Real Time Thermocouple Data Driven Fatigue Life Evaluation of Coke Drum

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Introduction

Coke Drum

A Coke Drum is a type of pressure vessel that uses heat and pressure to refine complex hydrocarbons into lighter, more useful, products, such as gasoline, diesel, and jet fuel.

Coke drums are an integral part of Coker units and serve as the final step in the cracking process.

During this process, crude oil is fed into a Coker, where it is first heated to cracking temperature in a furnace. It is then sent through a transfer line to the coke drum for final processing.

Coking Process

To avoid thermal shock induced stresses on vessel, at first the drum is preheated to certain predefined temperature before pumping hot oil.

High viscous hot oil is filled into drum from bottom up. After filling up to recommended maximum level, under the pressure the hot oil gets solidified releasing required by products (Coking Process). The leftover material is called coke.

This coke will build up in the drum and once full, the drum must be taken offline and the coke is removed using high pressure water cutters for either reclamation or storage.

Ideal Operation Cycle

1. Pre – heating

To avoid thermal shock induced stresses on vessel, at first the drum is preheated to certain predefined temperature before pumping hot oil.

2. Filling

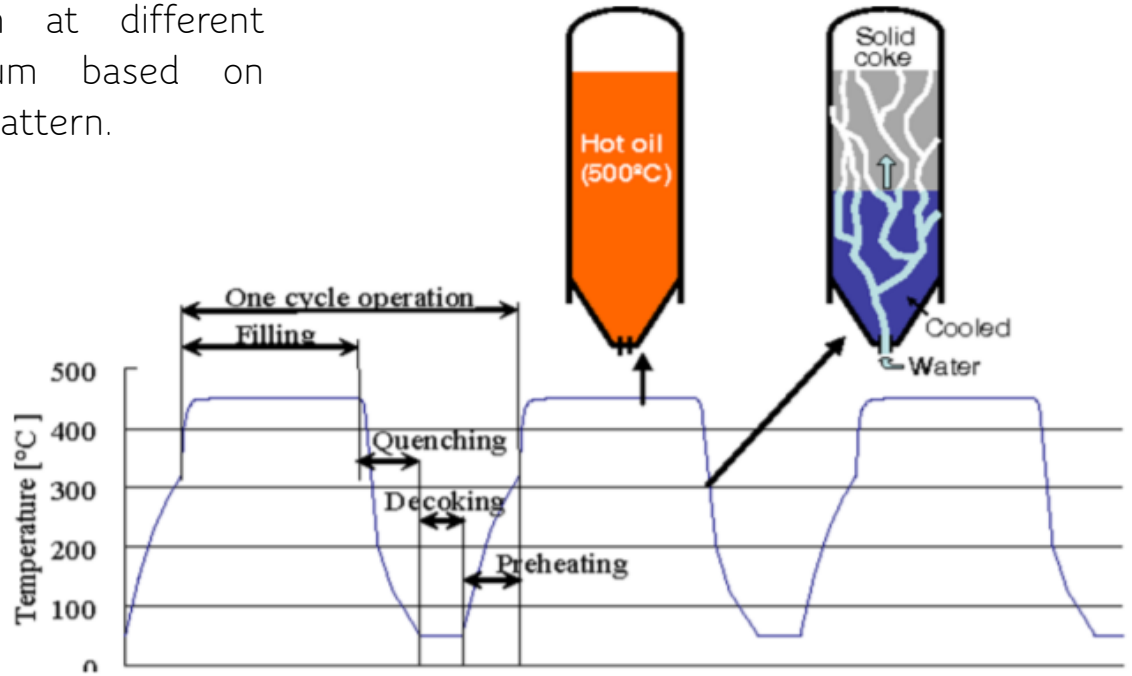
High viscous hot oil is filled into drum from bottom up. After filling up to recommended maximum level, under the pressure the hot oil gets solidified over a time releasing required by products (Coking Process).

3. Quenching

Once the hot oil is completely solidified, the water jet is pumped into drum from the bottom nozzle.
Since the solidified coke is porous in nature, the water cools down the drum at different sections of drum based on established flow pattern.

4. Decoking

Once quenching process is done, the coke is cut out and removed (Decoking Process).



Problem

Actual Operation Cycle

Coke Drum is designed for 20 years of Fatigue Life. Due to various parameter & factors, the Coke drum gets damaged much prior to the designed life.

Due to the uncertainties in operation procedure like, rise in supply-demand, poor quality batch of Crude, Inefficient performance of ancillary equipment's in process line, the actual process temperature cycle differs significantly from Ideal desired temperature pattern.

As a result, the Coke Drum starts to deteriorate earlier than the expected time. In case of unplanned shutting down of coke drum operation in refinery incurs major loss of up to 30-40% of efficiency of Unit, which is never accepted. If not examined timely, the deterioration in the coke drum may cause a failure and the entire process may be shut down. This would cause a huge loss to the company and may even cause serious accidents.

Critical Failure Point

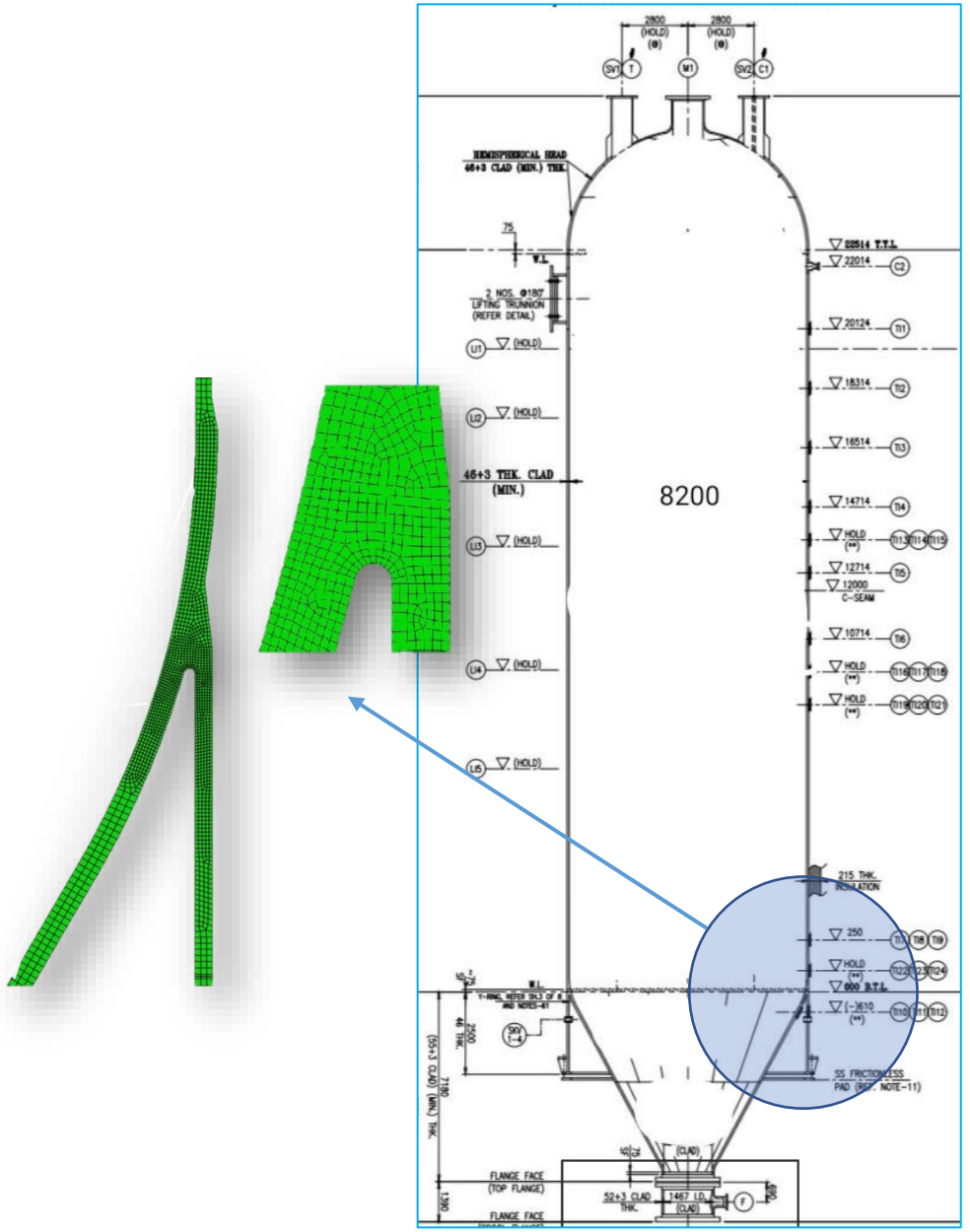
Skirt Cone Junction

Coke drum is designed in a way to accommodate expansion & contraction. It expands during filling and contracts itself & crushes the solidified coke.

During this process, drum support skirt is subjected to radial expansion & contraction. And the skirt is the weakest point of entire coke drum.

Due to fatigue load the first crack initiates at support skirt-cone junction. Further, this zone experiences the greater thermal gradient as it is extended from shell which has direct contact with operating liquid.

This is very common failure location and since the weakest of entire vessel, evaluation at this point is considered to be critical compared to other locations of the vessel.



Design Project Brief

Project Details

This project aims at collection of temperature data for every minute of operation from the actual refinery for a maximum time period of operation possible.

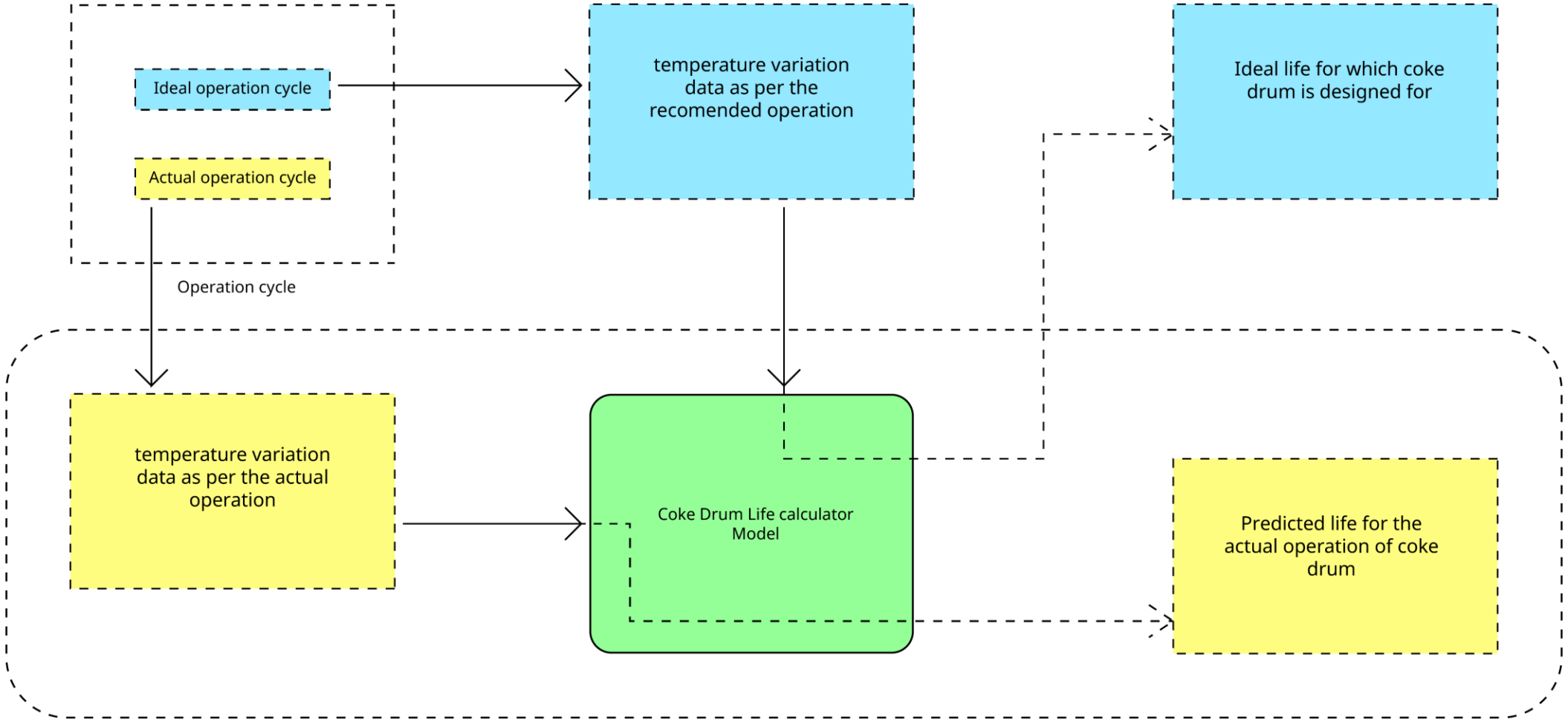
Further the collected raw data is filtered appropriately and every aspect of data point is being given a new, hard look, from correctness of data point to the optimum time period of operation.

