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Glass-melting furnaces wear automatic calculation development and implementation

Tutor

prof. Milena Salvo

Industrial tutor

Fabrice Verry

Candidate

Maxime Hachet

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Abstract

The work presented here has been effectuated during an internship at Saint-Gobain Isover, which is a company that manufactures glass wool, used for the insulation, in particular of the buildings. The glass wool is made thanks to furnaces (electrical or flame) to melt the glass. These furnaces are worn by the glass corrosion and that can induce issues and a limited lifetime of the furnace, so this wear has to be controlled.

The aim of this work is to create new tools, especially as curves, to study and control this wear. These new tools must be simple to use and the most automatic possible to save time. The achievement of this project can be separated in two parts. The first one, necessary to do the second part, is to homogenize the files in which the user write the wear values that he measures in the plants. This consists in a new Excel file in which several calculations are done automatically thanks to formulas, to satisfy the goal of time saving. This file have one sheet for each part of the furnace (the tankwall, the bottom, the throat and the forehearth) because measurements are performed on all these parts. The user write in this file some data like the wear he measures or the thickness of the layers of materials of the furnace, and several other data are automatically calculated from that, like the thickness remaining if the wear is considered for example.

The second part of the work is to plot curves thanks to the data of the file of the first part. There are curves regarding the wear of the tankwall and the forehearth and curves regarding the number of overcoating (addition of a material layer to increase the total thickness of the tankwall). Some curves are used to focus on a single plant and others are used to make comparisons between the plants. Zones are defined for the tankwall of the electrical and flame furnaces to be able to know which part of the furnace is more impacted by the wear, and to compare the same zone when a comparison is effectuated between plants, in order to be relevant. The user can choose which zone have to be displayed on the plot thanks to the implementation of a filter with checkboxes. The same system is done to choose which plant must be compared in the comparison plots.

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Acronyms

CRIR

Centre de Recherche Isolation de Rantigny

TA

Technical Assistance

NOMFB

Number Of Months From Beginning

SP

Specific Pull

CP

Cumulated Pull

SCP

Specific Cumulated Pull

1. Company presentation

This work was done during an internship at Isover, which is a subsidiary of the Saint-Gobain group. The Saint-Gobain group, based in Courbevoie, France, designs, manufactures and distributes materials for construction and industry [1]. Its subsidiary Isover deals with the insulation materials. It has over than 60 production sites all over the world and one research center, the Centre de Recherche Isolation de Rantigny (CRIR), in which the internship was conducted. The insulation products of Isover are in majority glass wool but also rock wool. These products allow a very good thermal insulation thanks to a low thermal conductivity of the glass or the rock but above all thanks to the still air contained between the glass or the rock fibers, which have an incredibly low thermal conductivity. They also allow a very good acoustic insulation. These products are widely used in housing.

1.1. Glass wool production process at Isover

Fig.1 : Representation of the glass wool production process at Isover

The internship concerned the glass wool. At Isover, the glass wool is fabricated with the following process (Fig.1). The beginning of the process is the same used to make float glass. So first, the different raw materials are weighted by means of silos (1) and put on conveyors. The principal material used to make glass is SiO_2that come from sand but there are also a lot of additive oxides that change glass properties, like for example Na_2O, CaO or B_2O_3. Cullet, that is already formed glass coming from waste of production or recycling, is also used. All these materials are mixed and enter the furnace (2), which is the main topic of this work. The furnace can be electrical furnace, flame furnace or hybrid. Here the materials melt and become molten glass. It goes, then, into the forehearth (3) and pass by spinners to make glass fibers. A polymeric binder is added to link the fibers together. This binder is wet, so it is necessary to use an oven (4) to evaporate all the water contained in the binder. The glass wool mat is cut at the required size (5) and then is set in correct form (6) and stored (7) [2].

1.2. Types of furnaces

The work was conducted within the melting technical assistance (Melting TA) team which deals with the furnace and the forehearth. This team organizes and supervises the furnaces construction, does repair works, and evaluate the furnaces and forehearth conditions through data analyze, measurements, endoscopy and thermal inspection. The Isover factories are using two types of furnaces, the electrical furnaces or the flame furnaces.

1.2.1. Electrical furnaces

In the electrical furnaces, the glass is molten by Joule effect thanks to the electrical current which flows between the electrodes. Because the glass at low temperature is a bad electrical conductor, it is necessary to preheat the furnace from ambient temperature to 1200-1300°C to benefit the good electrical conduction of the molten glass. This preheating is called tempering and is done thanks to burners. Once the glass is molten, it is possible to totally benefit the electric power to heat the glass. The electrodes must be inside the glass bath to heat efficiently. Initially, they were on the bottom of the furnace (bottom-electrodes), but they used to get worn out, which caused maintenance issues so there are more and more electrodes positioned on the side walls of the furnace and dive into the glass bath from the top (top-electrodes), as it is possible to see on Fig.2. In the electrical furnaces, the batch is brought by a mobile conveyer, which puts a 15-20cm batch layer on all the surface of the molten glass. This layer, progressively absorbed by the furnace, is constantly renewed for creating in the meantime an insulating layer reducing the thermal losses to the crown (the electrical furnace is an open structure and without this batch layer, the thermal losses by radiation would be very high). [3]

