Data Science for Manufacturing: Assignment 2 – Technical Report

Data processing, visualisation and analysis associated with the CMI industrial furnace

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Introduction

As part of the Data Science for Manufacturing course, we have been tasked with a second assignment to assess our knowledge of the processes and tools of data science applied in a manufacturing context. This assignment will focus on a real problem at AFRC: furnace heating and visualization of process data.

This technical report is composed of the following sections: introduction of the problem and objectives, where the data comes from, explanation of the data cleansing, carpentry, analysis and visualization and finally conclusions and future work section.

This report goes together with the technical presentation and Jupyter notebooks.

Aims & objectives

The aim of this project is to create python code to collect, format and visualise process data from the CMI gas fired furnace rather the current method which uses Excel and which is slow, limited and inefficient.
Code efficiency is an area I was particularly interested so for this reason I have added processing time measurement within the notebook to check elapsed time for different stages of the code.

Finally, I also wanted to use python functions to carry out some basic analysis such as detecting faulty sensors, filtering, signal integration, etc…

Regarding the furnace itself, the CMI furnace is located in the AFRC workshop and is shown in the figure below.

Figure 1 – Global view of the CMI gas fired furnace

It is considered as a medium size industrial furnace and can reach a maximum temperature of 1150 ºC. The useful volume above the grid has the following dimensions: 1000 x 1000 x 700 mm and the grid is supported by 5 firedogs.
The maximum heating rate is 200 °C/h and the expected temperature uniformity is ± 14 ºC when the furnace is running in steady state.

The furnace is heated by two natural gas burner BIC80 of 90 kW each.

The furnace is comprised of several elements (combustion air skid, gas skid, furnace BCU zone 1 and 2, door, etc…) that will be described in the next section and numerous process parameters/tags are being recorded within these.

In the future, the intention would be to deploy this methodology/strategy to other industrial furnaces with different data source such as Future Forge furnaces and AFRC member's furnaces.

Sources of data

Furnace Data

As mentioned before, 47 individual tags are currently being recorded at a fixed time interval of 2 s (frequency of 0.5 Hz). All these tags are visible on the various HMI views as represented below in Figure 2.

Figure 2 – HMI views of the different elements with tags of interest.

These views aim to draw together all the important information about the furnace to enable the operator to monitor furnace operation in a safely manner. They are also used to make process change by adjusting some parameters such as temperature, air flow rate, pressure set point, open/close the door etc…

The full list of Tags/process parameters and description is displayed in the table below.

Table 1 – List of furnace tags/process parameters with description and units

Reference	Unit	Description
AIR_0123_945_07_DPT	Nm^3/h	Air flow
AIR_0123_945_05_TE	°C	Air temperature
AIR_PID_COMBUSTION_AIR_PV	mBar	Air pressure PID contol value
AIR_PID_COMBUSTION_AIR_SP	mBar	Air pressure set point
AIR_PID_COMBUSTION_AIR_OUT	%	Fan power use
AIR_PID_COMBUSTION_AIR_ACT_P		PID action Proportional
AIR_PID_COMBUSTION_AIR_ACT_I		PID action Integral
AIR_PID_COMBUSTION_AIR_ACT_D		PID action Derivative
AIR_DRIVE_AIR_SPEED	RPM	Fan speed
AIR_0123_945_03_PT	mBar	Air pressure
FURNACE_PID_FURNACE_PRESSURE_SP	mBar	PID Pressure Set point
FURNACE_PID_FURNACE_PRESSURE_OUT	%	Opening use
FURNACE_0126_341_04_O2	%	O2 Concentration
FURNACE_0126_341_02_PDT	%	PID opening contol value
FURNACE_PID_FURNACE_PRESSURE_ACT_P		PID action Proportional
FURNACE_PID_FURNACE_PRESSURE_ACT_I		PID action Integral
FURNACE_PID_FURNACE_PRESSURE_ACT_D		PID action Derivative
FURNACE_PID_FURNACE_PRESSURE_PV	Pa	Pressure Process Value
GAS_0110_943_07_FT_Nm3_h	m^3/h	Gas flow rate
GAS_0110_943_13_TE	°C	Gas temperature
GAS_0110_943_14_PT	mBar	Gas Pressure
GAS_0110_943_07_FT_m3_h	m^3/h	Gas flow rate
PID_ZONE_1_PV	°C	PID temperature control value
PID_ZONE_1_SP	°C	PID temperature Set Point
PID_ZONE_1_OUT	%	Burner Zone 1 cycle usage
PID_ZONE_1_0104_300_01_TEC	°C	TC Zone 1
PID_ZONE_1_ACT_P		PID action Proportional
PID_ZONE_1_ACT_I		PID action Integral
PID_ZONE_1_ACT_D		PID action Derivative
PID_ZONE_1_0126_341_06_TC	°C	Exhaust temperature
PID_ZONE_2_OUT_PV	°C	PID temperature control value
PID_ZONE_2_OUT_SP	°C	PID temperature Set Point
PID_ZONE_2_OUT	%	Burner Zone 2 cycle usage
PID_ZONE_2_0104_300_02_TEC	°C	TC Zone 2
PID_ZONE_2_ACT_P		PID action Proportional
PID_ZONE_2_ACT_I		PID action Integral
PID_ZONE_2_ACT_D		PID action Derivative
ROOF_0104_300_01_TC	°C	External Furnace wall/WDS
ROOF_0104_300_02_TC	°C	WDS/WSB1100
ROOF_0104_300_03_TC	°C	WSB1100/WSB1100
ROOF_0104_300_04_TC	°C	WSB1100/JM23
ROOF_0104_300_05_TC	°C	JM23/JM26
ROOF_0104_300_06_TC	°C	JM23/JM26 - Hearth
ROOF_0104_300_07_TC	°C	Top Chimney
ROOF_0104_300_08_TC	°C	External Furnace wall
ROOF_0104_300_09_TC	°C	Room Temperature
ROOF_0104_300_10_TC	°C	Centre of grid

The process data is recorded on a NAS (network attached storage) and consists of multiple CSV files (one per sensors / per ~day approx)) (see Figure 3).
All the process data are time series i.e process value vs time stamp which is different from the data we have been using in the course workshops.
Each individual file has a size of couple of MB so the total dataset size of the can go up to several GB depending on the duration of the heat treatment being considered.