From the processed temperature data, the operating data points are segregated as different zones like constant temperature zone, heating zone, cooling zone, temperature switching zones.

Based on statistical evaluation, the effect of each zone on fatigue life of coke drum is evaluated using Finite Element Analysis as guided by ASME Code of Construction.

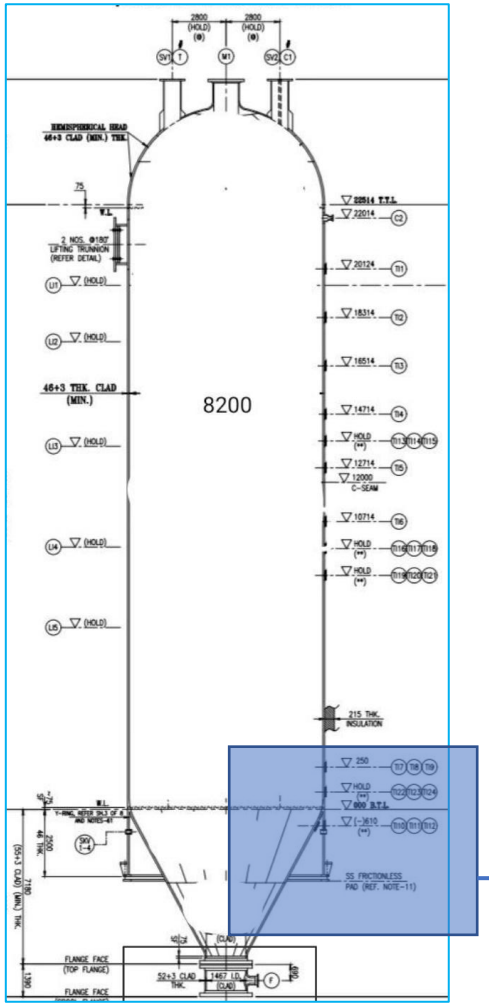
From the results we propose the predictive model to evaluate life of coke drum

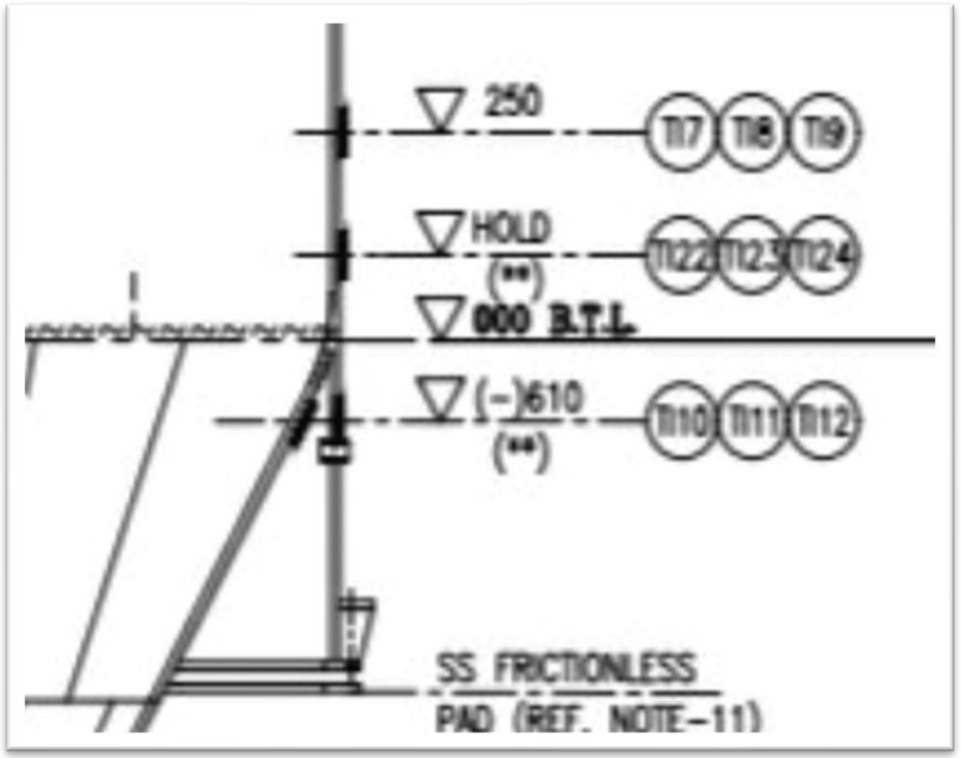
Project Scheme



Presently missing model in the Industry – Scope of the project

Data Source





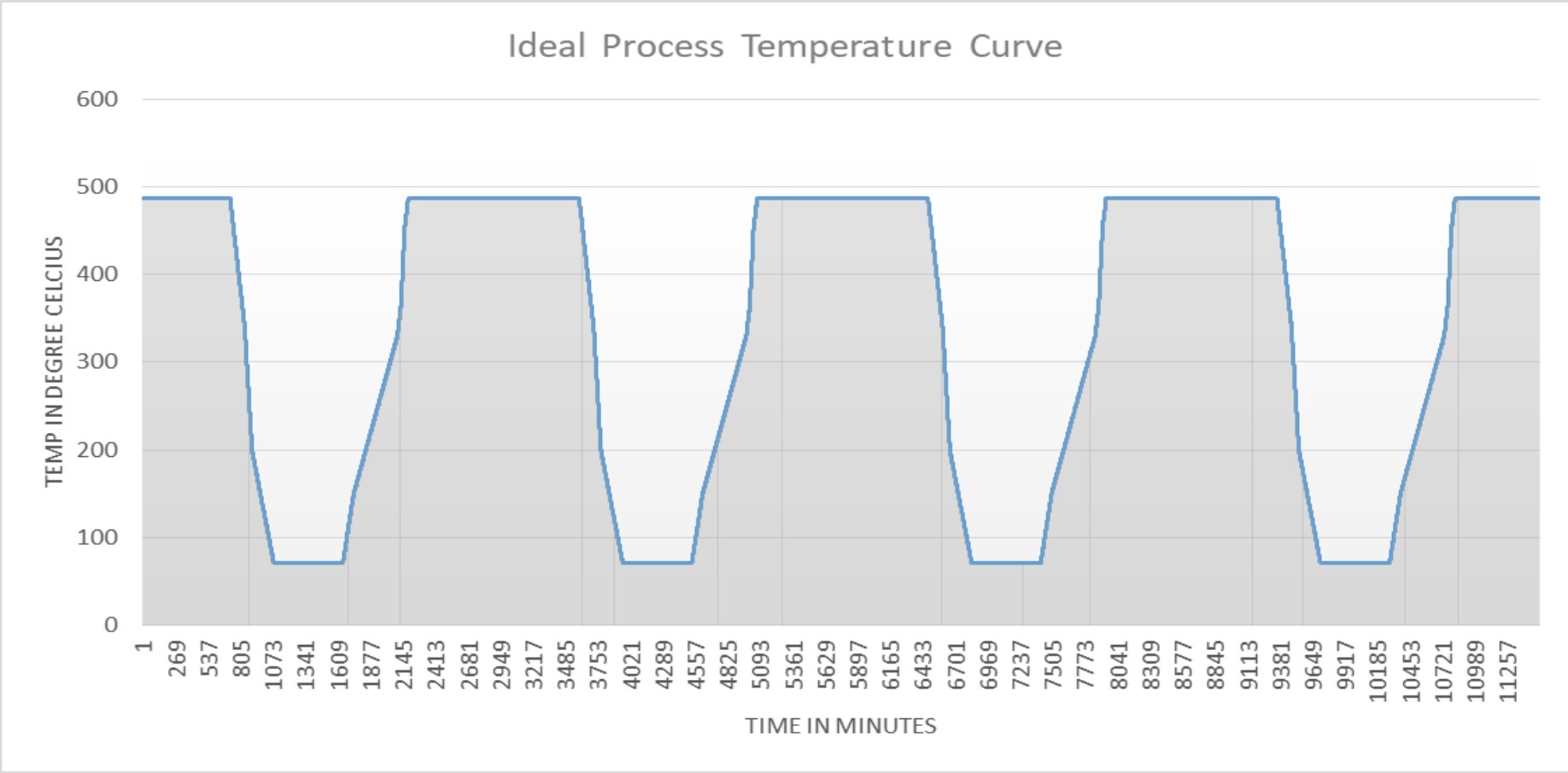
Surface Thermocouple Sensors

Based on Process/Inspection Monitoring Requirement, multiple skin thermocouples are installed on drums at different locations along the axial length.

For this Project Thermocouple data at support skirt-cone-shell junction is considered.

These sensors provide the temperature data at regular intervals which is the main predictor variable in this project.

Ideal Temperature Curve



The Curve is representative of hot oil desired temperature; however, the actual thermocouple data will be different because of convective heat transfer coefficients of hot oil & metals thermal property (conductivity, specific heat transfer capability etc..)

Site Thermocouple Data

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1		TC.604TI2460.	TC.604TI2461.	TC.604TI2462/	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.
2	01-09-2020 00:00	414.15	417.55	398.89	401.02	417.28	398.46	802.9	420.68	408.22	411.69	402.56	328.48	405.95	400.32	401.98	352.71	342.78	311.11	313.92	300.38
3	01-09-2020 00:01	413.99	417.58	398.98	401.14	417.33	401.27	802.9	420.73	408.27	411.69	402.61	328.29	406	400.34	401.95	352.66	342.74	310.96	313.97	300.36
4	01-09-2020 00:02	414.06	417.53	399.09	401.29	417.41	399.97	802.9	420.81	408.34	411.69	402.63	328.37	406.03	400.32	401.85	352.58	342.59	310.83	313.97	300.28
5	01-09-2020 00:03	414.15	417.6	399.16	401.4	417.48	401.7	802.9	420.88	408.42	411.69	402.58	327.85	406.03	400.34	401.8	352.56	342.49	311.1	314.07	300.5
6	01-09-2020 00:04	414.15	417.85	399.19	401.47	417.56	403.46	802.9	421.01	408.4	411.69	402.56	327.07	406.03	400.27	401.7	352.56	342.51	311.16	314.27	300.58
7	01-09-2020 00:05	414.3	417.95	399.24	401.6	417.58	401.72	802.9	421.06	408.27	411.74	402.56	326.61	406.08	400.31	401.5	352.51	342.49	310.86	314.25	300.41
8	01-09-2020 00:06	414.39	418.05	399.31	401.7	417.63	404.08	802.9	421.11	408.27	411.77	402.56	326.26	406.11	400.46	401.37	352.43	342.46	310.83	314.29	300.33
9	01-09-2020 00:07	414.39	418.2	399.39	401.82	417.71	402.34	802.9	421.13	408.34	411.77	402.56	326.08	406.06	400.57	401.4	352.41	342.51	311.13	314.45	300.57
143982	09-12-2020 23:40	405.92	418.59	380.79	802.9	392.33	389.55	802.9	398.52	382.06	418.46	409.38	347.76	419.07	412.9	423.17	355.69	349.94	321.65	321.35	317.55
143983	09-12-2020 23:41	406.57	419.15	381.11	802.9	392.63	390.09	802.9	398.83	382.36	418.59	409.48	347.41	419.19	413.08	423.4	355.95	350.32	322.2	321.7	317.86
143984	09-12-2020 23:42	406.98	419.31	381.54	802.9	392.93	390.64	802.9	399.18	382.61	418.69	409.6	346.88	419.34	413.28	423.57	356.22	350.74	322.75	322.05	317.99
143985	09-12-2020 23:43	407.06	419.31	382.09	802.9	393.24	391.19	802.9	399.46	382.89	418.82	409.7	346.18	419.5	413.5	423.72	356.47	351.05	323.18	322.33	318.29
143986	09-12-2020 23:44	407.22	419.36	382.64	802.9	393.59	391.67	802.9	399.73	383.14	418.97	409.78	345.42	419.6	413.83	423.88	356.75	351.32	323.61	322.75	319.01
143987	09-12-2020 23:45	407.46	419.43	383.17	802.9	393.92	392.13	802.9	400.03	383.37	419.07	409.86	344.42	419.67	414.25	424.03	357.05	351.67	323.92	322.94	318.93
143988	09-12-2020 23:46	407.71	419.65	383.7	802.9	394.27	392.43	802.9	400.34	383.55	419.19	409.93	343.54	419.75	414.56	424.08	357.25	352	324.24	323.14	319.45
143989	09-12-2020 23:47	407.95	419.76	384.18	802.9	394.6	392.76	802.9	400.69	383.8	419.3	410.01	342.78	419.73	414.74	424.18	357.5	352.25	324.67	323.39	320
143990	09-12-2020 23:48	408.19	419.86	384.63	802.9	394.95	393.13	802.9	401.02	384.05	419.37	410.03	342.07	419.85	414.89	424.28	357.75	352.53	325.02	323.66	320.17
143991	09-12-2020 23:49	408.44	420.4	385.08	802.9	395.28	393.51	802.9	401.32	384.28	419.5	410.13	341.39	419.93	415.04	424.31	357.98	352.78	325.37	324.06	320.76
143992	09-12-2020 23:50	409	421.05	385.48	802.9	395.53	393.94	802.9	401.62	384.5	419.6	410.23	340.57	419.98	415.19	424.4	358.3	353.06	325.7	324.47	320.91
143993	09-12-2020 23:51	409.41	421.46	385.81	802.9	395.85	394.34	802.9	401.92	384.78	419.67	410.31	339.42	420.05	415.44	424.56	358.73	353.31	325.85	324.94	321.07
143994	09-12-2020 23:52	409.34	421.52	386.02	802.9	396.18	394.72	802.9	402.17	385.03	419.8	410.38	338.13	420.22	415.74	424.61	359.28	353.68	325.93	325.37	321.01
143995	09-12-2020 23:53	409.57	421.34	386.12	802.9	396.53	395.05	802.9	402.45	385.26	419.95	410.41	336.9	420.45	415.95	424.66	359.98	354.13	326.2	325.8	321.1
143996	09-12-2020 23:54	410.05	421.36	386.14	802.9	396.86	395.35	802.9	402.75	385.48	420.05	410.51	335.79	420.68	416.15	424.73	360.64	354.49	326.38	326.15	321.35
143997	09-12-2020 23:55	410.54	421.56	386.29	802.9	397.11	395.7	802.9	403.01	385.66	420.18	410.61	334.93	420.9	416.32	424.81	361.24	354.79	326.5	326.45	321.43
143998	09-12-2020 23:56	410.71	421.49	386.52	802.9	397.34	395.93	802.9	403.28	385.91	420.33	410.73	334.47	421.13	416.43	424.88	361.79	355.09	326.7	326.75	321.58
143999	09-12-2020 23:57	410.71	421.27	386.84	802.9	397.62	396.23	802.9	403.58	386.11	420.43	410.84	334.26	421.36	416.6	424.96	362.32	355.44	326.88	327.2	321.81
144000	09-12-2020 23:58	410.55	420.94	387.17	802.9	397.87	396.46	802.9	403.84	386.32	420.55	410.96	334.01	421.58	416.73	425.03	362.95	355.77	327.08	327.58	321.93
144001	09-12-2020 23:59	410.31	420.71	387.47	802.9	398.1	396.61	802.9	404.11	386.54	420.7	411.06	333.91	421.76	416.85	425.11	363.48	356.02	327.21	327.79	322.4
144002	10-12-2020 00:00	410.38	420.76	387.77	802.9	398.42	396.81	802.9	404.41	386.82	420.85	411.19	334.01	421.96	416.95	425.19	363.83	356.3	327.43	328.08	322.59