Fig.2 : Crown of an electrical furnace with top-electrodes [3]

1.2.2. Flame furnaces

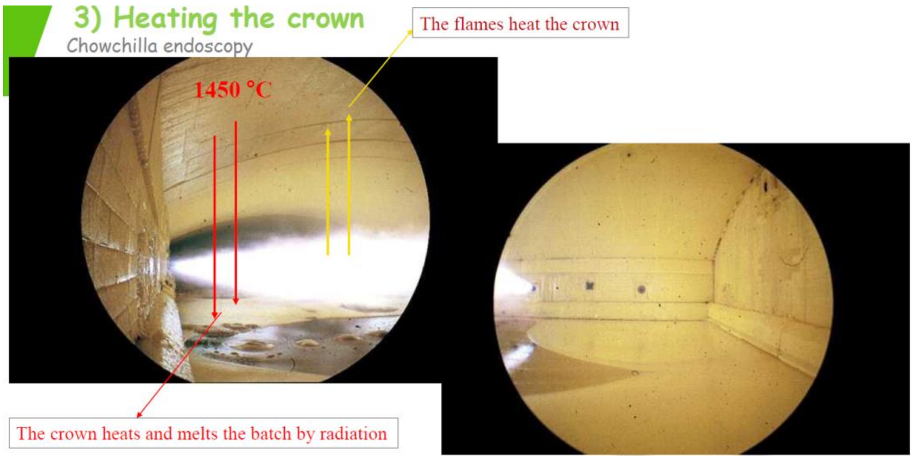


Fig.3 : Crown of a flame furnace [4]

On the contrary, in the flame furnaces, the glass is molten thanks to burners located over the glass bath which are heating the crown, so the crown is hot. In this case the glass is not heated directly but by the confined heat of the flames in the space between the glass and the crown and also by the radiation of the heated crown. That is why it is strictly necessary to keep the furnace close in order to not have heat waste. The burners can work with air or oxygen (air-gas or oxy-gas). [4]

1.2.3. Hybrid furnaces

Because of the gas crisis and for an environmental purpose (CO2 emissions reduction), more and more flame furnaces are transformed into hybrid furnaces by adding electrodes on the furnace. The goal is to reduce the gas consumption by using also electric energy in flame furnaces.

2. Context and purpose of the project

One of the missions of the Melting TA team is to do audits. It consists ofageneral inspection of a furnace to indicate at the factory manager which are the maintenance operations that must be done, and which process parameters must be changed in order to have a good product. A big part of these audits is wear measurements of the different parts of the furnace and the forehearth. Indeed, because of the corrosion of the glass, the blocks that constitute the walls of the furnace and the forehearth undergo wear over time. A too large wear can lead to a glass leakage, that is the glass which is going outside of the furnace, and this event is to avoid at all costs. That is why these wear measurements are really important.

At the beginning of the internship, all the wear measurement was filled manually in different files and then some calculations were done always manually. This take a lot of time and is error-prone. The aim of the work is, therefore, to automatize the more calculations possible, and to plot graph for analyses, thanks to these calculations, always automatically and in the most ergonomic way possible. Thus, the user should fill only the thickness of the blocks, the position and the wear of each blocks measured and all the rest should be automatic. This work was performed mainly on Excel.

3. State of the art

The state of the art of this project was mainly based on the existing files and methods at the beginning of the work. Indeed, it is very important to study these files to understand which data and information are important and how the methods can be facilitated.In order for me to see concretely what the conduct of an audit is, where and how were made the wear measurement, one month after the beginning of the internship, I went with a member of the team, Daniel Granger, to the plant of Askim, in Norway, to see him make an audit. It was also the opportunity to visit the plant, and see the machines used in the factories and all the fabrication process in reality.

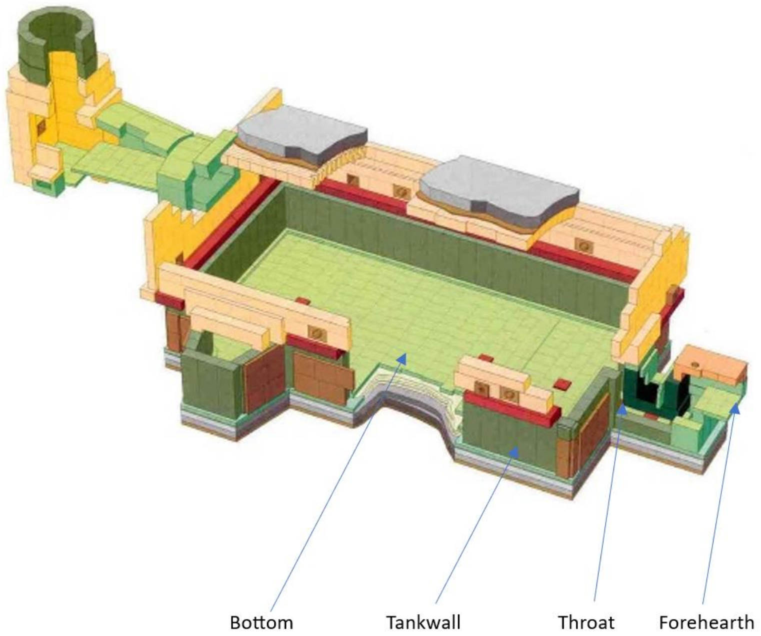


Fig.4 :Indications of the zones on a flame furnace [4]