FURNACE_0126_341_02_PDT_37	15/10/2022 19:38	Microsoft Excel Comma...	2,402 KB
FURNACE_0126_341_02_PDT_38	16/10/2022 23:31	Microsoft Excel Comma...	2,391 KB
FURNACE_0126_341_02_PDT_39	18/10/2022 03:25	Microsoft Excel Comma...	2,326 KB
FURNACE_0126_341_02_PDT_40	19/10/2022 07:19	Microsoft Excel Comma...	2,323 KB
FURNACE_0126_341_02_PDT_41	20/10/2022 11:14	Microsoft Excel Comma...	2,507 KB
FURNACE_0126_341_04_O2_7	13/09/2022 04:48	Microsoft Excel Comma...	6,679 KB
FURNACE_0126_341_04_O2_8	13/09/2022 09:35	Microsoft Excel Comma...	4,860 KB
FURNACE_0126_341_04_O2_9	14/09/2022 09:35	Microsoft Excel Comma...	5,384 KB
FURNACE_0126_341_04_O2_10	15/09/2022 13:29	Microsoft Excel Comma...	4,276 KB
FURNACE_0126_341_04_O2_11	16/09/2022 17:23	Microsoft Excel Comma...	2,385 KB
FURNACE_0126_341_04_O2_12	17/09/2022 21:17	Microsoft Excel Comma...	2,374 KB
FURNACE_0126_341_04_O2_13	19/09/2022 01:11	Microsoft Excel Comma...	2,321 KB
FURNACE_0126_341_04_O2_14	20/09/2022 05:05	Microsoft Excel Comma...	2,378 KB
FURNACE_0126_341_04_O2_15	21/09/2022 08:59	Microsoft Excel Comma...	2,393 KB
FURNACE_0126_341_04_O2_16	22/09/2022 12:53	Microsoft Excel Comma...	4,632 KB
FURNACE_0126_341_04_O2_17	23/09/2022 16:47	Microsoft Excel Comma...	11,420 KB
FURNACE_0126_341_04_O2_18	24/09/2022 20:41	Microsoft Excel Comma...	11,341 KB
FURNACE_0126_341_04_O2_19	26/09/2022 00:35	Microsoft Excel Comma...	11,305 KB
FURNACE_0126_341_04_O2_20	27/09/2022 04:28	Microsoft Excel Comma...	3,614 KB
FURNACE_0126_341_04_O2_21	28/09/2022 08:22	Microsoft Excel Comma...	2,393 KB
FURNACE_0126_341_04_O2_22	28/09/2022 09:09	Microsoft Excel Comma...	67 KB
FURNACE_0126_341_04_O2_23	29/09/2022 13:02	Microsoft Excel Comma...	2,339 KB
FURNACE_0126_341_04_O2_24	30/09/2022 16:56	Microsoft Excel Comma...	2,341 KB
FURNACE_0126_341_04_O2_25	01/10/2022 20:50	Microsoft Excel Comma...	2,338 KB
FURNACE_0126_341_04_O2_26	03/10/2022 00:44	Microsoft Excel Comma...	2,338 KB
FURNACE_0126_341_04_O2_27	04/10/2022 04:38	Microsoft Excel Comma...	2,341 KB
FURNACE_0126_341_04_O2_28	05/10/2022 08:32	Microsoft Excel Comma...	2,334 KB
FURNACE_0126_341_04_O2_29	06/10/2022 12:26	Microsoft Excel Comma...	2,337 KB
FURNACE_0126_341_04_O2_30	07/10/2022 16:20	Microsoft Excel Comma...	2,335 KB
FURNACE_0126_341_04_O2_31	08/10/2022 20:14	Microsoft Excel Comma...	2,341 KB
FURNACE_0126_341_04_O2_32	10/10/2022 00:08	Microsoft Excel Comma...	2,342 KB
FURNACE_0126_341_04_O2_33	11/10/2022 04:02	Microsoft Excel Comma...	2,223 KB
FURNACE_0126_341_04_O2_34	12/10/2022 07:56	Microsoft Excel Comma...	2,157 KB
FURNACE_0126_341_04_O2_35	13/10/2022 11:50	Microsoft Excel Comma...	2,115 KB
FURNACE_0126_341_04_O2_36	14/10/2022 15:44	Microsoft Excel Comma...	2,101 KB
FURNACE_0126_341_04_O2_37	15/10/2022 19:38	Microsoft Excel Comma...	2,145 KB
FURNACE_0126_341_04_O2_38	16/10/2022 23:31	Microsoft Excel Comma...	2,133 KB
FURNACE_0126_341_04_O2_39	18/10/2022 03:25	Microsoft Excel Comma...	2,076 KB
FURNACE_0126_341_04_O2_40	19/10/2022 07:19	Microsoft Excel Comma...	2,005 KB
FURNACE_0126_341_04_O2_41	20/10/2022 11:14	Microsoft Excel Comma...	2,233 KB
FURNACE_PID_FURNACE_PRESSURE_ACT_D_7	13/09/2022 04:48	Microsoft Excel Comma...	8,263 KB
FURNACE_PID_FURNACE_PRESSURE_ACT_D_8	13/09/2022 09:35	Microsoft Excel Comma...	6,114 KB
FURNACE_PID_FURNACE_PRESSURE_ACT_D_9	14/09/2022 09:35	Microsoft Excel Comma...	6,651 KB

Figure 3 – Typical CSV files being recorded on the NAS.

In general, no IP restrictions apply to make use of the furnace process data files so they can be use freely for this assignment.

This set of data was recorded from the heating treatment of steel parts at 1100 degC for various oxygen concentration within the furnace (different air to fuel ratio settings on the burners) as well as a test run of the furnace beforehand. The total duration is more than a month (this was chosen intentionally to represent the worst-case scenario i.e. largest amount of data to check efficiency of python for extremely large dataset).

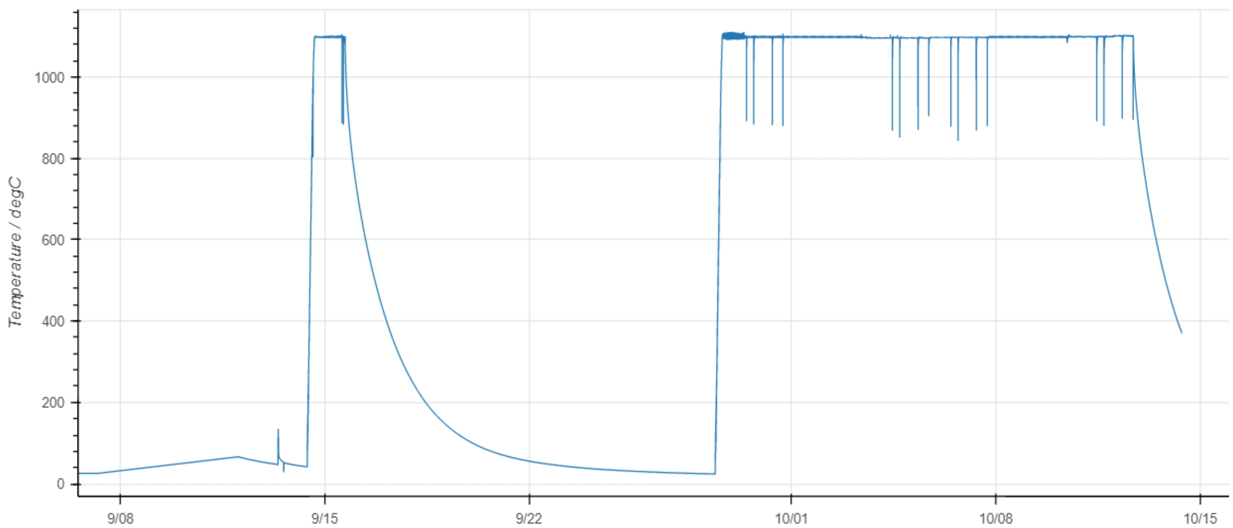

Figure 4 – Global view of the temperature profile within the furnace for the whole heat treatment duration.