Historian of Temperature data was recorded for every one-minute operations. From 1st of Sep 2020 to 10th of Dec 2020.

Ideally one complete cycle designed 48 hour ~ 2880 minutes. We have got 100 days of data, which means 50 complete cycle data to get processed.

Data Pre-processing - Clean Up

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1		TC.604TI2460.	TC.604TI2461.	TC.604TI2462/	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.604TI2462(	TC.
2	01-09-2020 00:00	414.15	417.55	398.89	401.02	417.28	398.46	802.9	420.68	408.22	411.69	402.56	328.48	405.95	400.32	401.98	352.71	342.78	311.11	313.92	300.38
3	01-09-2020 00:01	413.99	417.58	398.98	401.14	417.33	401.27	802.9	420.73	408.27	411.69	402.61	328.29	406	400.34	401.95	352.66	342.74	310.96	313.97	300.36
4	01-09-2020 00:02	414.06	417.53	399.09	401.29	417.41	399.97	802.9	420.81	408.34	411.69	402.63	328.37	406.03	400.32	401.85	352.58	342.59	310.83	313.97	300.28
5	01-09-2020 00:03	414.15	417.6	399.16	401.4	417.48	401.7	802.9	420.88	408.42	411.69	402.58	327.85	406.03	400.34	401.8	352.56	342.49	311.1	314.07	300.5
6	01-09-2020 00:04	414.15	417.85	399.19	401.47	417.56	403.46	802.9	421.01	408.4	411.69	402.56	327.07	406.03	400.27	401.7	352.56	342.51	311.16	314.27	300.58
7	01-09-2020 00:05	414.3	417.95	399.24	401.6	417.58	401.72	802.9	421.06	408.27	411.74	402.56	326.61	406.08	400.31	401.5	352.51	342.49	310.86	314.25	300.41
8	01-09-2020 00:06	414.39	418.05	399.31	401.7	417.63	404.08	802.9	421.11	408.27	411.77	402.56	326.26	406.11	400.46	401.37	352.43	342.46	310.83	314.29	300.33
9	01-09-2020 00:07	414.39	418.2	399.39	401.82	417.71	402.34	802.9	421.13	408.34	411.77	402.56	326.08	406.06	400.57	401.4	352.41	342.51	311.13	314.45	300.57
143982	09-12-2020 23:40	405.92	418.59	380.79	802.9	392.33	389.55	802.9	398.52	382.06	418.46	409.38	347.76	419.07	412.9	423.17	355.69	349.94	321.65	321.35	317.55
143983	09-12-2020 23:41	406.57	419.15	381.11	802.9	392.63	390.09	802.9	398.83	382.36	418.59	409.48	347.41	419.19	413.08	423.4	355.95	350.32	322.2	321.7	317.86
143984	09-12-2020 23:42	406.98	419.31	381.54	802.9	392.93	390.64	802.9	399.18	382.61	418.69	409.6	346.88	419.34	413.28	423.57	356.22	350.74	322.75	322.05	317.99
143985	09-12-2020 23:43	407.06	419.31	382.09	802.9	393.24	391.19	802.9	399.46	382.89	418.82	409.7	346.18	419.5	413.5	423.72	356.47	351.05	323.18	322.33	318.29
143986	09-12-2020 23:44	407.22	419.36	382.64	802.9	393.59	391.67	802.9	399.73	383.14	418.97	409.78	345.42	419.6	413.83	423.88	356.75	351.32	323.61	322.75	319.01
143987	09-12-2020 23:45	407.46	419.43	383.17	802.9	393.92	392.13	802.9	400.03	383.37	419.07	409.86	344.42	419.67	414.25	424.03	357.05	351.67	323.92	322.94	318.93
143988	09-12-2020 23:46	407.71	419.65	383.7	802.9	394.27	392.43	802.9	400.34	383.55	419.19	409.93	343.54	419.75	414.56	424.08	357.25	352	324.24	323.14	319.45
143989	09-12-2020 23:47	407.95	419.76	384.18	802.9	394.6	392.76	802.9	400.69	383.8	419.3	410.01	342.78	419.73	414.74	424.18	357.5	352.25	324.67	323.39	320
143990	09-12-2020 23:48	408.19	419.86	384.63	802.9	394.95	393.13	802.9	401.02	384.05	419.37	410.03	342.07	419.85	414.89	424.28	357.75	352.53	325.02	323.66	320.17
143991	09-12-2020 23:49	408.44	420.4	385.08	802.9	395.28	393.51	802.9	401.32	384.28	419.5	410.13	341.39	419.93	415.04	424.31	357.98	352.78	325.37	324.06	320.76
143992	09-12-2020 23:50	409	421.05	385.48	802.9	395.53	393.94	802.9	401.62	384.5	419.6	410.23	340.57	419.98	415.19	424.4	358.3	353.06	325.7	324.47	320.91
143993	09-12-2020 23:51	409.41	421.46	385.81	802.9	395.85	394.34	802.9	401.92	384.78	419.67	410.31	339.42	420.05	415.44	424.56	358.73	353.31	325.85	324.94	321.07
143994	09-12-2020 23:52	409.34	421.52	386.02	802.9	396.18	394.72	802.9	402.17	385.03	419.8	410.38	338.13	420.22	415.74	424.61	359.28	353.68	325.93	325.37	321.01
143995	09-12-2020 23:53	409.57	421.34	386.12	802.9	396.53	395.05	802.9	402.45	385.26	419.95	410.41	336.9	420.45	415.95	424.66	359.98	354.13	326.2	325.8	321.1
143996	09-12-2020 23:54	410.05	421.36	386.14	802.9	396.86	395.35	802.9	402.75	385.48	420.05	410.51	335.79	420.68	416.15	424.73	360.64	354.49	326.38	326.15	321.35
143997	09-12-2020 23:55	410.54	421.56	386.29	802.9	397.11	395.7	802.9	403.01	385.66	420.18	410.61	334.93	420.9	416.32	424.81	361.24	354.79	326.5	326.45	321.43
143998	09-12-2020 23:56	410.71	421.49	386.52	802.9	397.34	395.93	802.9	403.28	385.91	420.33	410.73	334.47	421.13	416.43	424.88	361.79	355.09	326.7	326.75	321.58
143999	09-12-2020 23:57	410.71	421.27	386.84	802.9	397.62	396.23	802.9	403.58	386.11	420.43	410.84	334.26	421.36	416.6	424.96	362.32	355.44	326.88	327.2	321.81
144000	09-12-2020 23:58	410.55	420.94	387.17	802.9	397.87	396.46	802.9	403.84	386.32	420.55	410.96	334.01	421.58	416.73	425.03	362.95	355.77	327.08	327.58	321.93
144001	09-12-2020 23:59	410.31	420.71	387.47	802.9	398.1	396.61	802.9	404.11	386.54	420.7	411.06	333.91	421.76	416.85	425.11	363.48	356.02	327.21	327.79	322.4
144002	10-12-2020 00:00	410.38	420.76	387.77	802.9	398.42	396.81	802.9	404.41	386.82	420.85	411.19	334.01	421.96	416.95	425.19	363.83	356.3	327.43	328.08	322.59

Error Readings.
Maximum temp is 500 degree Celsius

Some Thermocouples were not functioning which were prominently visible from the data retrieved. Those thermocouple data are removed at first place.

