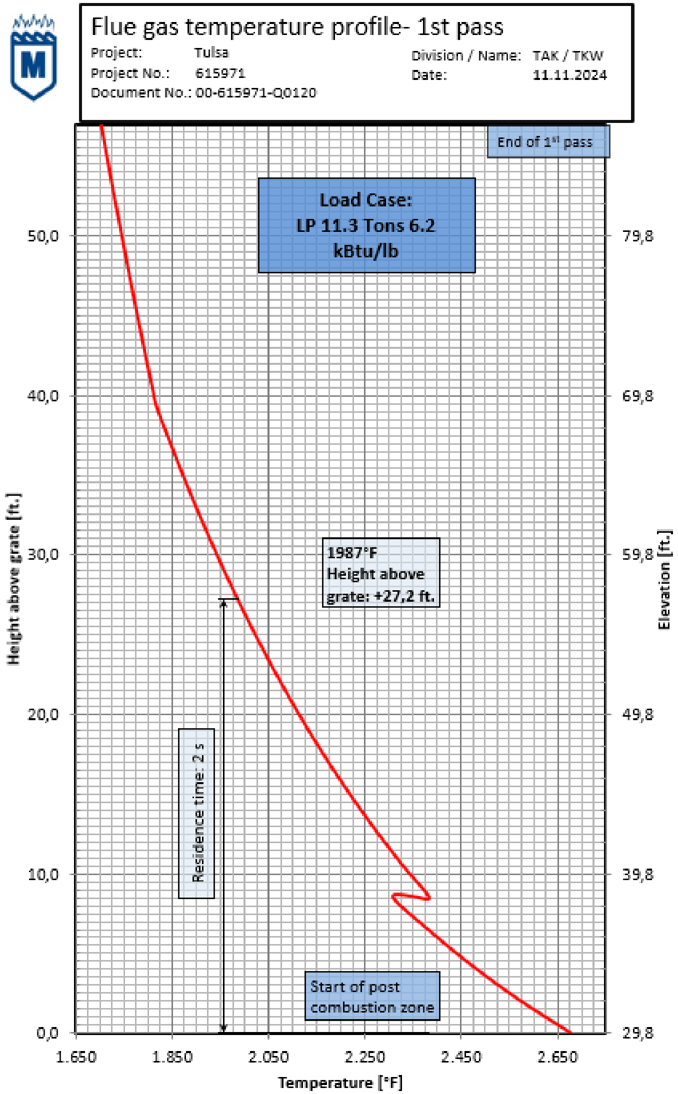
Results for Model D



- The residence time of two seconds ends 27.5 ft. over the grate
- At this height, the temperature is 1958 °F
- The residence time of one second ends 14.5 ft. above the grate
- At this height, the temperature is 2190 °F
- Temperature at 70 ft. is 1795 °F
- At a temperature of 2000 °F, the residence time is 1,8 s
- At a temperature of 1975 °F, the residence time is 1,9 s
- At a temperature of 1800 °F, the residence time is 3,0 s
- Temperature at grate level is 2,594 °F

6. Results

Results for Model E



- The residence time of two seconds ends 27.2 ft. over the grate
- At this height, the temperature is 1987 °F
- The residence time of one second ends 14.3 ft. above the grate
- At this height, the temperature is 2234 °F
- Temperature at 70 ft. is 1810 °F
- At a temperature of 2000 °F, the residence time is 1,9 s
- At a temperature of 1975 °F, the residence time is 2,1 s
- At a temperature of 1800 °F, the residence time is 3,2 s
- Temperature at grate level is 2,680 °F

7. Source of Literature

[1] Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam, IAPWS R7-97(2012)

[2] FDBR-Handbuch, Wärme-und Strömungstechnik, 2013

Remark: FDBR is now VAIS, Weblink: VAIS-Handbuch Wärme- und Strömungstechnik- VAIS

[3] Wärmetechnische Berechung der Wasserrohrkessel, Wasserohrkesselverband Düsseldorf, 1963

[4] Refractory linings for Waste Combindes Heat & Power plants and Bio Mass Boilers with adhesive Tile system, Jünger+Gräter GmbH, Issue Nov 30, 2010

[5] Temperature sensor technology: adjusting refractory lining to the requirements, Joos Brell, Dominik Molitor, Grabriele Magel, Sabine Hohmuth,2019