So, as I have observed, during an audit, the wear measurement which are performed concern four main zones, which are the tankwall, the bottom, the throat and the forehearth. As indicated on the Fig.4, the tankwall refers to all the blocks located around the glass on the furnace. The bottom is the floor of the furnace. The throat is the opening in which the glass flow to get out of the furnace and to go into the forehearth, which is the channel that lead the glass to the fiberizing zones and the following of the process. I was able to do myself a wear measurement on the forehearth. For that, when the forehearth is built, before starting the production, a reference is taken thanks to a metal rod. This rod is put in the forehearth by one side, against the opposite block, and the length of rod remaining out of the forehearth is measured. Then, during the production, to do a wear measurement, the same metal rod is put in the feeder in the same way, and, measuring the length of rod remaining out of the forehearth this time, it is possible to know the thickness of block lost, which is the wear of the block.

Once these measurements are done, they are filled in an Excel file. There is one Excel file by plant and by campaign. A campaign corresponds to the production period of a furnace. Whenthe wear is too important, the furnace is destroyed and rebuilt, and a new campaign is started. So the Excel files are following a furnace during all its lifetime, and they look like the one displayed on Fig.5. The sheet displayed is the one of the tankwall wear measurement of the plant of Akeno. Different information are available on this sheet. From left to right there is:

- The block number which allows to identify on which block are done the measurements. Indeed, it is not necessary to measure the wear on all the blocks, but only on some of them in different zones to know the global state of the furnace. Usually, the measurements are done on the same blocks in order to follow the evolution of the wear.

- The distance from the top of the tankwall to identify at what depth the measurement were done.
- The original design of the tankwall with the material used and its initial thickness.
- The overcoatings with the the date, the material used, the height on the tankwall, and the thickness of this new layer. An overcoating is an add of a new layer of material to increase the total thickness and avoid a glass leakage that could be caused by a too high wear. They are usually installed when a big part of the thickness of the current layer is gone and the risk of a glass leakage is expected shortly.
- The wear which is 0 at the date of beginning of the campaign (column Q here).
- The wear at each date of measurements

Block Nr.	Distance from top	original design		1st Overcoating				2nd Overcoating				3rd Overcoating				04/04/2017	05/04/2019	18/10/2019	Date	Date	Date	Date	Date
		mm	material	date	material	height (mm)	thick. (mm)	date	material	height (mm)	thick. (mm)	date	material	height (mm)	thick. (mm)	Wear (mm)	Wear (mm)	Wear (mm)	Wear (mm)	Wear (mm)	Wear (mm)	Wear (mm)	Wear (mm)
	25															0	89	117					
	50															0	72	86					
22	75	250	Wool30													0	53	69					
	100															0	33	33					
	150															0	17	17					
	25															0	80	99					
	50															0	59	69					
30	75	250	Wool30													0	42	42					
	100															0	25	28					
	150															0	13	13					
	25															0	61	72					
	50															0	40	47					
35	75	250	Wool50													0	13	14					
	100															0	10	10					
	150															0	10	10					
	25															0	76	93					
	50															0	70	71					
39	75	250	Wool30													0	35	38					
	100															0	32	36					
	150															0	23	26					
	25															0	66	90					
	50															0	68	87					
56	75	250	Wool30													0	33	51					
	100															0	27	38					
	150															0	22	25					
	25															0	46	57					
	50															0	46	56					
60	75	250	Wool50													0	30	41					

Tankwall | Dwg tank | Graphique1 | Data bottom | Dwg bottom | Data throat | data feeder | D...

Fig.5 : Excel sheet of the wear measurements on the tankwall on the plant of Akeno [5]

This is an example but nearly all the Excel files of wear measurement of the different plant are different [6] [7]. The information founded on these files are usually similar to those of this example but there are also some differences. Some information are available on the file of some plants but not of all of them. Also, the name of a same information, and the arrangement of the rows and the columns can be different between one file and another, and that can complicate the work to automate calculations for comparisons between plants.

As shown on Fig.6, Fig.7 and Fig.8, the same type of sheet is used for the bottom, the throat and the forehearth.