Data Pre-processing - Filtering

Initial correct readings

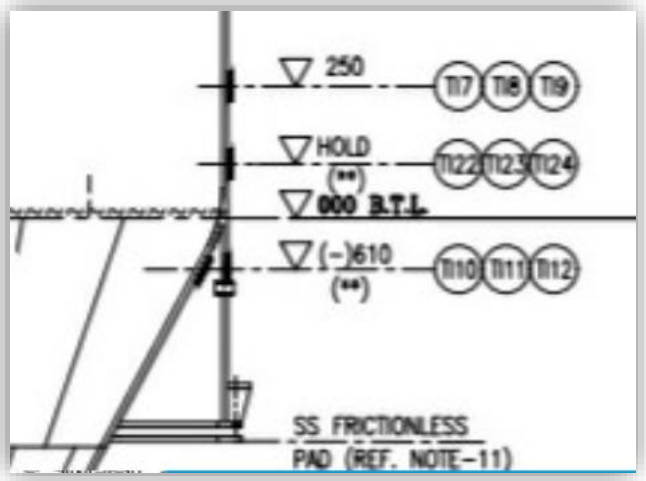
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1		TC.604TI2460.	TC.604TI2461.	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.604TI2462	TC.
2	01-09-2020 00:00	414.15	417.55	398.89	401.02	417.28	398.46	802.9	420.68	408.22	411.69	402.56	328.48	405.95	400.32	401.98	352.71	342.78	311.11	313.92	300.38
3	01-09-2020 00:01	413.99	417.58	398.98	401.14	417.33	401.27	802.9	420.73	408.27	411.69	402.61	328.29	406	400.34	401.95	352.66	342.74	310.96	313.97	300.36
4	01-09-2020 00:02	414.06	417.53	399.09	401.29	417.41	399.97	802.9	420.81	408.34	411.69	402.63	328.37	406.03	400.32	401.85	352.58	342.59	310.83	313.97	300.28
5	01-09-2020 00:03	414.15	417.6	399.16	401.4	417.48	401.7	802.9	420.88	408.42	411.69	402.58	327.85	406.03	400.34	401.8	352.56	342.49	311.1	314.07	300.5
6	01-09-2020 00:04	414.15	417.85	399.19	401.47	417.56	403.46	802.9	421.01	408.4	411.69	402.56	327.07	406.03	400.27	401.7	352.56	342.51	311.16	314.27	300.58
7	01-09-2020 00:05	414.3	417.95	399.24	401.6	417.58	401.72	802.9	421.06	408.27	411.74	402.56	326.61	406.08	400.31	401.5	352.51	342.49	310.86	314.25	300.41
8	01-09-2020 00:06	414.39	418.05	399.31	401.7	417.63	404.08	802.9	421.11	408.27	411.77	402.56	326.26	406.11	400.46	401.37	352.43	342.46	310.83	314.29	300.33
9	01-09-2020 00:07	414.39	418.2	399.39	401.82	417.71	402.34	802.9	421.13	408.34	411.77	402.56	326.08	406.06	400.57	401.4	352.41	342.51	311.13	314.45	300.57
143982	09-12-2020 23:40	405.92	418.59	380.79	802.9	392.33	389.55	802.9	398.52	382.06	418.46	409.38	347.76	419.07	412.9	423.17	355.69	349.94	321.65	321.35	317.55
143983	09-12-2020 23:41	406.57	419.15	381.11	802.9	392.63	390.09	802.9	398.83	382.36	418.59	409.48	347.41	419.19	413.08	423.4	355.95	350.32	322.2	321.7	317.86
143984	09-12-2020 23:42	406.98	419.31	381.54	802.9	392.93	390.64	802.9	399.18	382.61	418.69	409.6	346.88	419.34	413.28	423.57	356.22	350.74	322.75	322.05	317.99
143985	09-12-2020 23:43	407.06	419.31	382.09	802.9	393.24	391.19	802.9	399.46	382.89	418.82	409.7	346.18	419.5	413.5	423.72	356.47	351.05	323.18	322.33	318.29
143986	09-12-2020 23:44	407.22	419.36	382.64	802.9	393.59	391.67	802.9	399.73	383.14	418.97	409.78	345.42	419.6	413.83	423.88	356.75	351.32	323.61	322.75	319.01
143987	09-12-2020 23:45	407.46	419.43	383.17	802.9	393.92	392.13	802.9	400.03	383.37	419.07	409.86	344.42	419.67	414.25	424.03	357.05	351.67	323.92	322.94	318.93
143988	09-12-2020 23:46	407.71	419.65	383.7	802.9	394.27	392.43	802.9	400.34	383.55	419.19	409.93	343.54	419.75	414.56	424.08	357.25	352	324.24	323.14	319.45
143989	09-12-2020 23:47	407.95	419.76	384.18	802.9	394.6	392.76	802.9	400.69	383.8	419.3	410.01	342.78	419.73	414.74	424.18	357.5	352.25	324.67	323.39	320
143990	09-12-2020 23:48	408.19	419.86	384.63	802.9	394.95	393.13	802.9	401.02	384.05	419.37	410.03	342.07	419.85	414.89	424.28	357.75	352.53	325.02	323.66	320.17
143991	09-12-2020 23:49	408.44	420.4	385.08	802.9	395.28	393.51	802.9	401.32	384.28	419.5	410.13	341.39	419.93	415.04	424.31	357.98	352.78	325.37	324.06	320.76
143992	09-12-2020 23:50	409	421.05	385.48	802.9	395.53	393.94	802.9	401.62	384.5	419.6	410.23	340.57	419.98	415.19	424.4	358.3	353.06	325.7	324.47	320.91
143993	09-12-2020 23:51	409.41	421.46	385.81	802.9	395.85	394.34	802.9	401.92	384.78	419.67	410.31	339.42	420.05	415.44	424.56	358.73	353.31	325.85	324.94	321.07
143994	09-12-2020 23:52	409.34	421.52	386.02	802.9	396.18	394.72	802.9	402.17	385.03	419.8	410.38	338.13	420.22	415.74	424.61	359.28	353.68	325.93	325.37	321.01
143995	09-12-2020 23:53	409.57	421.34	386.12	802.9	396.53	395.05	802.9	402.45	385.26	419.95	410.41	336.9	420.45	415.95	424.66	359.98	354.13	326.2	325.8	321.1
143996	09-12-2020 23:54	410.05	421.36	386.14	802.9	396.86	395.35	802.9	402.75	385.48	420.05	410.51	335.79	420.68	416.15	424.73	360.64	354.49	326.38	326.15	321.35
143997	09-12-2020 23:55	410.54	421.56	386.29	802.9	397.11	395.7	802.9	403.01	385.66	420.18	410.61	334.93	420.9	416.32	424.81	361.24	354.79	326.5	326.45	321.43
143998	09-12-2020 23:56	410.71	421.49	386.52	802.9	397.34	395.93	802.9	403.28	385.91	420.33	410.73	334.47	421.13	416.43	424.88	361.79	355.09	326.7	326.75	321.58
143999	09-12-2020 23:57	410.71	421.27	386.84	802.9	397.62	396.23	802.9	403.58	386.11	420.43	410.84	334.26	421.36	416.6	424.96	362.32	355.44	326.88	327.2	321.81
144000	09-12-2020 23:58	410.55	420.94	387.17	802.9	397.87	396.46	802.9	403.84	386.32	420.55	410.96	334.01	421.58	416.73	425.03	362.95	355.77	327.08	327.58	321.93
144001	09-12-2020 23:59	410.31	420.71	387.47	802.9	398.1	396.61	802.9	404.11	386.54	420.7	411.06	333.91	421.76	416.85	425.11	363.48	356.02	327.21	327.79	322.4
144002	10-12-2020 00:00	410.38	420.76	387.77	802.9	398.42	396.81	802.9	404.41	386.82	420.85	411.19	334.01	421.96	416.95	425.19	363.83	356.3	327.43	328.08	322.59

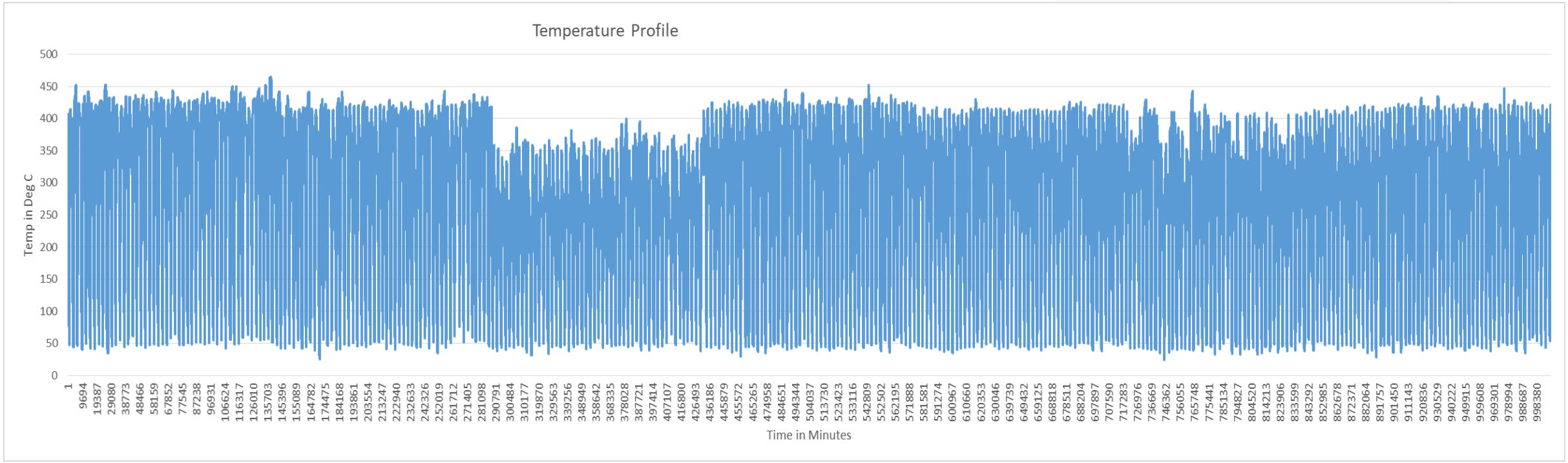
Error Readings.
Maximum temp is 500 degree Celsius

Some Thermocouples were initially functioning well but not functioning after some time, which were prominently visible from the data retrieved. Those thermocouple data are removed at first place.

Support Skirt Cone Junction

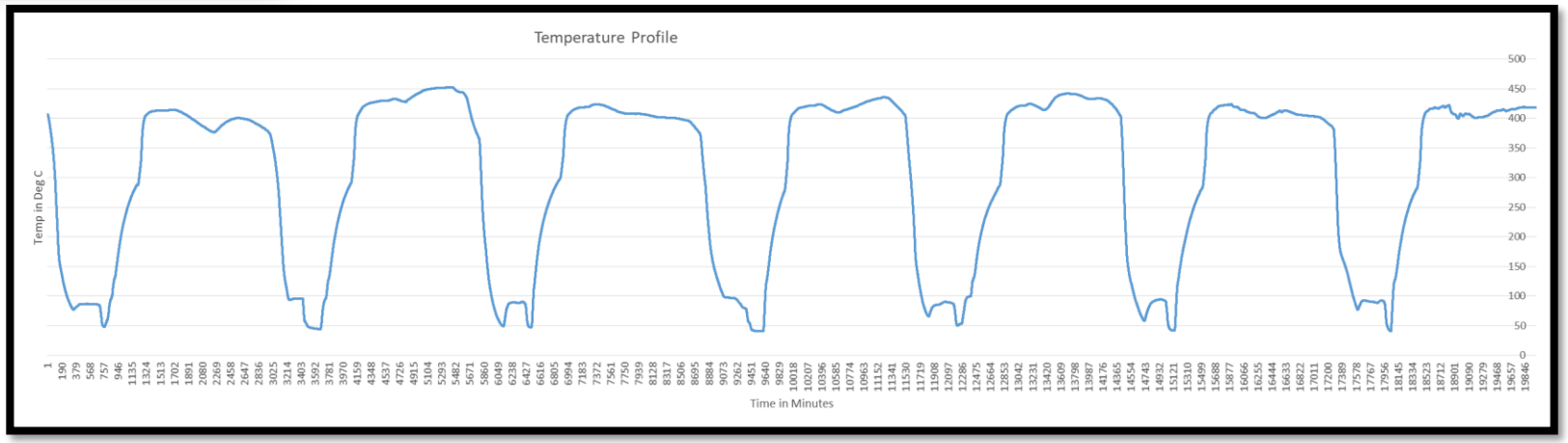
As we can see there are 3 thermocouples in a particular elevation and so have appended all these data under single streams.