Optional: Instrumented part temperature data

For some experiments, we also record temperature data on a laptop from thermocouples installed in the instrumented metal part via National Instrument CompactDAQ system / NI 9213 module. (See Figure 5)

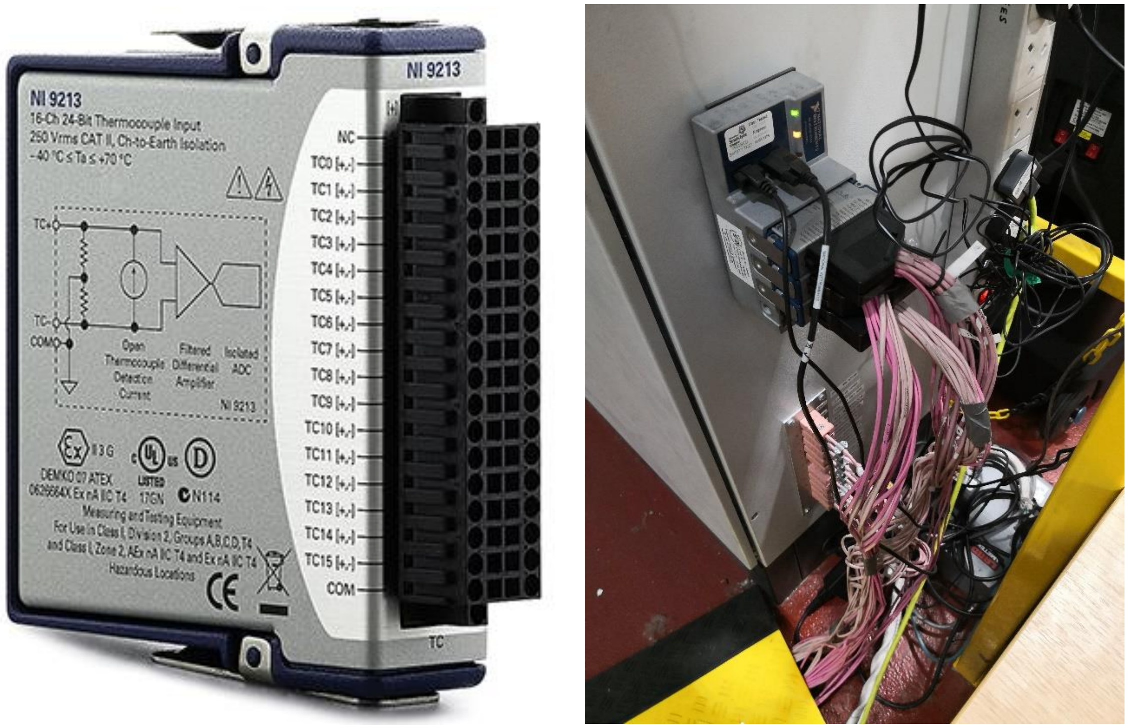

Figure 5 – Left: The NI-9213 is a high-density thermocouple module for CompactDAQ chassis (16 channels). Right: NI setup on CMI gas furnace with attached thermocouples.

This additional data is recorded on a laptop which has different clock than the Siemens PLC and needs to be realigned in time with the furnace data. The data format is also different with a single file being recorded which contains all the Thermocouple channels for the whole experiment duration.

There might be IP restrictions on these data.

Optional: Ignition platform data

Additionally, if time allows, I would like to use data recorded via the Ignition platform which was setup this year as part of Resume project. The Ignition software also pulls the data from the furnace PLC/HMI and record it on its own SQL database.
Two datasets are available, the SQL CMI_DB database which has data recorded at fixed interval of 1 s and there is also the option to export manually the data (of selected tags) from the chart area (these tags are recorded on value change not fixed interval, this was done to reduce dataset size and optimize disk space).

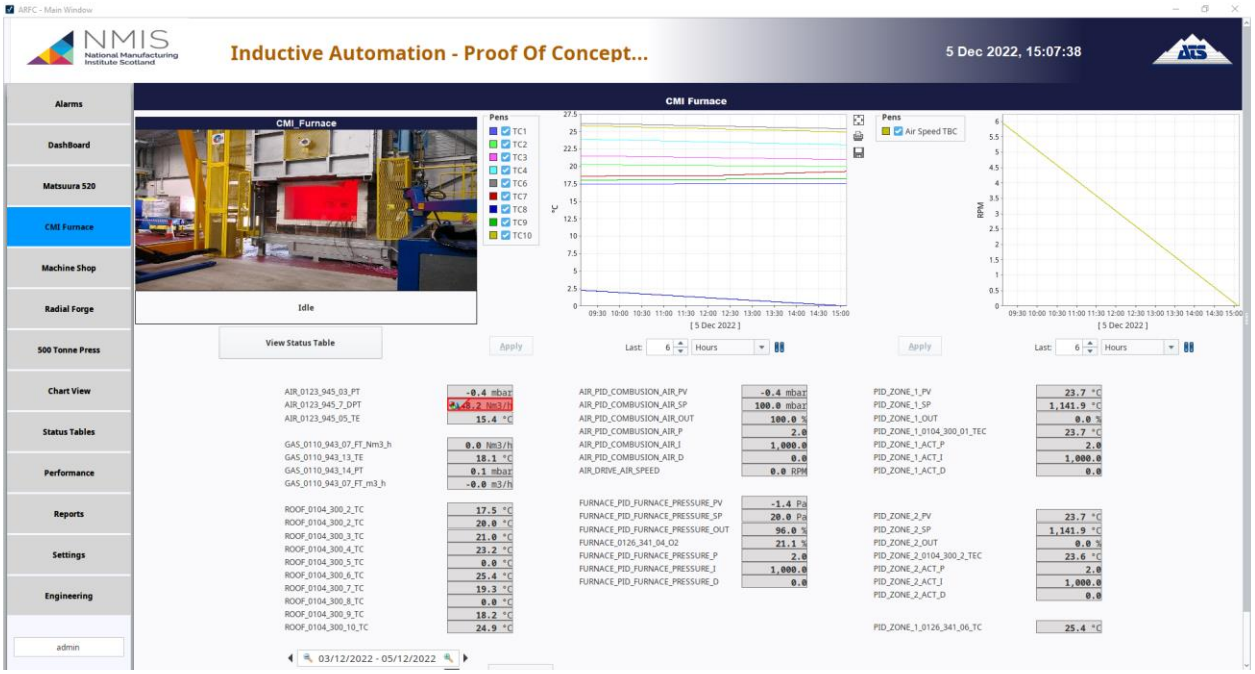

Figure 6 – Screenshot from Inductive Automation dashboard for the CMI Furnace

It could be interesting to do some comparative performance analysis depending on the source of the dataset.