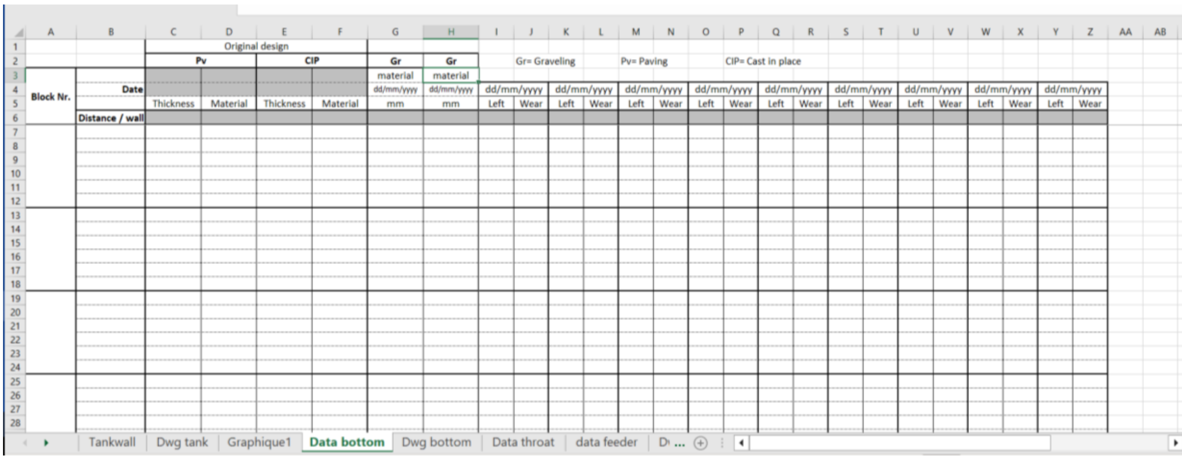


Fig.6 :Excel sheet of the wear measurements on the bottom on the plant of Akeno

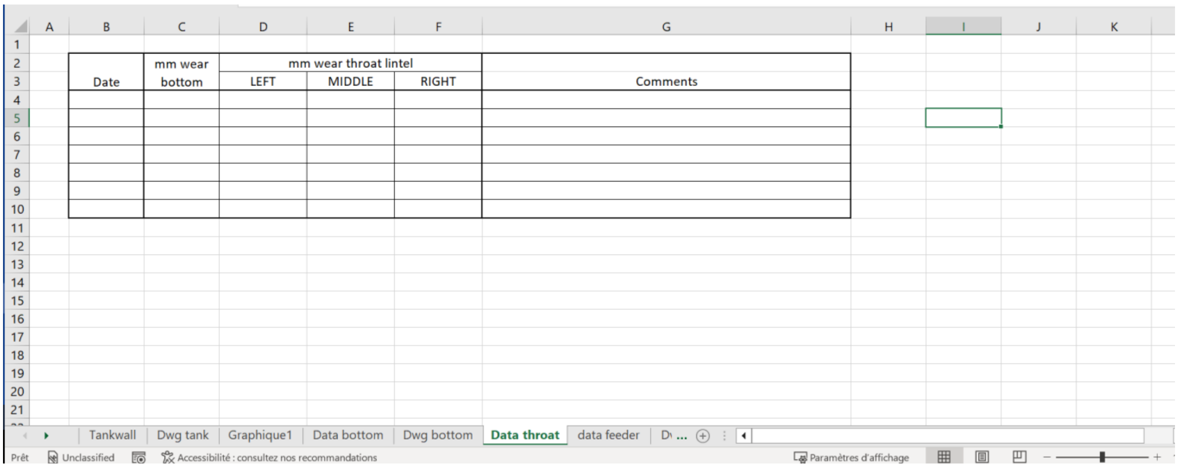


Fig.7 :Excel sheet of the wear measurements on the throat on the plant of Akeno

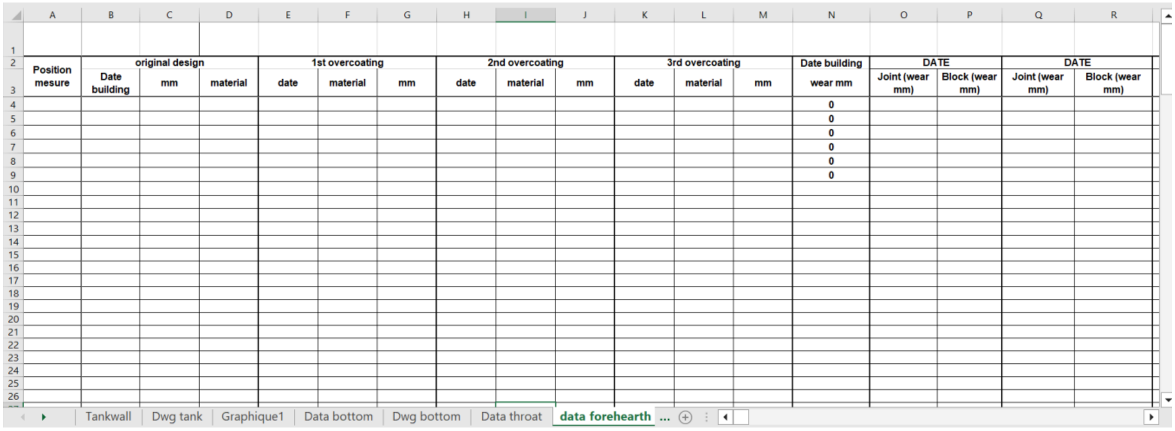


Fig.8 : Excel sheet of the wear measurements on the forehearth on the plant of Akeno