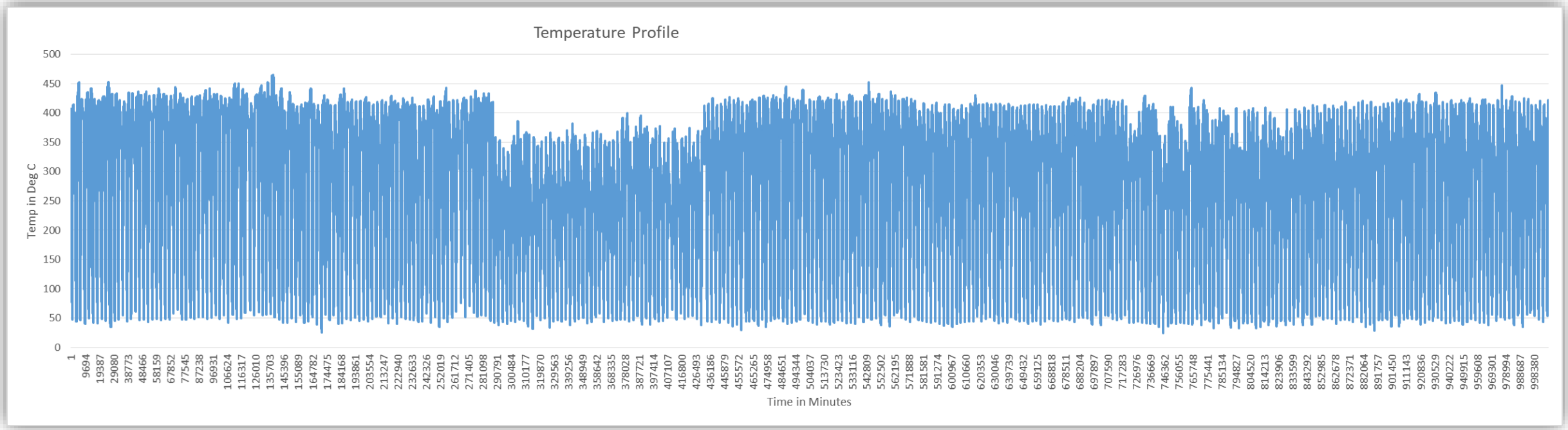




Data Profiling : Envelop Detection

LOCAL ZOOMED PLOT



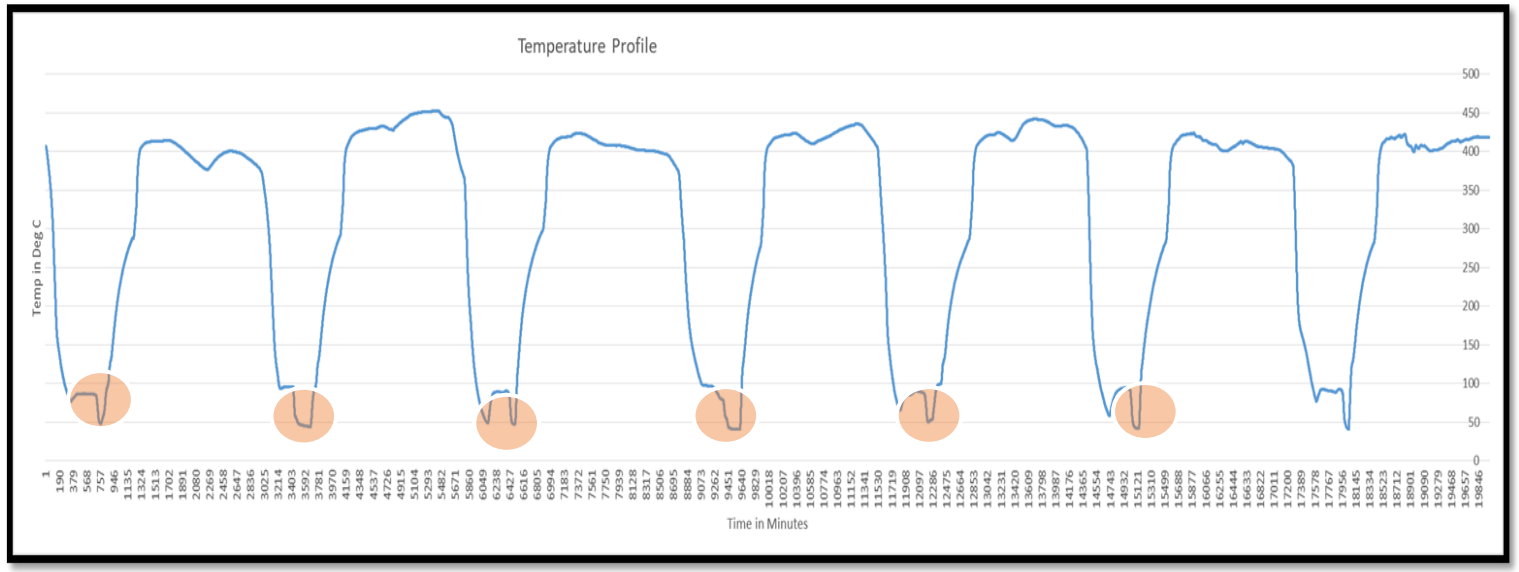


Data Processing

This is the Plot, but we got to find first segregate individual Cycles.

The orange dots are the cycle completion points. We have to capture those points at first instance.

Using Piecewise Linear Fit library of python, we could establish those points without much taxing.



Now, for an approximation we have divided the curve into 7 straight lines.

As there is a curvilinear portion at the transitions of curves, there we have used higher order curve fitting.

Instead of running with huge unknown data set, I have used curve fitting with known cyclic data.

Data Processing

At first ideal process curve itself loaded for programming.

Here, the parameters measured are,

Cycle Time,

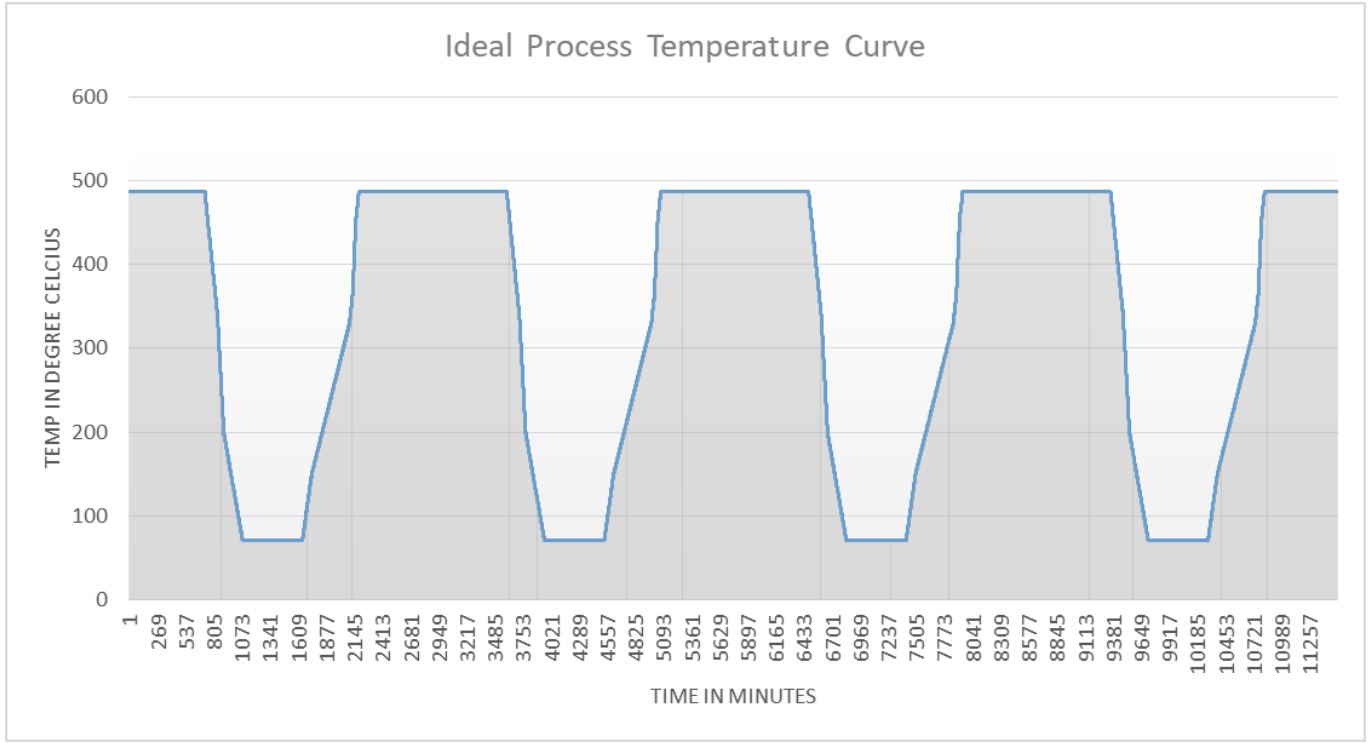
Heating rate,

Cooling Rate,

Switch Temperature,

Maximum Temperature

Minimum Temperature



Since these parameters are well known, these outputs generated should be inline.

Also, I wanted to note down the time points & respective temperature to regenerate the curve with minimal points.

And I also plotted the curves to visually see whether things are in place.

Output Files

ex - Notepad

File Edit Format View Help

```
Cycle No: 1
Maximum Temperature:     487.12
Minimum Temperature:      21.74
Duration of Cycle:       2878
Switch Temperature:    325.728
Heating Rate:      2.090
Cooling Rate:      2.333

# Cycle Data
0.000,70.000
100.000,21.741
741.545,325.728
815.217,485.917
861.163,486.318
907.109,486.719
953.054,487.120
1000.000,487.000
1532.664,487.000
2234.000,487.000
2354.000,340.000
2414.000,200.000
2594.001,70.000
2598.538,70.000
2878.000,70.000
# Cycle Completed

Cycle No: 2
```

ex - Notepad

File Edit Format View Help

```
Cycle No: 2
Maximum Temperature:     487.15
Minimum Temperature:      21.74
Duration of Cycle:       2878
Switch Temperature:    325.803
Heating Rate:      2.090
Cooling Rate:      2.333

# Cycle Data
0.000,70.000
100.000,21.741
741.704,325.803
814.864,485.695
860.898,486.179
906.932,486.662
952.966,487.146
1000.000,487.000
2234.000,487.000
2354.000,340.000
2414.001,199.998
2414.622,199.551
2594.001,70.000
2853.137,70.000
2878.000,70.000
# Cycle Completed

Cycle No: 3
```

ex - Notepad

File Edit Format View Help

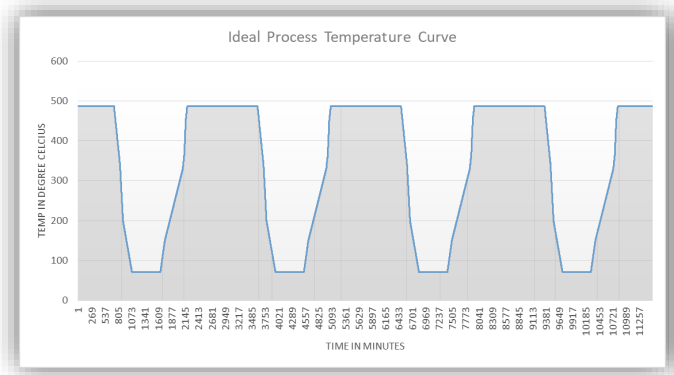
```
Cycle No: 3
Maximum Temperature:     487.12
Minimum Temperature:      21.74
Duration of Cycle:       2878
Switch Temperature:    325.728
Heating Rate:      2.090
Cooling Rate:      2.333

# Cycle Data
0.000,70.000
100.000,21.741
741.545,325.728
815.217,485.917
861.163,486.318
907.109,486.719
953.054,487.120
1000.000,487.000
2229.483,487.000
2234.000,487.000
2354.000,340.000
2364.273,316.030
2414.000,200.000
2594.001,70.000
2878.000,70.000
# Cycle Completed
```

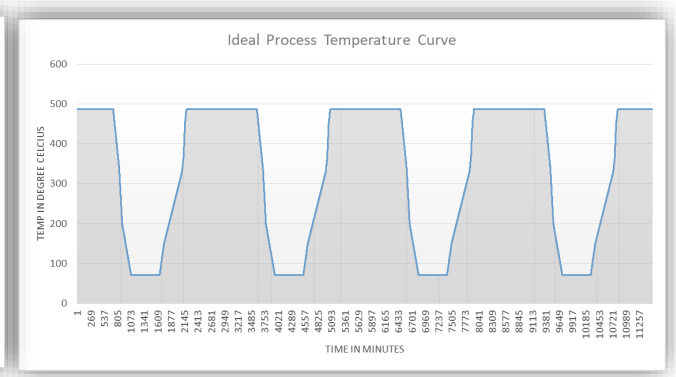
ex - Notepad

File Edit Format View Help

```
# Maximum Temperature
487.120
487.146
487.120
Maximum :487.1463, Minimum: 487.1204
Mean :487.1290, Standard Deviation:  0.0122

# Minimum Temperature
21.741
21.741
21.741
Maximum :21.7409, Minimum: 21.7408
Mean :21.7408, Standard Deviation:  0.0000

# Duration of Cycle
2878.000
2878.000
2878.000
Maximum :2878.0000, Minimum: 2878.0000
Mean :2878.0000, Standard Deviation:  0.0000

# Switch Temperature
325.728
325.803
325.728
Maximum :325.8028, Minimum: 325.7278
Mean :325.7528, Standard Deviation:  0.0354
```

Output Files

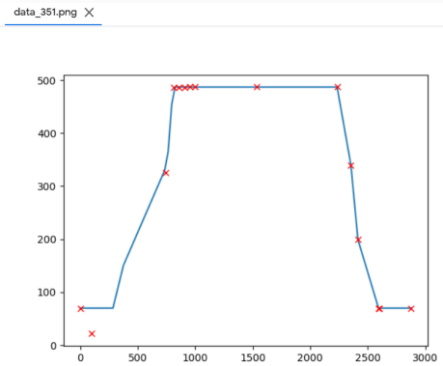


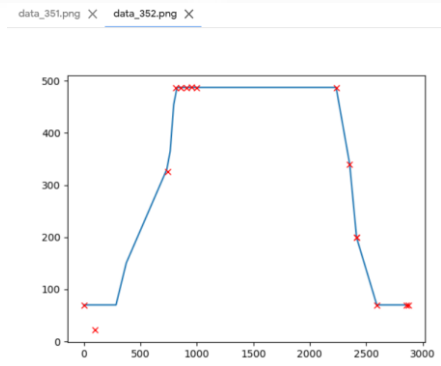


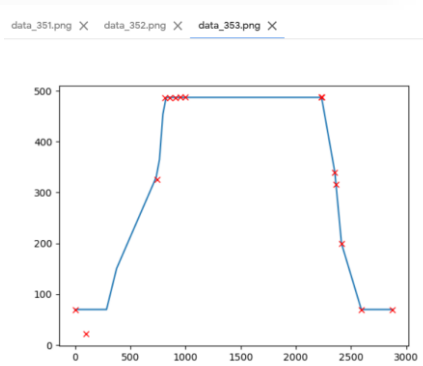
ex - Notepad

File Edit Format View Help

```
# Maximum Temperature
487.120
487.146
487.120
Maximum :487.1463, Minimum: 487.1204
Mean :487.1290, Standard Deviation:  0.0122

# Minimum Temperature
21.741
21.741
21.741
Maximum :21.7409, Minimum: 21.7408
Mean :21.7408, Standard Deviation:  0.0000

# Duration of Cycle
2878.000
2878.000
2878.000
Maximum :2878.0000, Minimum: 2878.0000
Mean :2878.0000, Standard Deviation:  0.0000

# Switch Temperature
325.728
325.803
325.728
Maximum :325.8028, Minimum: 325.7278
Mean :325.7528, Standard Deviation:  0.0354
```