Data cleansing

As the data from the CSV files is pretty cleaned and only consists in automatic generated time series (process value vs time stamp), data cleansing/processing should be minimal to create uniform/consistent datasets. From past experience, we have seen that the last line can be corrupted so this will need to be monitored and fixed. Also important to note that the separator is ";" not "," (see Figure 7).

AIR_0123_945_03_PT_13.csv | AIR_0123_945_03_PT_14.csv | AIR_0123_945_03_PT_15.csv | AIR_0123_945_03_PT_16.csv

```
Name;Date;Value
AIR_0123_945_03_PT;17/09/2022 21:12:50;0.6148727
AIR_0123_945_03_PT;17/09/2022 21:12:52;0.640191
AIR_0123_945_03_PT;17/09/2022 21:12:54;0.6148727
AIR_0123_945_03_PT;17/09/2022 21:12:56;0.6293403
AIR_0123_945_03_PT;17/09/2022 21:12:58;0.6510417
AIR_0123_945_03_PT;17/09/2022 21:13:00;0.6148727
AIR_0123_945_03_PT;17/09/2022 21:13:02;0.6510417
AIR_0123_945_03_PT;17/09/2022 21:13:04;0.6221065
AIR_0123_945_03_PT;17/09/2022 21:13:06;0.6148727
AIR_0123_945_03_PT;17/09/2022 21:13:08;0.6221065
AIR_0123_945_03_PT;17/09/2022 21:13:10;0.6510417
AIR_0123_945_03_PT;17/09/2022 21:13:12;0.6510417
AIR_0123_945_03_PT;17/09/2022 21:13:14;0.6510417
AIR_0123_945_03_PT;17/09/2022 21:13:16;0.6510417
AIR_0123_945_03_PT;17/09/2022 21:13:18;0.640191
AIR_0123_945_03_PT;17/09/2022 21:13:20;0.6510417
AIR_0123_945_03_PT;17/09/2022 21:13:22;0.6148727
AIR_0123_945_03_PT;17/09/2022 21:13:24;0.6148727
AIR_0123_945_03_PT;17/09/2022 21:13:26;0.6365741
AIR_0123_945_03_PT;17/09/2022 21:13:28;0.6148727
AIR_0123_945_03_PT;17/09/2022 21:13:30;0.640191
AIR_0123_945_03_PT;17/09/2022 21:13:32;0.6510417
```

Figure 7 – Typical format of CSV file recorded on the NAS (separator is ;)

Regarding the data recorded on the database of the ignition platform and exported manually via the CSV button, it can be seen that some tags contain NaN in their first couple of lines (arbitrary depending on when the data was recorded) (see Figure 8). This can be explained as these data are recorded on value change not on fixed time interval.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	t_stamp	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work	hot_work
2	01:00.2	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	21.3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
3	01:00.5	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	21.3	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	0.397859	NaN	NaN	NaN
4	01:00.5	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.0706	NaN	NaN	NaN	NaN	0.397859	NaN	NaN	NaN
5	01:00.5	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.0706	NaN	NaN	NaN	NaN	0.397859	NaN	NaN	NaN
6	01:00.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.0706	NaN	NaN	NaN	NaN	0.397859	NaN	NaN	NaN
7	01:01.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.0706	NaN	NaN	NaN	NaN	0.397859	NaN	20	NaN
8	01:01.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.10532	NaN	NaN	NaN	NaN	0.397859	NaN	20	NaN
9	01:01.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.25318	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.10532	NaN	NaN	NaN	NaN	0.397859	NaN	20	NaN
10	01:01.5	-0.25318	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.25318	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.10532	NaN	NaN	NaN	NaN	0.397859	NaN	20	NaN
11	01:02.2	-0.25318	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.25318	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.10532	NaN	NaN	NaN	NaN	0.397859	NaN	20	NaN
12	01:02.5	-0.25318	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.25318	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.04058	NaN	NaN	NaN	NaN	0.397859	NaN	20	NaN
13	01:02.5	-0.25318	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.04058	NaN	NaN	NaN	NaN	0.397859	NaN	20	NaN
14	01:02.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.04058	NaN	NaN	NaN	NaN	0.397859	NaN	20	NaN
15	01:03.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.04058	NaN	NaN	NaN	NaN	0.397859	NaN	20.10001	NaN
16	01:03.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.04058	NaN	NaN	NaN	NaN	0.441262	NaN	20.10001	NaN
17	01:04.2	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.04058	NaN	NaN	NaN	NaN	0.441262	NaN	20.10001	NaN
18	01:04.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.28935	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.0055	NaN	NaN	NaN	NaN	0.441262	NaN	20.10001	NaN
19	01:04.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.25318	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.0055	NaN	NaN	NaN	NaN	0.441262	NaN	20.10001	NaN
20	01:04.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.25318	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.0055	NaN	NaN	NaN	NaN	0.441262	NaN	20.10001	NaN
21	01:05.5	-0.28935	NaN	NaN	NaN	NaN	NaN	NaN	NaN	-0.25318	NaN	NaN	21.3	NaN	NaN	NaN	NaN	-1.0055	NaN	NaN	NaN	NaN	0.347222	NaN	20.10001	NaN

Figure 8 – Typical format of data exported manually from the ignition platform via the CSV export button.

Data carpentry

The following section will explain how we plan to change the data to enable analysis & visualization. In our project, data processing/carpentry will consist of multiple appending, grouping and potentially filtering (decrease recording frequency) to reduce dataset when possible.

The strategy I followed for the data processing is described below.