Another difference between the plants is the way to define thetankwall blocks numbers. As it is possible to see on Fig.9, for the plant of Akeno, the block number 1 is the block top left, and then the numbering continues clockwise. But on Fig.10, it is shown that for the plant of Ingleburn, the block number 1 is still the block top left but then the numbering is done counterclockwise. For the plant of Billesholm, the numbering is done clockwise but the block number 1 is at the right on the center. This blocks numbering can cause troubles. First because, it is not really ergonomic to not have the same way of numbering between the plants. But above all, because this is the numbering of the Melting TA, but other departments in the company have not the same numbering for the different plants. So, it can cause confusion and communication issues when one department talk about one specific block but the other department have an other map of the blocks numbers and think that they are talking about another block.

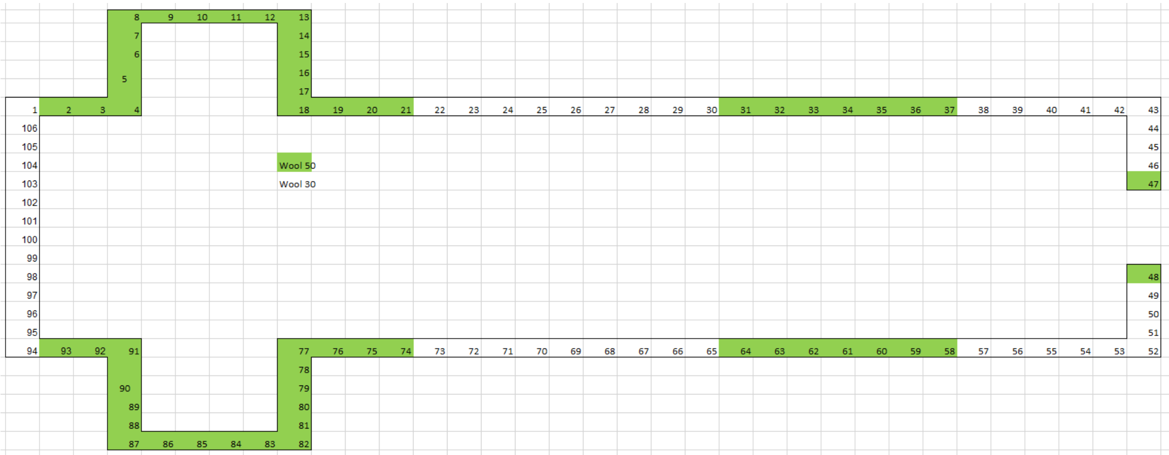


Fig.9 : Blocks numbering of the plant of Akeno [5]

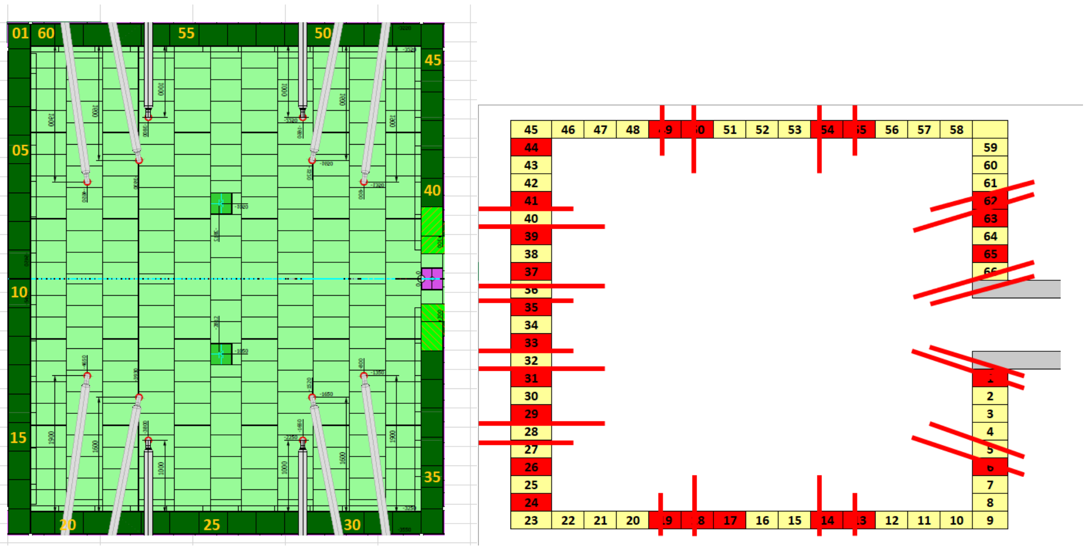


Fig.10 : Blocks numbering of the plant of Ingleburn (left) and Billesholm (right) [8] [9]

4. Implementation of a new tankwallblock numbering

In order to solve these problems caused by the heterogeneity of thetankwall block numbering methods, a standard numbering method has been defined. It has been decided that, now, the block number 1 should always be the block top left and then the numbering should continue clockwise. So this is like the numbering of Akeno displayed on Fig.9. A new drawing of the furnace with this new numbering has been made for every plants. For example, for Billesholm, its old numbering (Fig.10) didn't correspond to the new one so a new drawing showed on Fig.11 has been made.