ex - Notepad

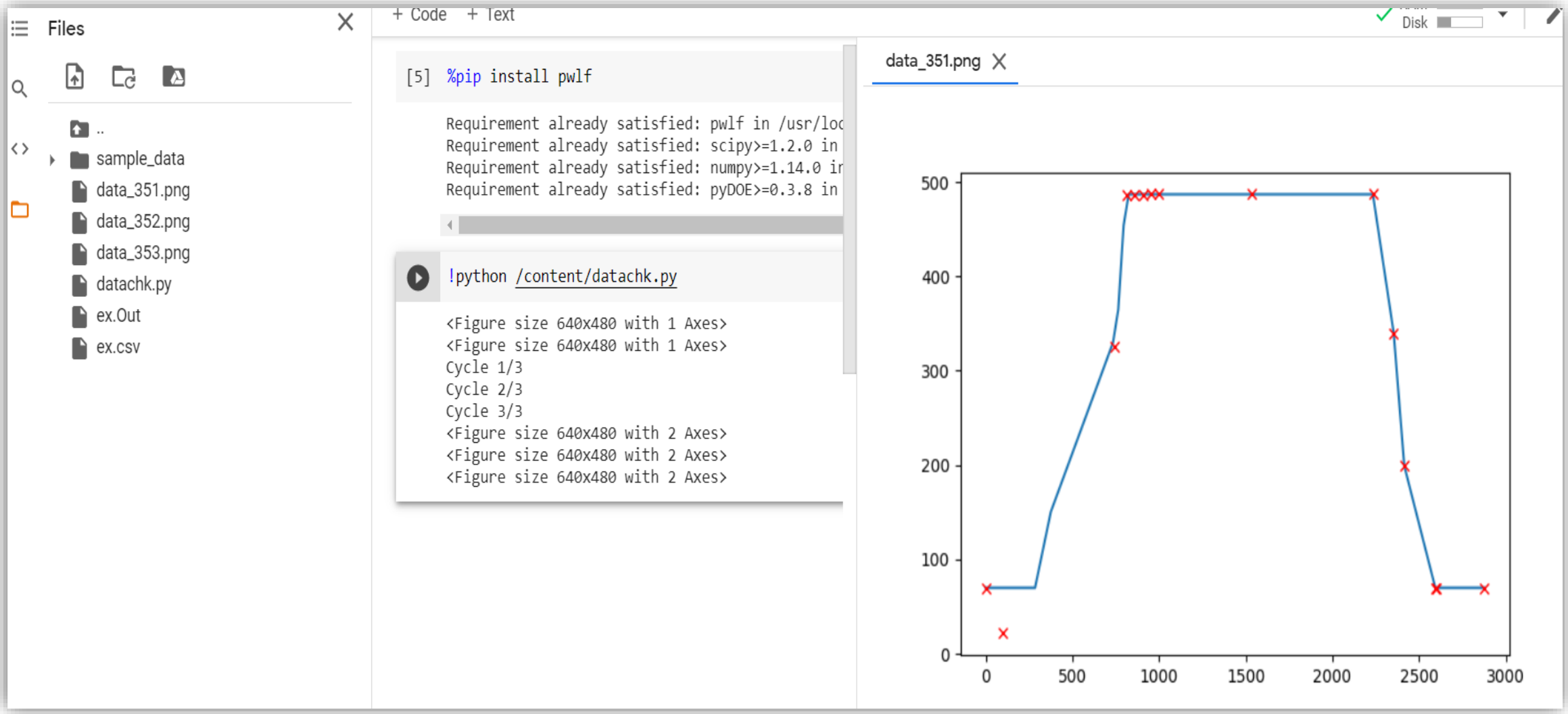
File Edit Format View Help

```
# Heating Rate
2.090
2.090
2.090
Maximum : 2.0905, Minimum:  2.0905
Mean : 2.0905, Standard Deviation:  0.0000

# Cooling Rate
2.333
2.333
2.333
Maximum : 2.3333, Minimum:  2.3333
Mean : 2.3333, Standard Deviation:  0.0000
```

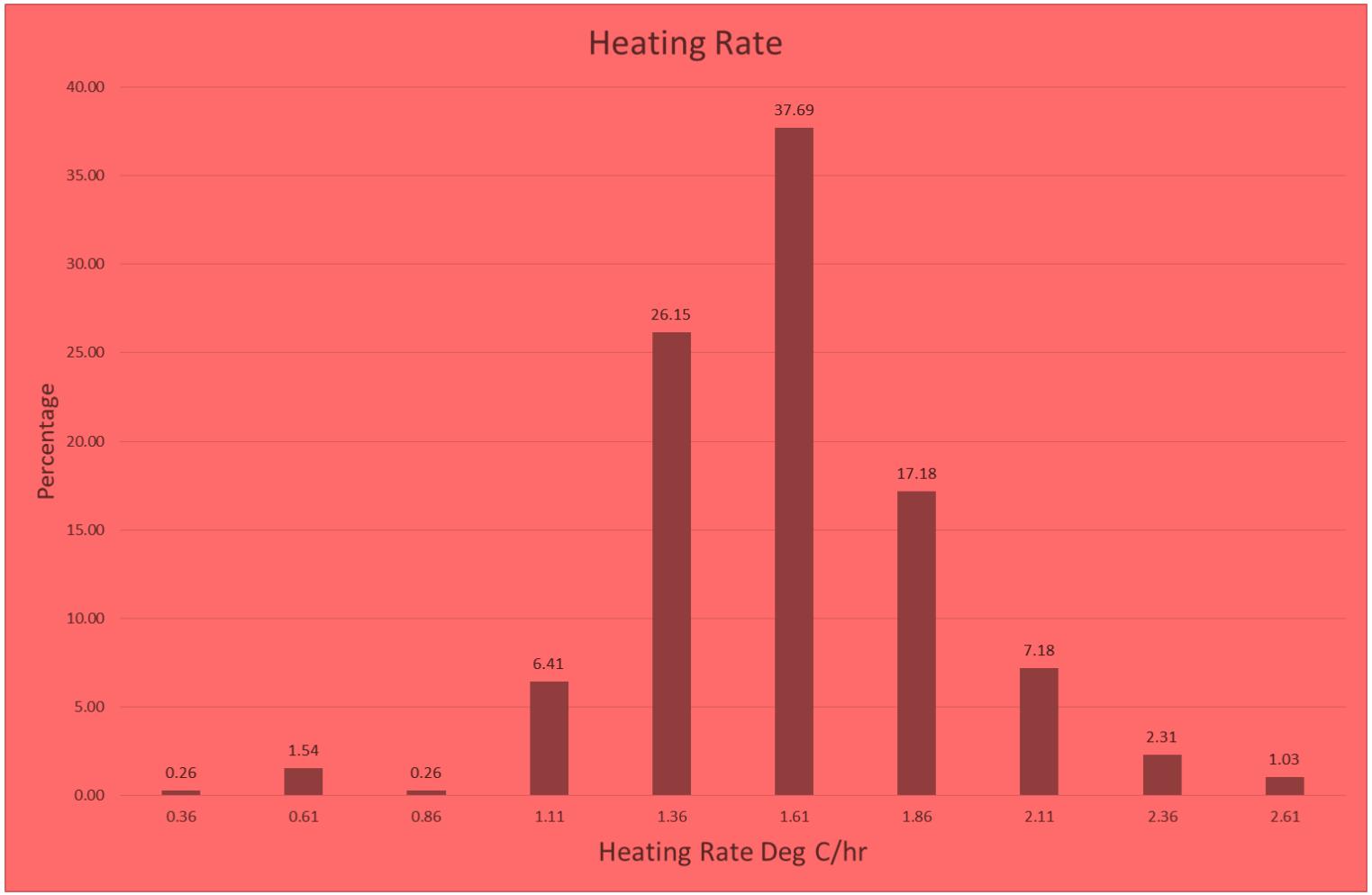
All Parameters are regenerated successfully in all three cycles.

As mentioned earlier, the higher order curve fitting was done in the actual curve data preprocessing

Google Collab Screenshot



Statistics of Data Analysis



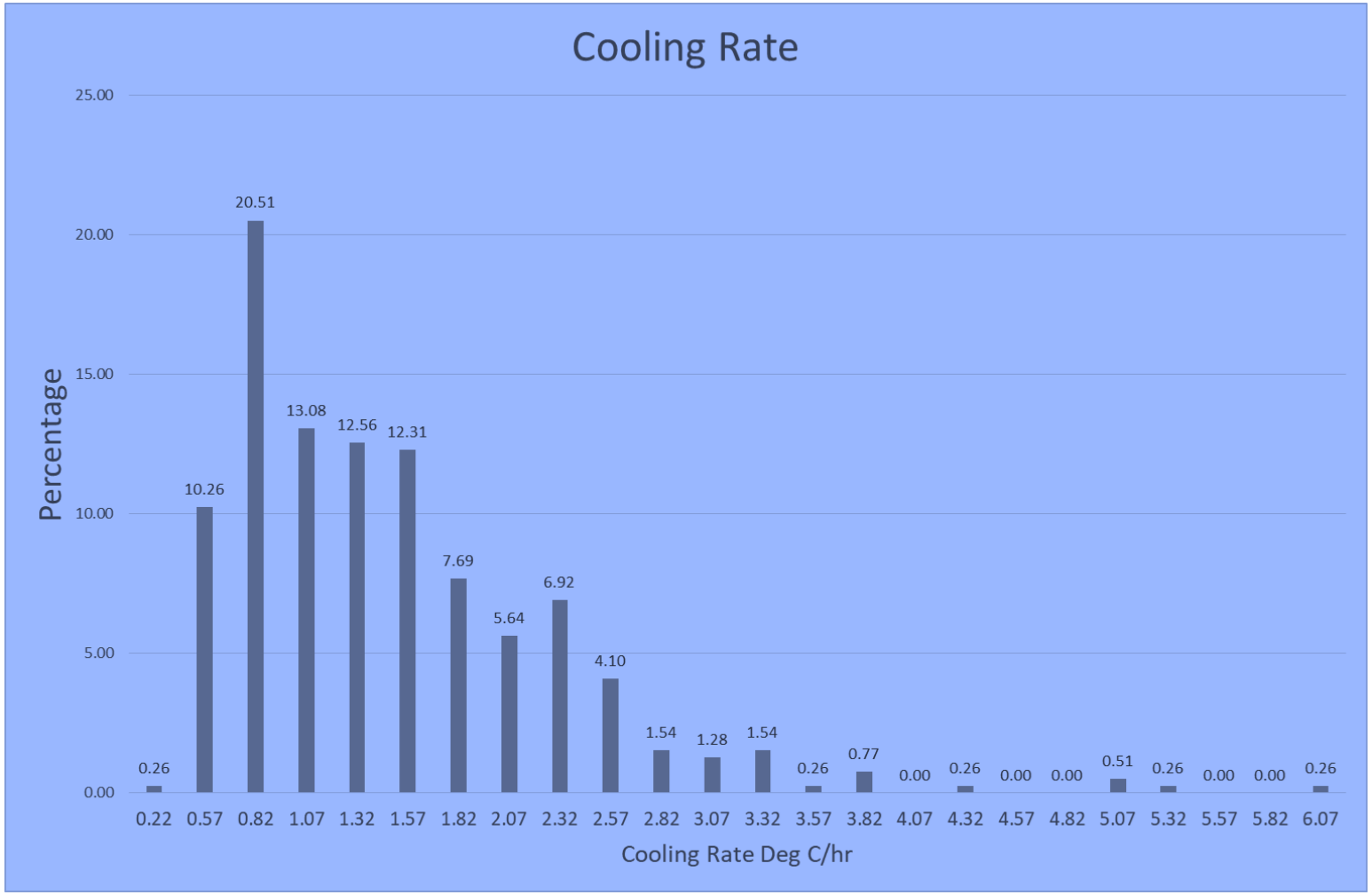
CYCLE	Heating Rate (°C/min)
IDEAL DESIRED PROCESS	3.0
SITE DATA	0.36 - 2.61
% of times within the Design Cycle Tolerance	100%

Higher the Heating Rate higher will the stress induced, resulting in reduced fatigue life.

Almost all data points are within Ideal Process Requirement.