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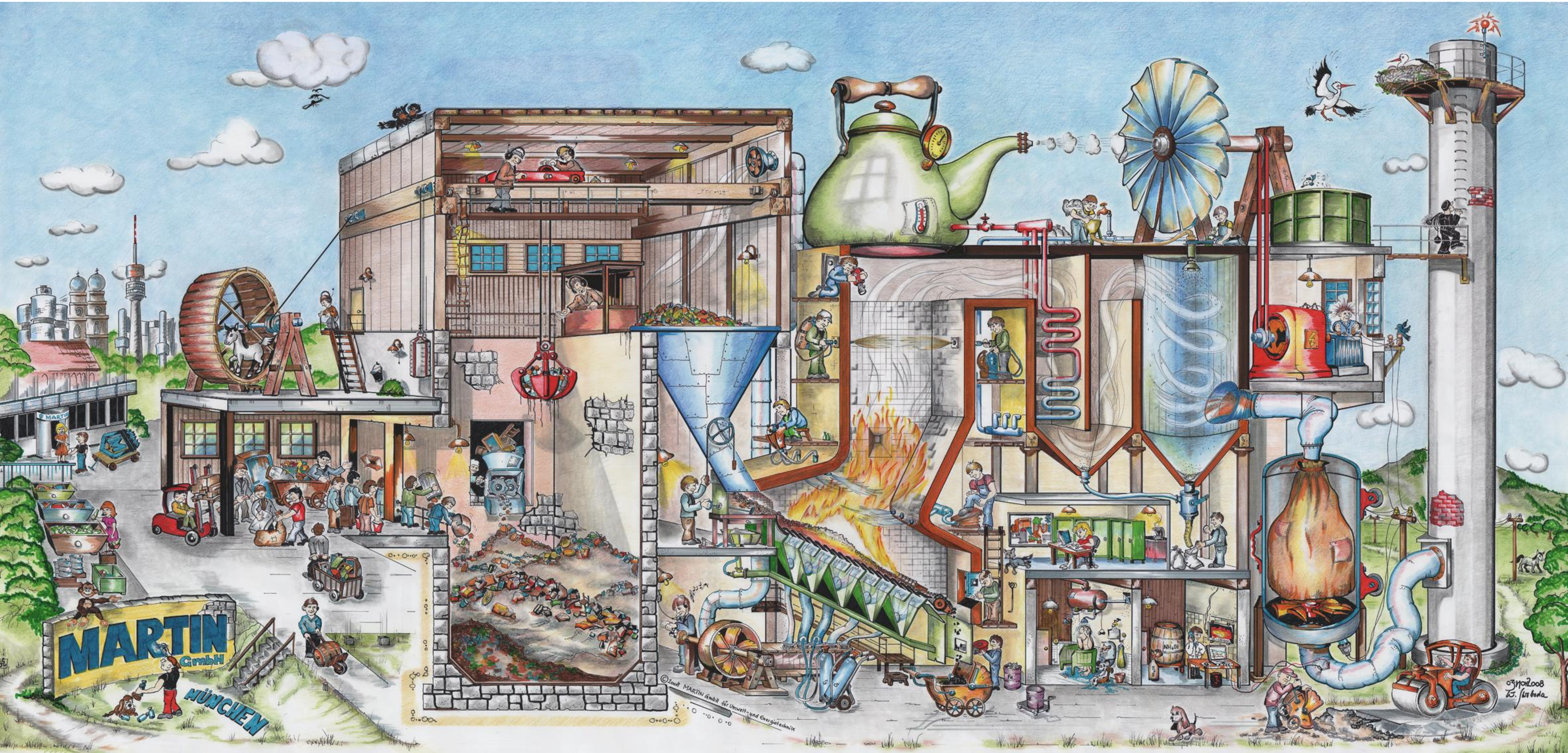
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MARTIN is a machinery and plant manufacturer. All products and services relate to the treatment of residual materials using customized solutions to exploit the individual energy and material potential of the various waste streams. The realization of thermal waste treatment plants requires a **high level of expertise in engineering and plant construction, from planning and delivery to commissioning and subsequent service**. We have extensive experience in this area, offering a portfolio of established incineration and waste and flue gas treatment technologies and cooperating with carefully selected and proven suppliers.