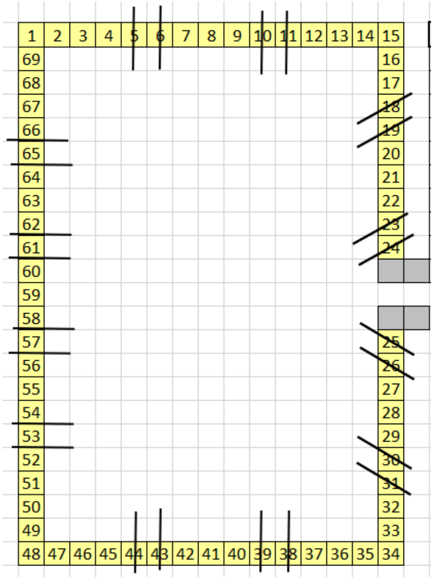


Fig.11 : New block numbering of the plant of Billesholm

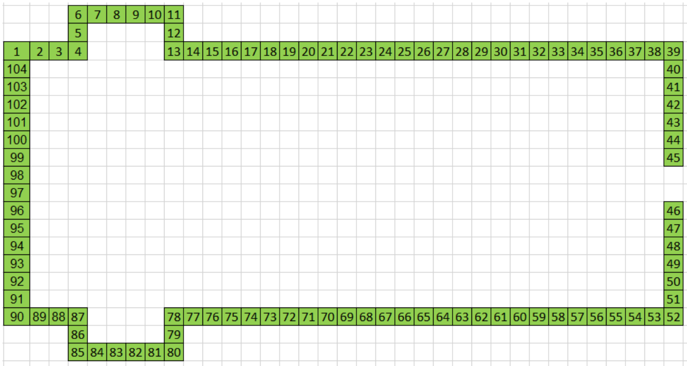
It is possible to see that there are three more blocks with the new numbering (69 against 66 with the old one). There are two reasons. First, because the block top right was not numbered in the old numbering. In this case, the new numbering is useful to fix some numbering issues. And, also, there are more blocks because the two blocks near the throat (24 and 25 on Fig.11) were not indicated on the old numbering but they are on the new one. The reason for that is because the old numbering was used only by the Melting TA, for the wear measurements, and these blocks were never measured. Now, these drawings are also used by other departments, for other things than wear measurements, so all the blocks must be numbered even if no measurements are performed on them.

4.1. Zones of the tankwall blocks

Once this new numbering method was defined, it was decided to split these tankwall blocks into different zones. Thanks to that it will be possible to make comparisons between the zones of the furnace, to see which zone has the bigger wear rate, using the measurement effectuated on each block. The zones defined on the electrical furnace and the flame furnace was not the same given the difference in term of technology and geometry between them.

For the electrical furnaces, the more interesting separation to make is between two categories: the blocks near the electrodes and the blocks far from the electrodes, even if more zones have been defined. Indeed, the blocks near the electrodes have a higher wear rate than the other, but apart from that, the wear is quite homogeneous.

For the flame furnaces, the wear is much more heterogeneous, so a lot of zones have been defined. These zones are showed on Fig.12 with the example of the plant of Bergisch. The drawing and the block numbers are available on the same excel sheet, so it is possible to see quickly the zone and the exact location of a block, and to find where are the different zones on the furnace. A code has also been defined with the initials of every zone in the column called “Trigram”. This code will allow to be faster to write the codes and the formulas afterward, when comparison curves will be created and automated.



Trigram	Positions	Block numbers
BWLC	Back wall left corner	1
LSWUD	Left side wall upstream doghouse	2-3
LDCBU	Left doghouse corner block upstream	4
SWLD	Side wall left doghouse	5-12
LDCBD	Left doghouse corner block downstream	13
LSWDD	Left side wall downstream doghouse	14-15
LSWUB	Left side wall upstream bubblers	16-27
LSWB	Left side wall bubblers	28-32
LSWDB	Left side wall downstream bubblers	33-38
FWLC	Front wall left corner	39
FWL	Front wall left	40-44
FWT	Front wall throat	45-46
FWR	Front wall right	47-51
FWRC	Front wall right corner	52
RSWDB	Right side wall downstream bubblers	53-58
RSWB	Right side wall bubblers	59-63
RSWUB	Right side wall upstream bubblers	64-75
RSWDD	Right side wall downstream doghouse	76-77
RDCBD	Right doghouse corner block downstream	78
SWRD	Side wall right doghouse	79-86
RDCBU	Right doghouse corner block upstream	87
RSWUD	Right side wall upstream doghouse	88-89
BWRC	Back wall right corner	90
BWRS	Back wall right side	91-95
BWC	Back wall center	96-99
BWLS	Back wall left side	100-104