There won't be any significant damage to the Designed Life of the Coke Drum

Statistics of Data Analysis



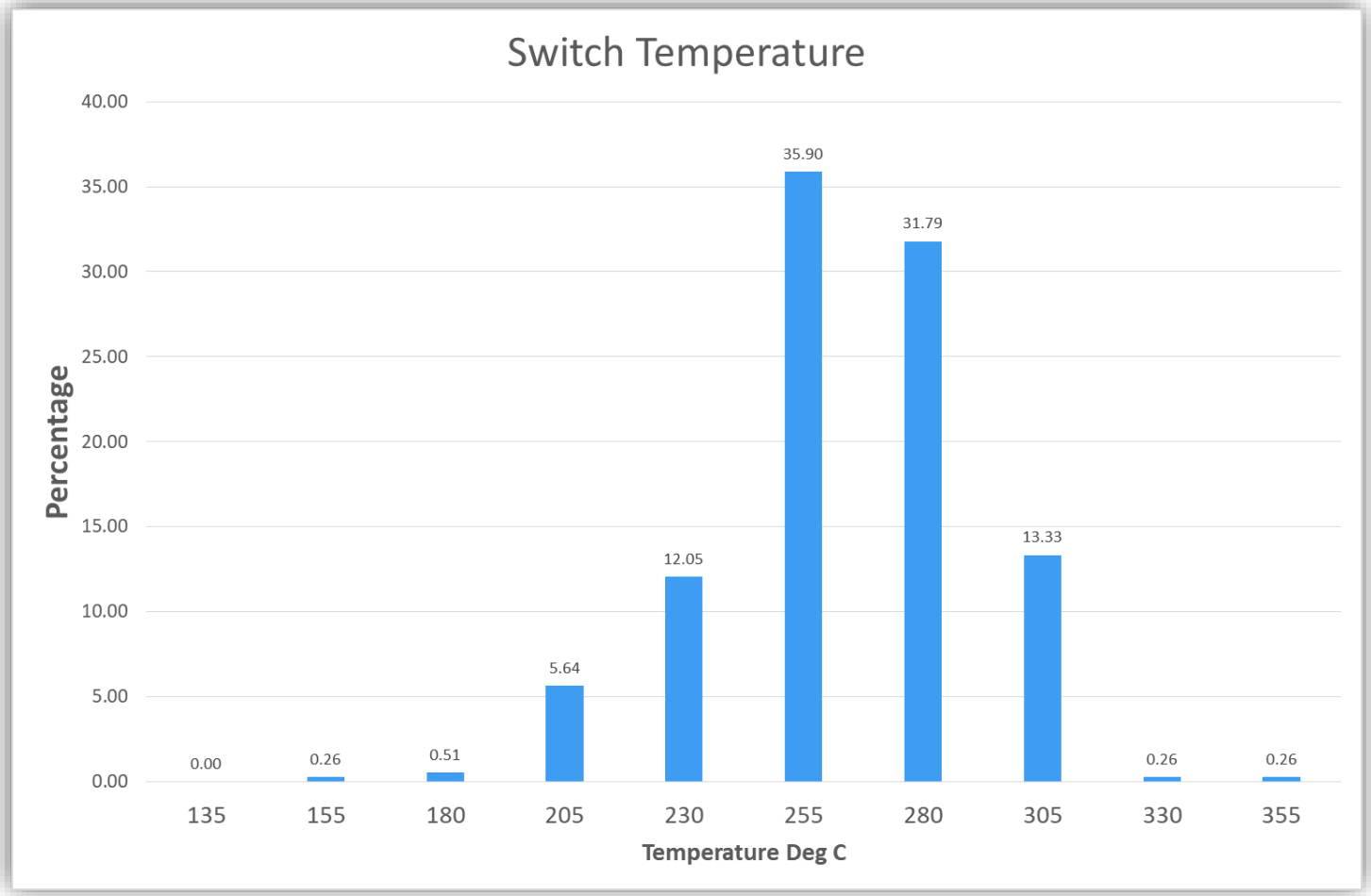
CYCLE	Cooling Rate (°C/min)
IDEAL DESIRED PROCESS	2.3
SITE DATA	0.22 - 6.03
% of times within the Design Cycle Tolerance	89.23%

Higher the Cooling Rate higher will the stress induced, resulting in reduced fatigue life.

Almost 90% data points are within Ideal Process Requirement.

Still, on the conservative front, we have assumed 0.85 deg/min in the FEA to evaluate fatigue life.

Statistics of Data Analysis

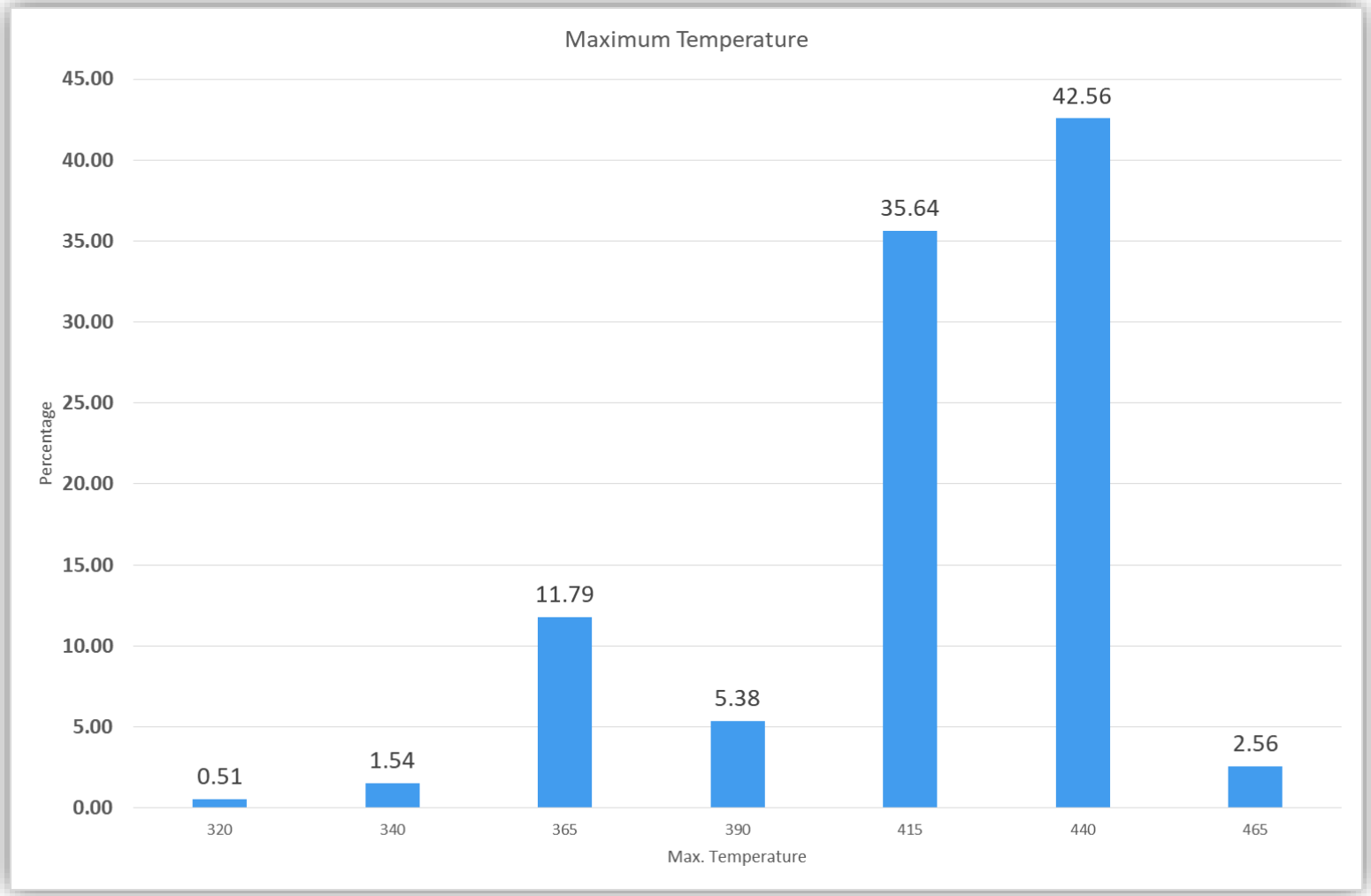


CYCLE	SWITCH TEMPERATURE (°C)
IDEAL DESIRED PROCESS	330
SITE DATA	139 - 341
% of times within the Design Cycle Tolerance	0.56%

The significant change in Switching Temperature is observed, which is not expected. This will significantly impact the fatigue life of the Coke drum.

Almost entire data points are beyond the desired level of temperature. A significance is assessed using FEA.

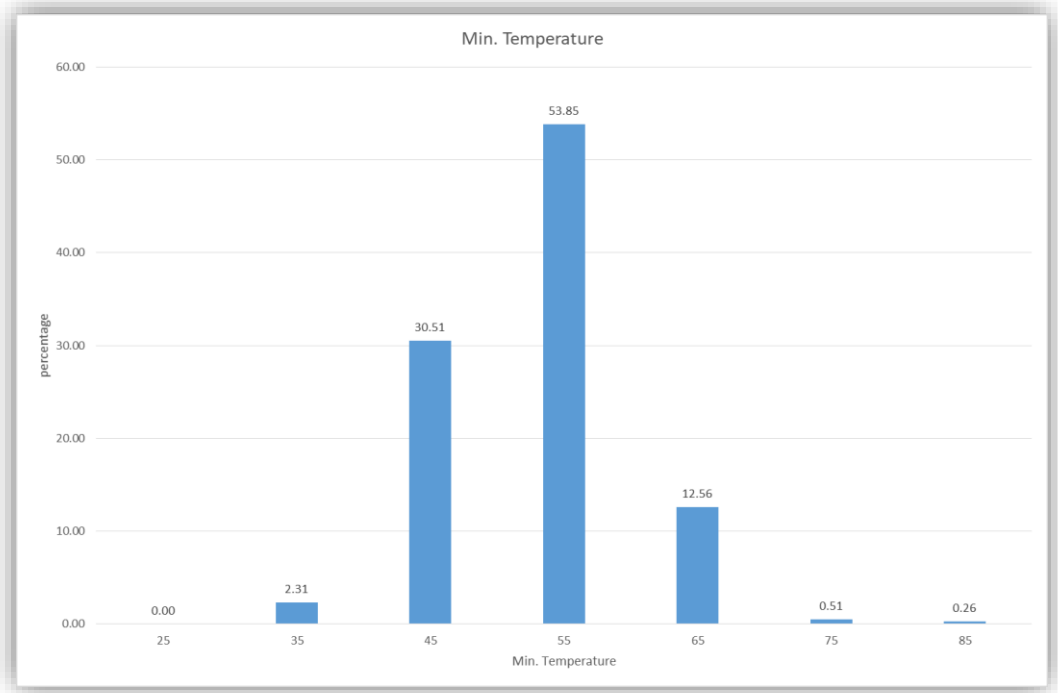
Statistics of Data Analysis



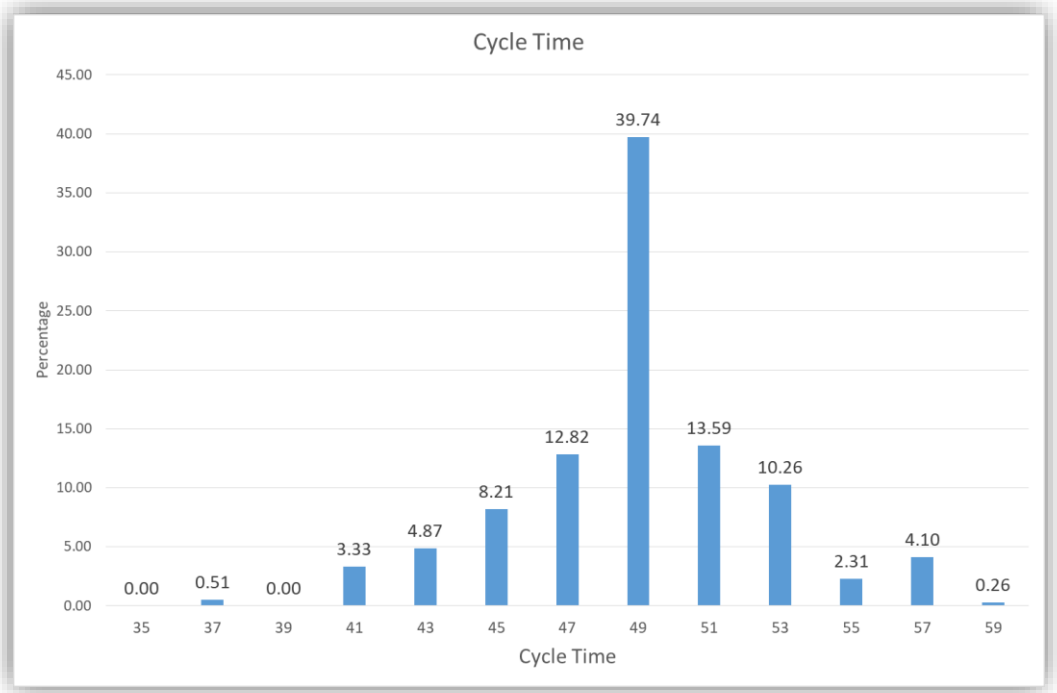
CYCLE	Max. Temperature (°C/min)
IDEAL DESIRED PROCESS	487
SITE DATA	465
% of times within the Desired Cycle Tolerance	100%

The maximum temperature observed is less than the desired process temperature. Though on the conservative front, the maximum temperature is considered in the FE Analysis.