With our plants and equipment, we contribute to the optimal and sustainable recycling of waste. As one of the world's leading suppliers of plants for thermal waste recycling, we offer our municipal and private customers a full range of services over the entire service life of plants. We are a **4th generation family business that thinks and acts for the long term.**

The MARTIN Group has around 750 employees and essentially comprises the following companies: **Martin GmbH für Umwelt- und Energietechnik** with headquarters in Munich, **LAB** as an established company in the field of exhaust gas cleaning systems, **Loibl** with expertise in the field of ash and slag transport, **MARTIN Caldeiras** as a production facility for cladding, **Explosion Power** with expertise in boiler cleaning systems (shock pulse generators) and **MARTIN AG** in Switzerland as a local and competent partner in the service and modernization sector over the life cycle of the plant.

Martin GmbH has over **650 reference plants (1180 units) worldwide with 100 years of experience**, LAB has 450 reference plants with 60 years of experience and Loibl has over 1000 references and more than 60 years of experience. MARTIN therefore has extensive in-house expertise in the key technologies for waste incineration plants.

MARTIN relies on high standards, close monitoring of suppliers and long-term partnerships to ensure quality.

Project: RMW Permit Application support Tulsa – 1st pass Temperature profile

Our client REWORLD contracted us to support their regulated medical waste (RMW) permit application in Tulsa, Oklahoma. MARTIN performed a combustion calculation based on operating data and created a temperature profile for the first boiler pass. To validate the operating data, a heat and mass balance calculation was performed for the boiler to determine the reliability of the operating data as the basis for the calculation.

The approach for creating the model is basically as follows (the page numbers refer to the presentation in the appendix):

1. Determination of a waste composition based on the calorific value specification (5.7 kBtu/lb) from REWORLD and correction curves from MARTIN (p. 7).
2. Execution of the combustion calculation with a waste throughput of 13.9 tons/hr (average throughput according to REWORLD data). Determination of the stoichiometric air requirement. Calculation of the actual excess air at the end of the boiler on the basis of the O2 measurement (10 %, dry) at the end of the boiler. Determination of the excess air in the combustion chamber based on the air measurements. Calculation of the flue gas composition in the combustion chamber and at the end of the boiler. (p. 8,9)
3. Checking the operating data for consistency by means of a global energy and mass balance around the entire boiler (p. 10,11). The balance is consistent. The operating data used from REWORLD is consistent.
4. Calculation of the combustion chamber temperature using a local energy and mass balance (p. 12,13).
5. Calculation of the heat transfer from the flue gas to the membrane wall in incremental steps based on the equations of the FDBR[1] and an assumed wall temperature. The resistance from the flue gas to the wall is by far the greatest thermal resistance. Most of the heat is transferred to the wall by thermal radiation. The T^4 dependence of thermal radiation (according to Stefan-Boltzmann law) dominates the shape of the temperature profile (p. 14,15).
6. Adjust the wall temperature until the flue gas temperature measurement from REWORLD matches +70 ft. in the model (p. 18).
7. Calculation of the specific volume and thus the flue gas velocity for many small incremental steps. Determination of residence times and temperatures at different levels (p. 19).

The approach for calculating the other load points is as follows (p. 21-24):

1. Combustion calculation is performed for other heating values and loads (model B-E). The calorific values are specifications from REWORLD. The composition is determined using correction curves from MARTIN. The excess air ratio, the false air and the air distribution are kept the same.
2. Using the different input data from the combustion calculation, the combustion chamber temperature is determined by means of a local energy and mass balance.
3. Performing the heat transfer calculation from the flue gas to the membrane wall in incremental steps based on the equations of the FDBR. The wall temperature is extrapolated with a linear correction curve for lower thermal load, based on known empirical system values.
4. Calculation of the specific volume and thus the flue gas velocity for many small incremental steps. Determination of the residence times at different heights.

Appendix:

- 250131_Tulsa_Residence Time.pdf

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[1] FDBR-Handbuch, Wärme- und Strömungstechnik, 2013
Remark: FDBR is now known as VAIS, Weblink: https://www.vais.de/arbeitshilfen/vais-handbuch-waerme-und-stroemungstechnik.html

Attachment B: Temperature Model Key Input Parameters

Figure 1. Temperature Model Key Input Parameters