Fig.12 : Drawing and zones of tankwall blocks of Bergisch plant

5. Implementation of a new file of wear measurement

Because of the heterogeneity of the Excel files of wear measurement between the plants, a new file has been created. This new file hastwo main advantages with respect to the old ones. First it is ergonomic. Indeed, it contains automatic calculations, so the user has to fill some data, and other data are directly calculated with no need for the user to do anything else. And secondly, it is the same file for all the plants, with the same names and number of rows and columns, which is much better to make automatic comparisons between plants afterward. It is very helpful for analysis performed thanks to a Python code. Indeed, the work described in this document is performed mainly on Excel but David Bousquet, which is working in a other team, does the same work but thanks to Python codes and to the software Power BI. Therefore, the idea is to facilitate his job also.So between the files of two plants, only the data filled inside vary, but the organization of the files is the same.

This new file has several sheets, and they will be detailed in the following. To understand better what the user has to fill and what is automatically calculated, there is a color code. The yellow cells have to be filled on time at the beginning of the campaign. These cells contain the cold data which are the data remaining always the same all along a campaign. The green cells must be filled by the users as we go along the furnace life when the wear measurements are performed. And the white cells are the cells containing a formula to fill it automatically and which the user must not touch.

5.1. The "Cold data" sheet

The cold data is the information about the furnace and the forehearth at the initial condition (start of campaign). They are sometimes used in several calculations, but, since they are not changing, it is possible to write it just one time in a campaign and then call them in other cells or in formulas. This is part of the automation, and this is easier and a gain of time compared to what was done before. Indeed, before the cold data had to be written each time they were used.

So, a sheet named "Cold data" was created for this purpose. As it is showed on Fig.13, two cold data have to be written by the user on column B :the area of the furnace and the date of beginning of the campaign. On column G, the user also write the zones of the forehearth. Since, the forehearth is different in all the plants, it was not possible to fix a list of these zones and the user must write it when the campaign begins. There are also four lists, which are used to create drop-down lists on the other sheets. In particular, there are the list of the overcoating materials (column J) and their suppliers (column I), and the list of the insulation materials (column M) and their suppliers (column L). On the column N the generic names of the insulation materials are written as a reminder for the user if he needs the correspondence between the commercial name and the generic name. The insulation materials are installed all around the furnace and the forehearth to reduce the thermal losses.