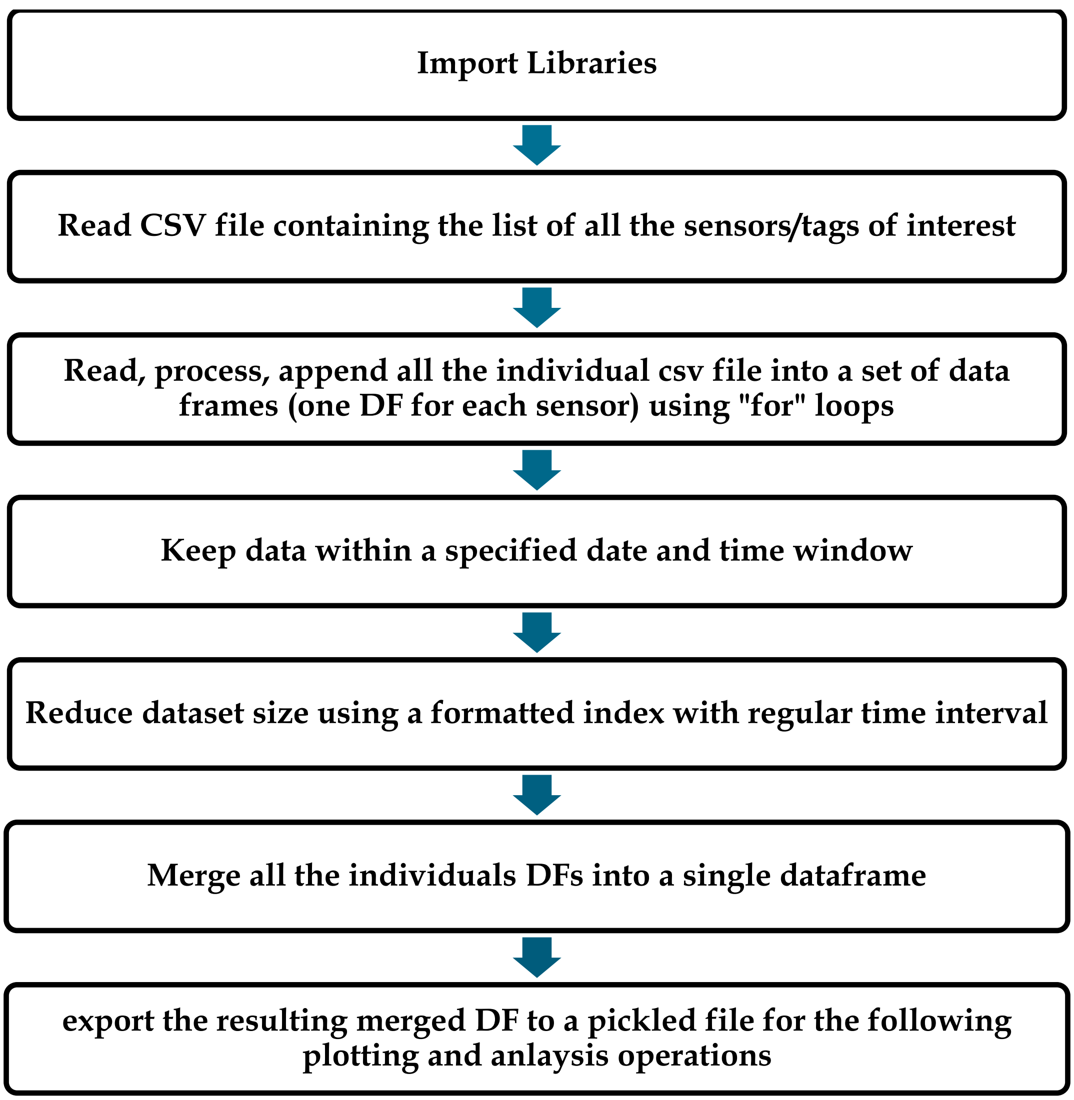

Figure 9 – Strategy for the data processing

I have taken the following assumptions:

- We have discarded lines with errors (< 0.00002% approx.)
- We have use interpolation to calculate values for intermediate time stamp.

Comments and notes have also been added within the notebook.

Out[4]:

Date	AIR_0123_945_07_DPT	AIR_0123_945_05_TE	AIR_PID_COMBUSTION_AIR_PV	AIR_PID_COMBUSTION_AIR_SP	AIR_PID_COMBU
2022-09-06 09:00:00	NaN	24.1	1.511863	100.0	
2022-09-06 09:00:10	NaN	24.1	1.482928	100.0	
2022-09-06 09:00:20	NaN	24.1	1.482928	100.0	
2022-09-06 09:00:30	NaN	24.1	1.519097	100.0	
2022-09-06 09:00:40	NaN	24.1	1.482928	100.0	
...	...	...	...	...	
2022-10-14 08:59:20	0.0	21.4	0.886140	100.0	
2022-10-14 08:59:30	0.0	21.4	0.893374	100.0	
2022-10-14 08:59:40	0.0	21.4	0.868056	100.0	
2022-10-14 08:59:50	0.0	21.4	0.868056	100.0	
2022-10-14 09:00:00	0.0	21.4	0.868056	100.0	

328321 rows × 35 columns

Figure 10 – Format of the final combined Pandas data frame.

The initial raw dataset consists of: 1645 csv files with a total size of 5.71 GB.
The final clean dataset consists of: Single Dataframe (Pickled pkl file) of 90.1 MB.

This corresponds to a memory reduction of almost 98.5% which is significant.

Data analysis and visualisation

For this particular project, I am trying various visualization tools and library to represent data over very long duration. I have found some very interesting libraries to make interactive plots.
Regarding the analysis, it will consist of various curve fitting, creating calculated tags with moving average, carrying out signal filtering etc…
We are also planning to carry out some calculation to estimate gas consumption for a selected period.

The strategy I followed for the data analysis and visualization is described below.

Import Libraries

↓

Import the resulting merged DF from the pickled file following the data processing

↓

Plot all sensors using subplots for a global visualisation

↓

Plot various temperature sensors using interactive plot with zoom in option

↓

Plot gas flow rate and oxygen concentration together with filtered data (smoother curves)

↓

Identify faulty temperature sensors

↓

Carry out some gas consumption calculation

↓

Use Bokeh plotting tool to make another interactive plot

Figure 11 – Strategy for the data analysis and visualization.

The Figure 12 shows all the subplots for all the sensors over the whole duration of the heat treatment. Most of them represent temperature sensors, pressure sensors, flowrate sensors, equipment usage, etc…
It is a good initial step to look at the overall process data and identify any faults or strange behaviours.