Statistics of Data Analysis



The minimum temperature is almost within the desired temperature limits. This does not have any significance in the Fatigue life of the Coke drum.



The desired designed operating time is 48 hours, however, most of the operation cycle time delays are due to coke cutting, quenching or other process after coking.

In general, increase in time period provides minor relaxation in stress accumulation and hence on the conservative front only 48 hr. is considered in the FE Analysis.

Statistics of Data Analysis

Cycle Basis	Switch Temp (°C)	Heating Rate (°C/min)	Cooling Rate (°C/min)	Max. Temperature (°C/min)
IDEAL DESIRED PARAMETER	330	3.0	2.3	487
SITE OPERATING DATA	139 - 341	0.36 - 2.61	0.22 - 6.03	465
% of times within the Desired CYCLE	0.56%	100%	89.23%	100%

Finite Element Analysis

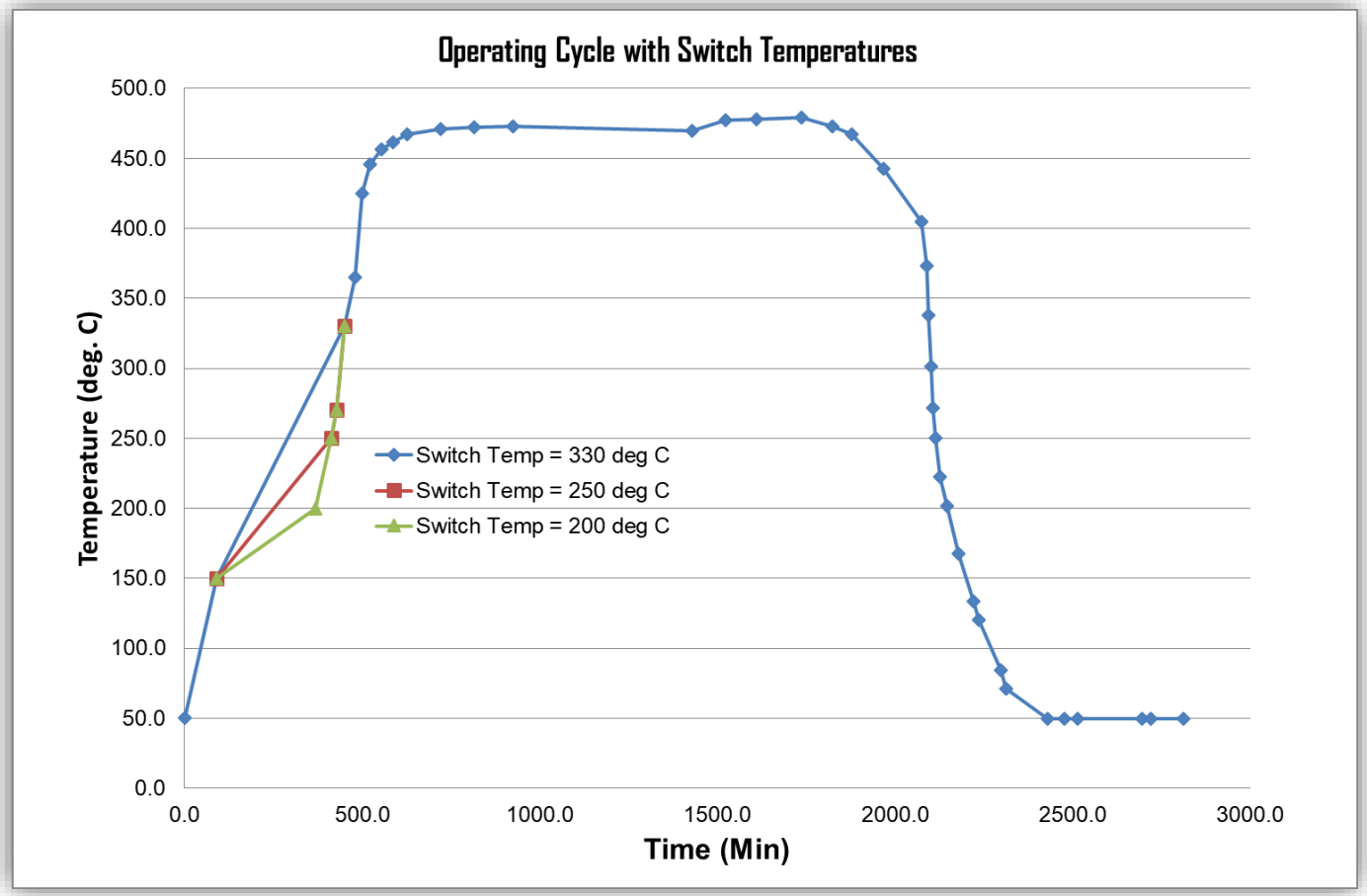
From the processed datasets, a comprehensive Finite Element Analysis is performed to evaluate the fatigue life of the Coke Drum.

Performing Fatigue Analysis for each and every dataset obtained is a computationally expensive task.

For evaluation of one cycle data, on a minimum of 4+ hours of CPU time is required on 12 Core Processor XEON Workstation with GPGPU enabled & 96 GB RAM Workstation and Post Processing the Output as per ASME Code Guidelines.

For the study, we have generated and most appropriate fitting curve from the data points receive and created a representative curve for the data points.

Finite Element Analysis



Using representative curve, the Fatigue life evaluation of coke drum is performed with changes in Heating Rate, Cooling Rate, Switch Temperature, Maximum Temperature, Minimum Temperature & Cycle Time.

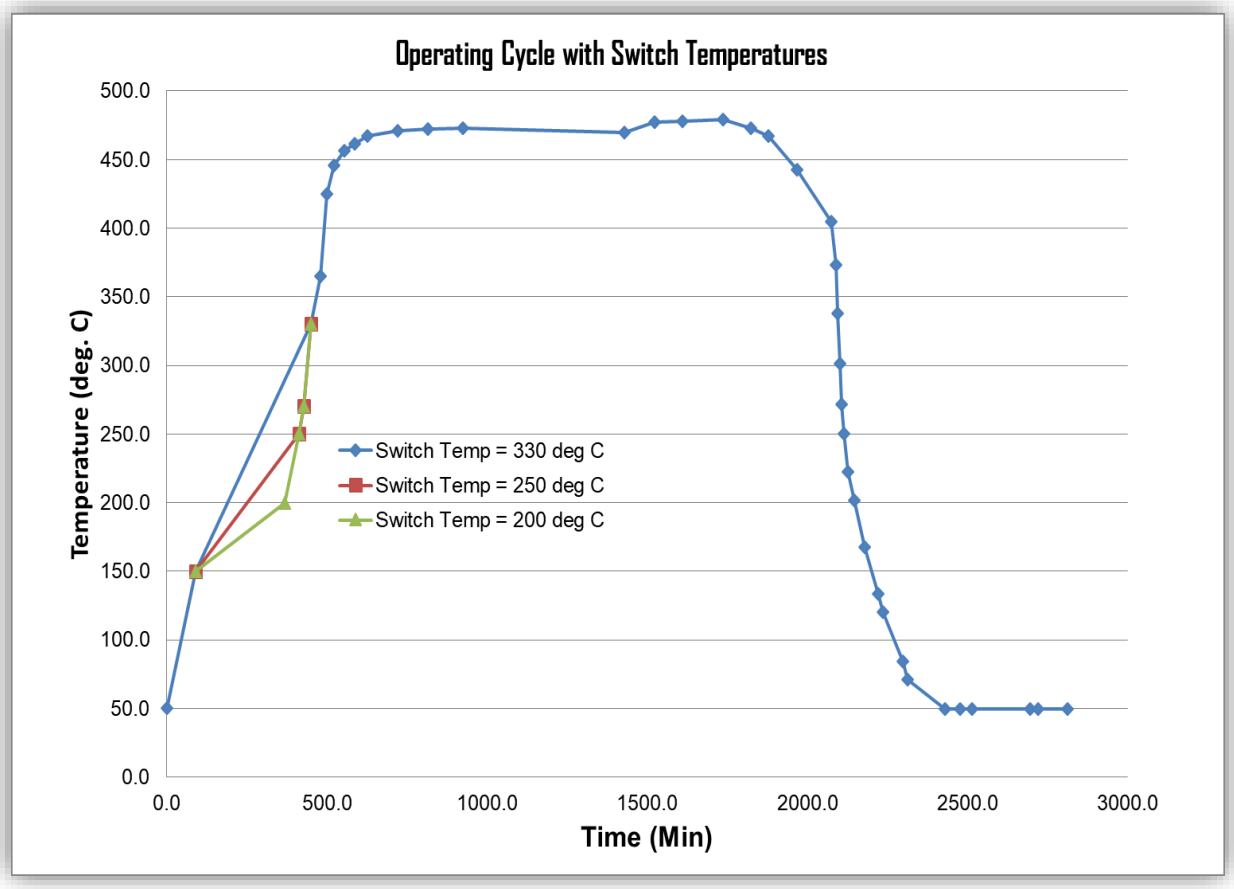
The Significant Switch influenced cycle curve is presented here.

Based on the statistics, curve with different switch temperature is generated and Fatigue evaluation is performed for the processed input curves.

In the similar way, different input curves have been generated for the all parameters and fatigue life evaluation is performed.

FEA is performed using ABAQUS Software.

Finite Element Analysis



Cycle Basis	Switch Temp (°C)	Heating Rate (°C/min)	Cooling Rate (°C/min)	Max. Temperature (°C/min)
IDEAL DESIRED PARAMETER	330	3.0	2.3	487
SITE OPERATING DATA	139 - 341	0.36 - 2.61	0.22 - 6.03	465
% of times within the Desired CYCLE	0.56 %	100%	89.23 %	100%

From the statistically obtained Heating rate & cooling rate, we found that there is no much difference in the overall fatigue life of the Coke drum.

However, the Switch Temperature & Maximum Temperature impacts a lot on fatigue life of the Coke drum.

Here, we have presented results of them.

Finite Element Analysis

	Switch Temp-200	Switch temp-250	Switch Temp-330	Max Temp 465	Max Temp 495
Plastic Strain	4.64E-03	2.64E-03	1.63E-03	1.08E-03	1.23E-03
Elastic Stress (MPa)	657.00	657.00	631.50	605.00	617.80
Youngs Modulus (MPa)	1.70E+05	1.70E+05	1.70E+05	1.70E+05	1.70E+05
Elastic Strain	3.88E-03	3.86E-03	3.71E-03	3.56E-03	3.63E-03
Total Strain	8.51E-03	6.51E-03	5.34E-03	4.64E-03	4.86E-03
Stress Range (MPa)	1.361E+03	1.11E+03	908.60	788.26	826.56
Stress Amplitude (MPa)	680.5	553.07	454.30	394.13	413.28
Allowable Years	2.19	3.79	6.50	9.69	8.45
Allowable Months	25.4	45.48	78.00	116.28	101.40

	Switch Temp-200	Switch temp-250	Switch Temp-330	Max Temp 465	Max Temp 495
Allowable Years	2.19	3.79	6.50	9.69	8.45
Allowable Months	25.4	45.48	78.00	116.28	101.40

This 9.5 year is the lower bound limit life of the joint since the representative temperature is developed conservatively considering all maximums on the statistics of the skin thermo-couple temperature data.

The actual life of the joint will be more than 9.5 years. To improve the fatigue life of the skirt joint, it is recommended that Client shall perform routine inspection and thermal monitoring as per the provided guidelines.

Reduction of switch temperature decreases the fatigue life of the joint. For example, reduction of switch temperature by 100 ºC reduces the fatigue life by around 50%.

Key Takeaways

- Thermo-couple temperature data shall be collected at regular intervals for verification with the design representative temperature cycle and for fatigue life estimation, if required.
- Client shall implement a comprehensive and structured program of inspections and/or monitoring. This program will help to monitor crack initiation and to plan inspection and possible repairs during turnarounds.
- The monitoring program enables the client to maintain to a minimum or optimize those factors that play a significant role in precipitating excessive stresses.
- Client shall perform routine inspection and thermal monitoring. If any operating or process parameter changes, variations in TI thermal gradients and thermal differentials can be used as a parameter to compare with the design represent temperature data.
- Severe thermal operation will reduce fatigue life significantly. Therefore, optimization of operation will be required.

- Based on the findings, the overall picture of different operational behavior impact on fatigue life of vessel is established.
- The Impact of different segments of operational parameters are studied and their significance are identified.
- Lower bound limit life of the Skirt-Cone Junction using the representative temperature is developed conservatively considering all maximums on the statistics of temperature data.
- To improve the fatigue life coke drum, thermal operating guidelines are provided for client to monitor and check the thermal transients and to evaluate the transient thermal impact of operational changes and to optimize operation, as needed.

Thank You