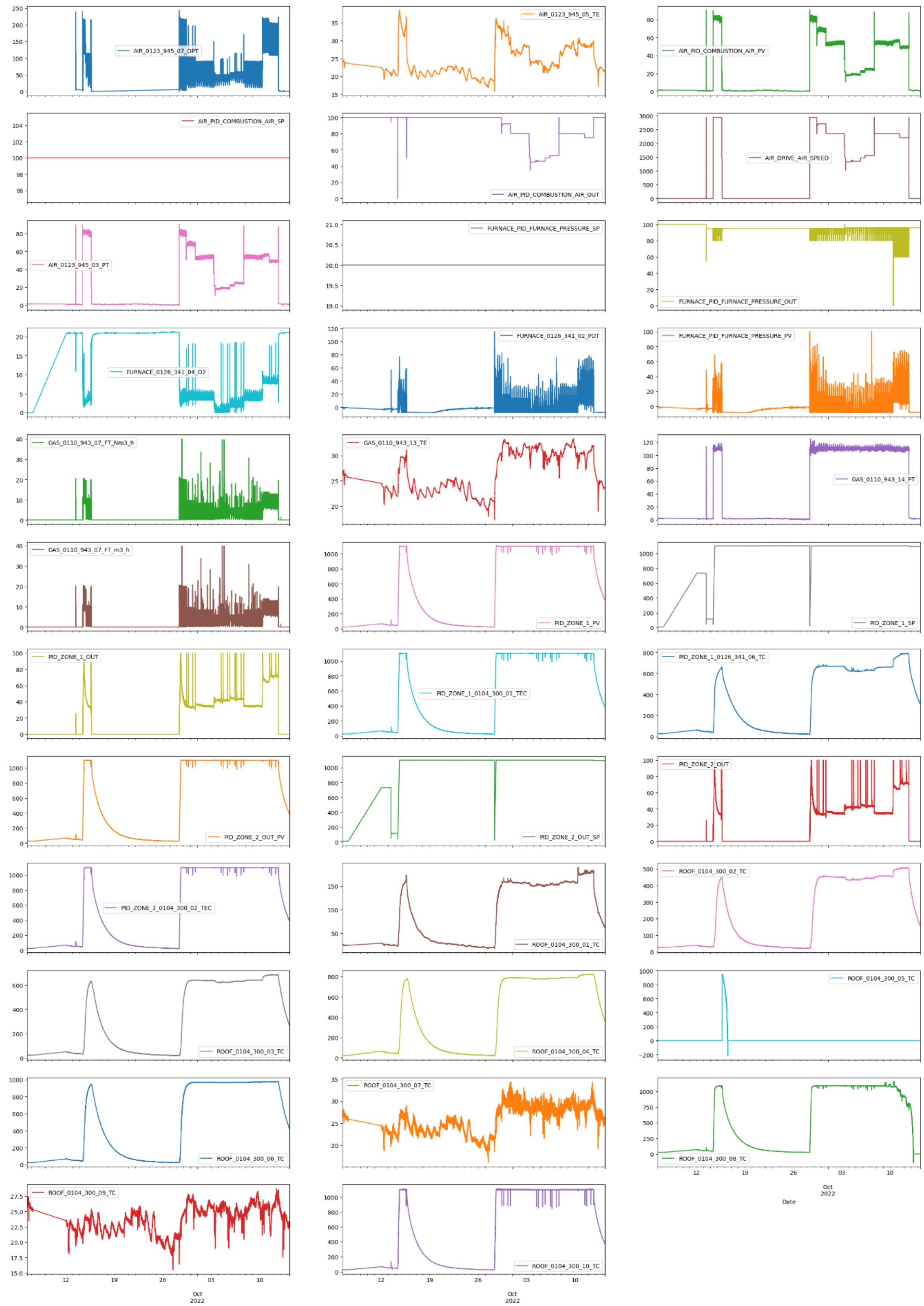

Figure 12 – Subplots for all the sensors over the whole duration of the heat treatment.

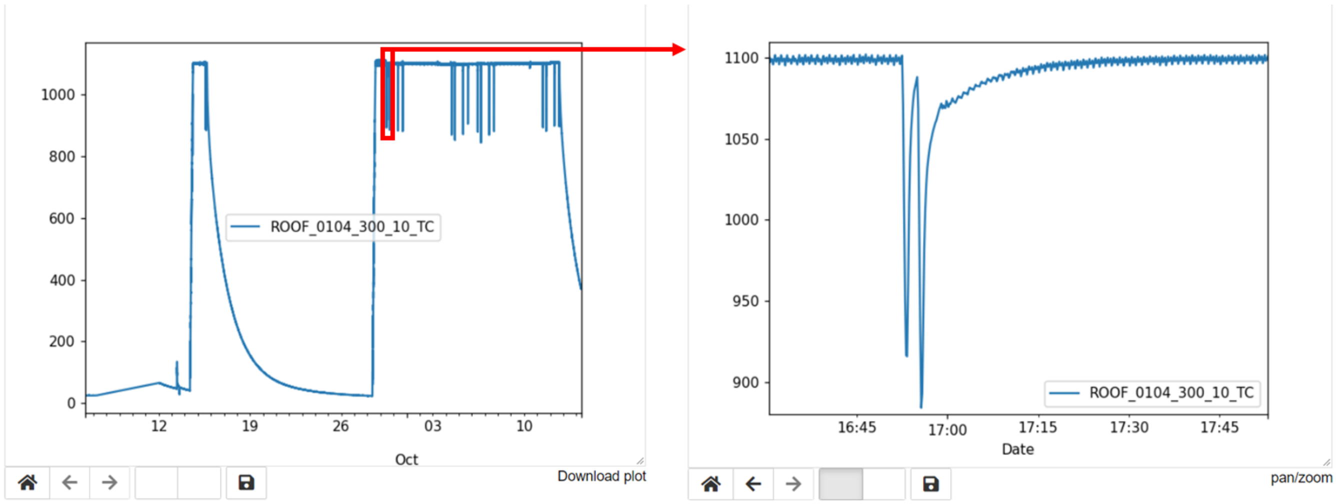

Figure 13 – Temperature graph from TC10 over the whole duration of the heat treatment as well as zoom of interest during unloading/loading of part.

The figure above represents the temperature of Thermocouple 10 (centre of the grid) over the whole heat treatment duration and is plotted using the NBAGG tool which allows to zoom in.

On the right hand side, we are looking at the data within 1h30 frame (red rectangle) corresponding to the unloading and loading of a new part (i.e. two consecutive door openings).

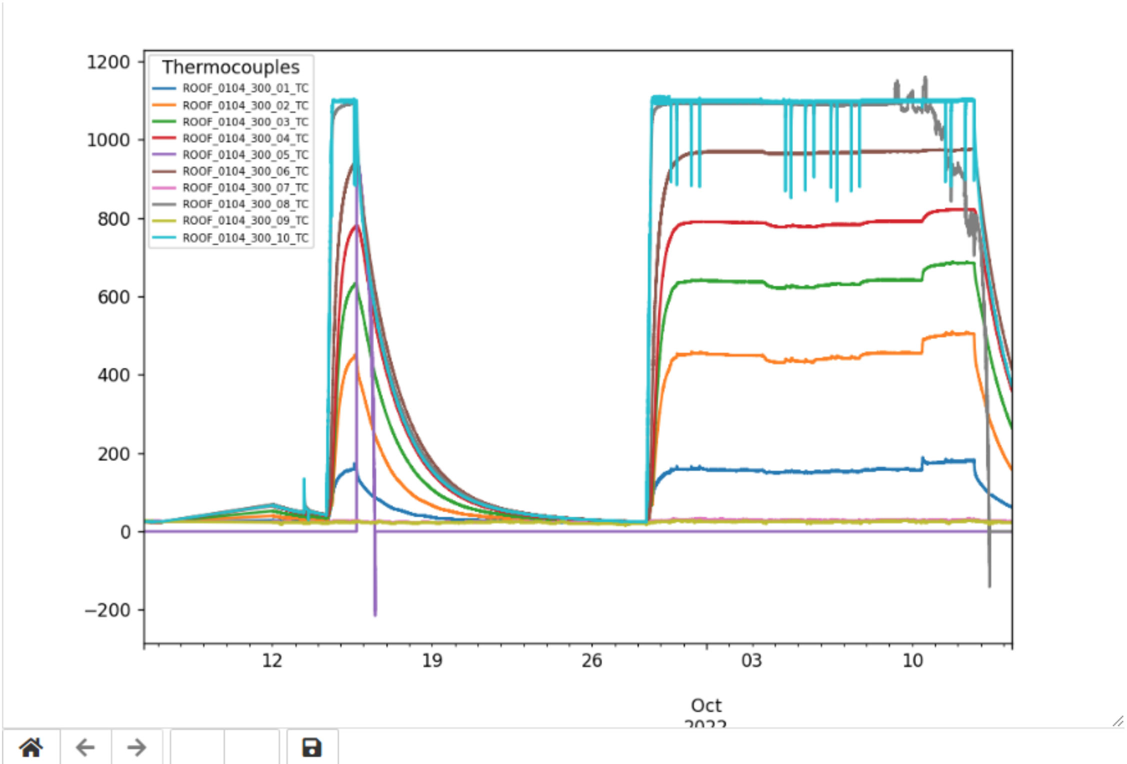

Figure 14 – Temperature profile of various thermocouples located in between the refractory wall layers.

This graph on Figure 14 shows the temperature profile of various thermocouples located in between the refractory wall layers. This is useful to check if the furnace has reach a steady state as it usually take a couple of days to heat up refractory compared to few hours to heat up the useful zone of the furnace.

Door openings can also be easily spotted looking at Thermocouple 10 which is located in the middle of the grid. It is also a good way to check any thermocouple failure. This will be discussed below

Faulty temperature sensors identification

```
In [15]:
df_Temp_sensors=df_merged_red.loc[:, df_merged_red.columns.str.contains('_TC|_TE|2_OUT_PV|1_PV', case=False, regex=True)]
Faulty_Temp_sensors=df_Temp_sensors.columns[((df_Temp_sensors < 0) | (df_Temp_sensors> 1500)).any()].tolist() #this detects
print('Faulty temperature sensors are:', Faulty_Temp_sensors)

Faulty temperature sensors are: ['ROOF_0104_300_05_TC', 'ROOF_0104_300_08_TC']
```

The line of code above allows us to detect any faulty temperature sensors (looking at any negative value and value above 1500 degC). This is quite common to have thermocouple failure in furnaces. TC_05 and TC_08 became faulty during this test.

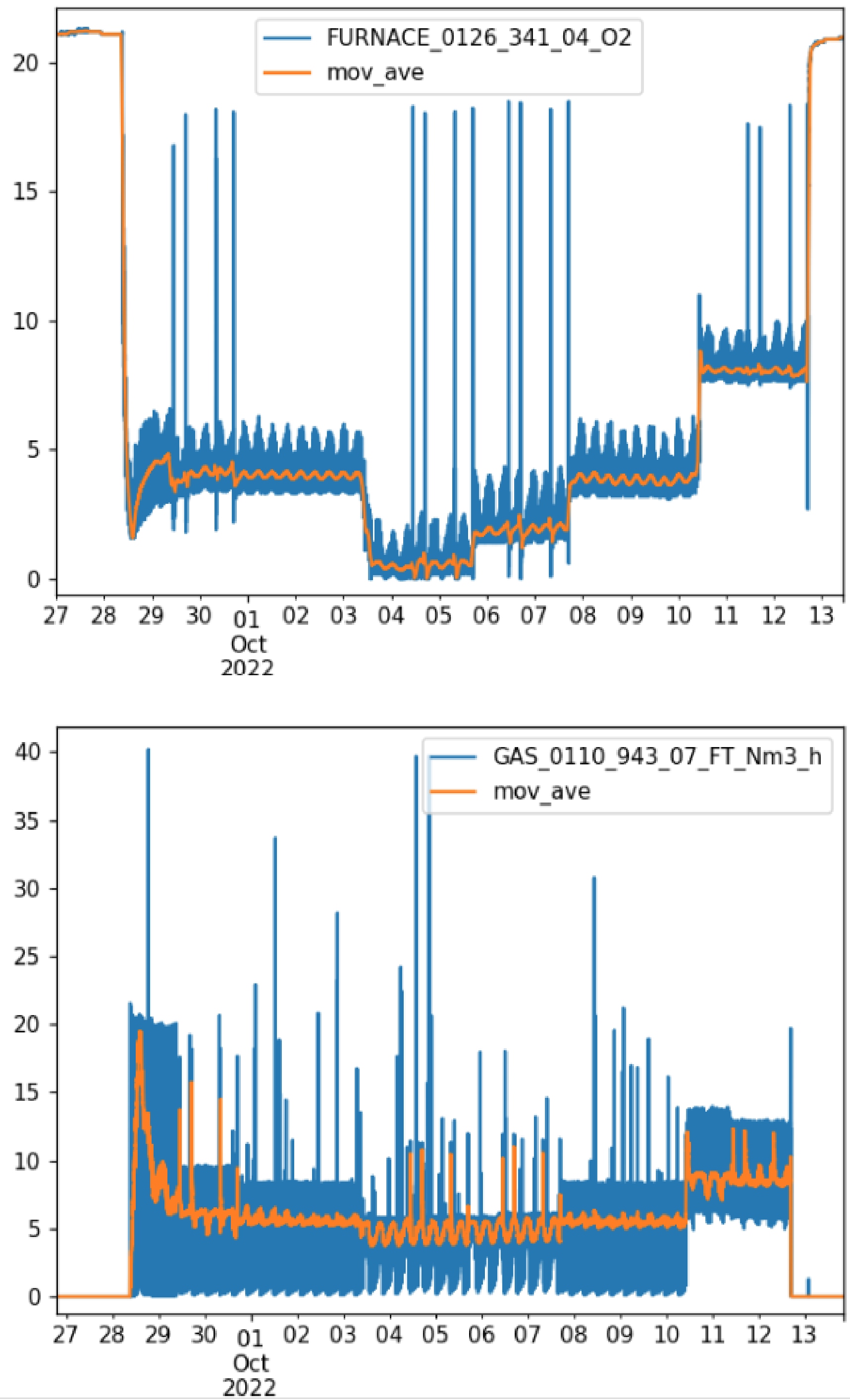

Figure 15 – Oxygen concentration profile and corresponding gas consumption for the different burner settings.

The graphs above represent the oxygen concentration and corresponding gas consumption when we set the burners at different air to fuel ratio. The targeted oxygen concentrations were: 0.5, 2, 4 and 8%.

It is interesting to see that the higher the air excess, higher is the gas consumption which is logical. To help with the visualisation, I decided to use the uniform_filter1D function to smooth the data. The data change very rapidly due to way the furnace is running with burners on and off.

In future, I would like to try to do some machine learning to correlate the following sensor data:

- Oxygen concentration (FURNACE_0126_341_04_O2)
- Pressure (FURNACE_PID_FURNACE_PRESSURE_PV)
- Gas flow rate (GAS_0110_943_07_FT_Nm3_h)
- Air Flow rate (AIR_0123_945_07_DPT)
- Burner usage in % (PID_ZONE_1_OUT)

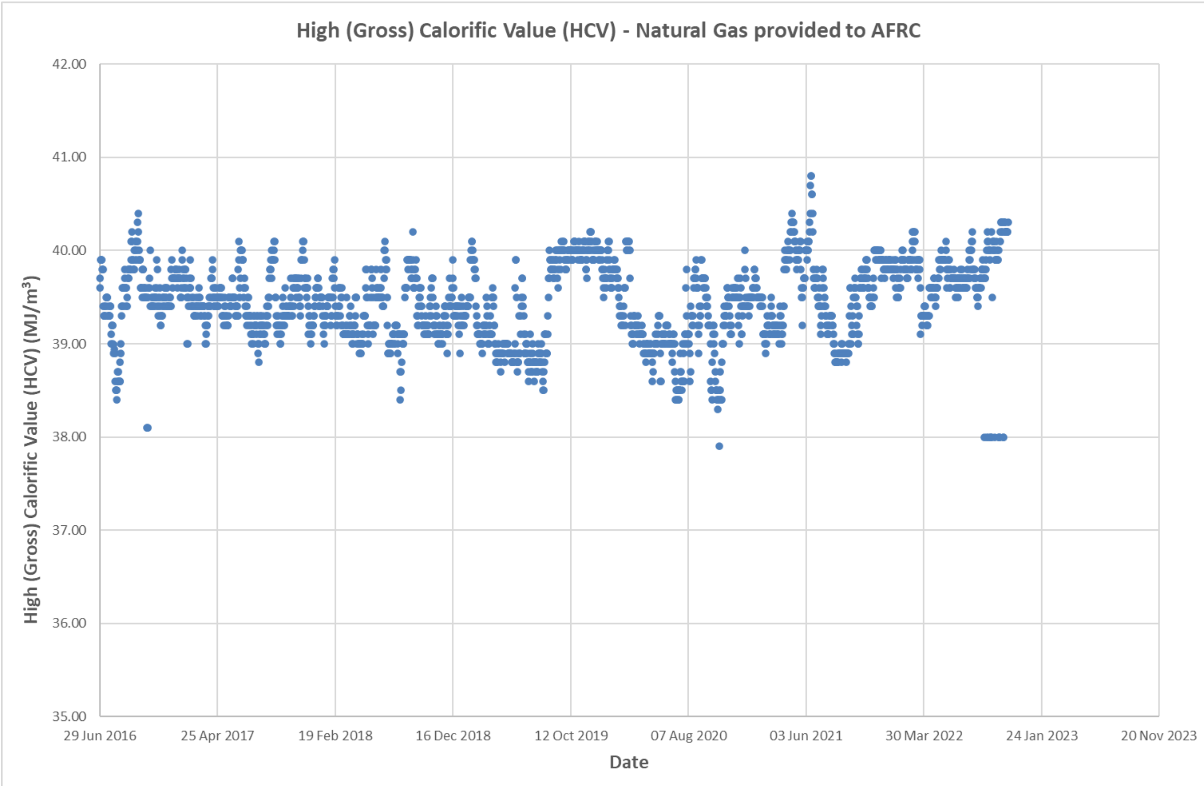

Figure 16 – Gross calorific value of natural gas supplied to AFRC since 2016

In term of gas consumption analysis, I have used the Trapz method in Numpy to calculate area under curve of Figure 15 (top). I was surprised and reassured that the integration of the raw data and smooth/filtered data give almost exactly the same result: 2401.971992052 m^3. This is detailed in the notebook.

A future work would be to tie in gas flowrate with calorific value on the day to get an estimate of the energy used rather than a volume of gas. The calorific values are usually provided every month by the energy supplier (Figure 16).

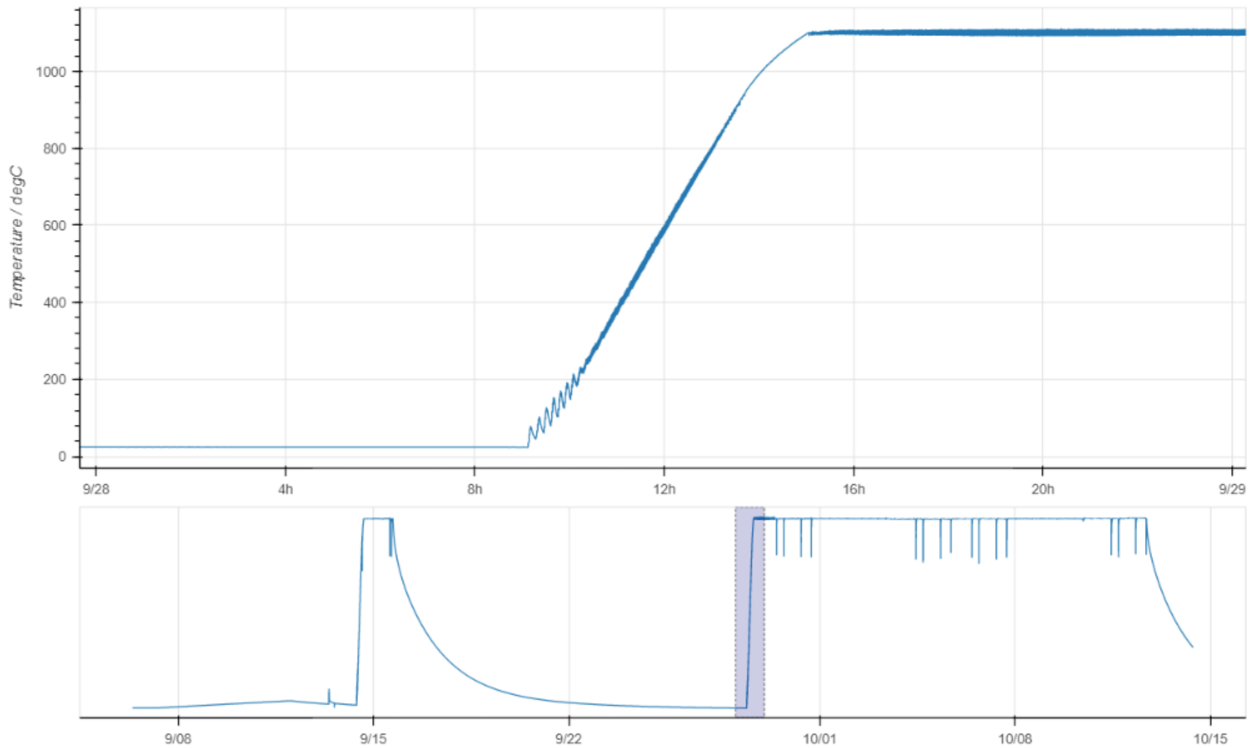

Figure 17 – Temperature graph using BOKEH library from TC10 over the whole duration of the heat treatment as well as zoom of interest during ramping up.

The Figure 17 above shows another example of interactive plotting using the BOKEH library. This is quite neat as it allow to show an highlighted area on the same graph.

Conclusions and future work

This second assignment was destined to assess our knowledge of the processes and tools of data science that we learned during the course and to apply it to a real industrial problem.

In my case, I wanted to look at the CMI gas furnace and find an efficient way to process all the process data to enable basic analysis and visualization. I would say that the code I wrote is allowing me to do that.

For this assignment, I did significant amount of research within the Python community and forums which has been very rewarding. I also managed to find and try out various interesting plotting tools.

Of course I see this as a work in progress and over the following months, I will keep optimizing the code and also spend more time on the analysis part, possibly looking at some machine learning.

In the future, the intention would be to deploy this methodology/strategy to other industrial furnaces with different data source such as Future Forge furnaces and AFRC member's furnaces.