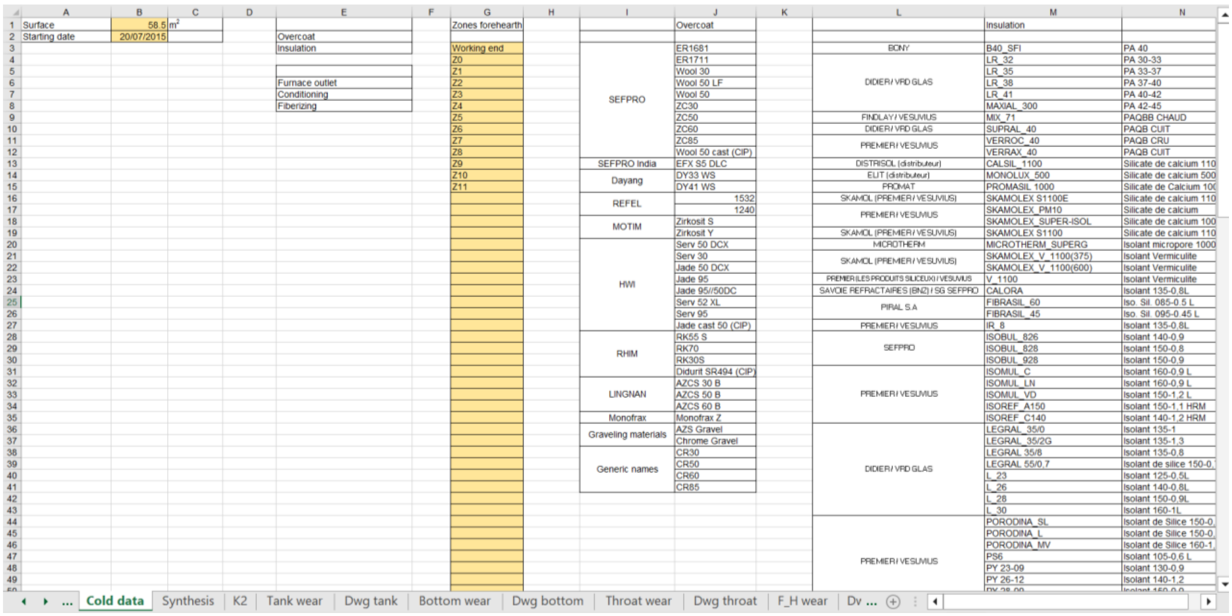


Fig.13 : Cold data sheet of the plant of Vamdrup

5.2. The "Tank wear" sheet

5.2.1. Electrical furnaces

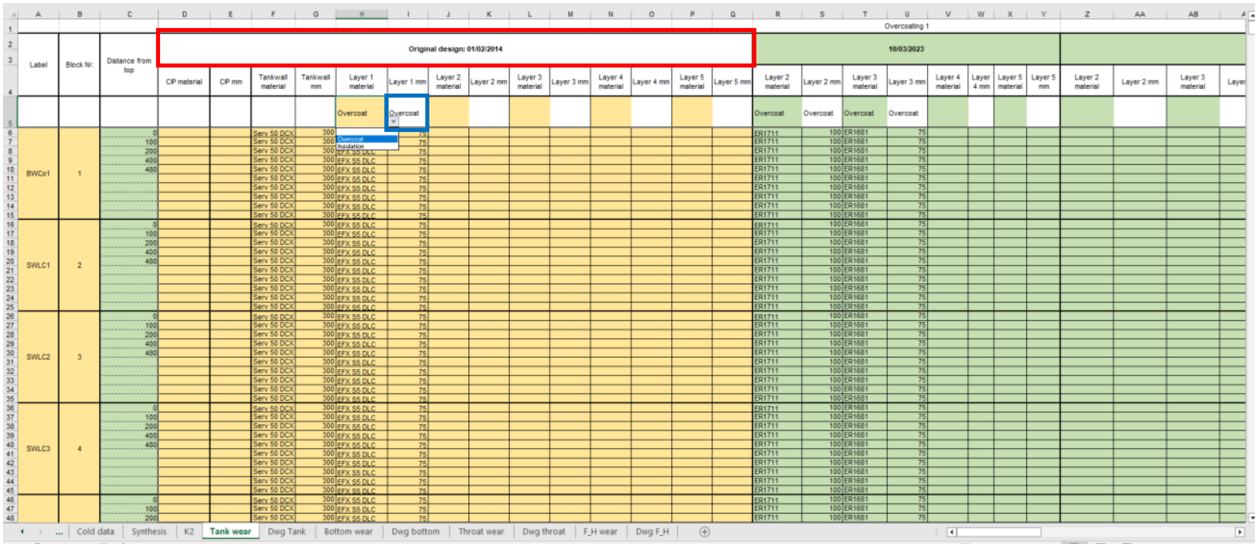


Fig.14 : Left part of the "Tank wear" sheet of the plant of Billesholm

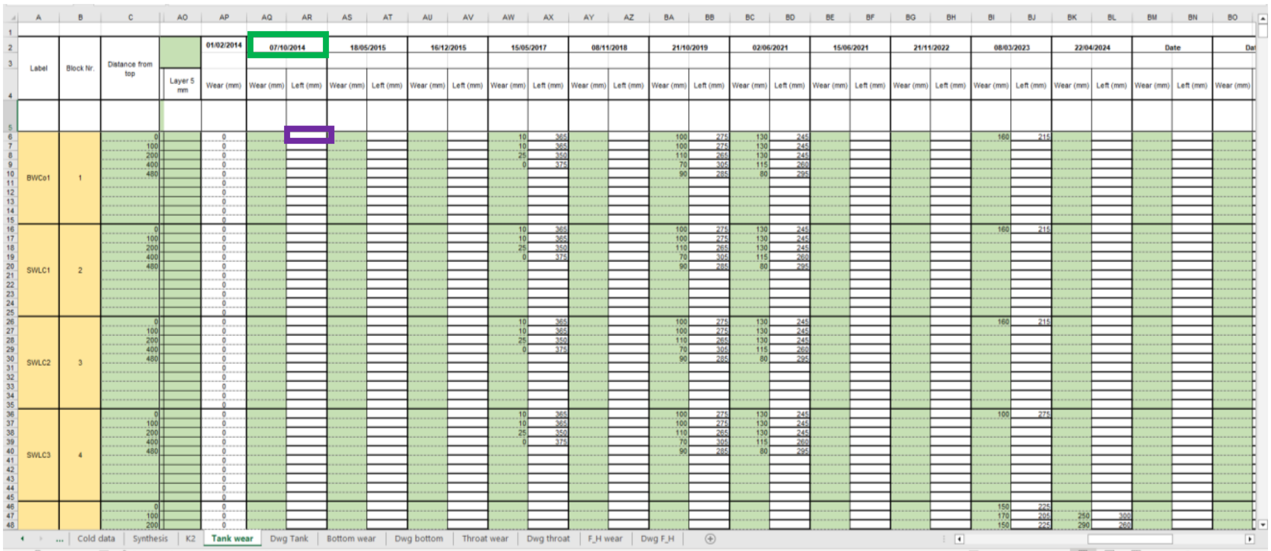


Fig.15 : Right part of the "Tank wear" sheet of the plant of Billesholm

The "Tank wear" sheet is not the same between electrical furnaces and flame furnaces. Regarding the electrical furnaces, an example is showed on Fig.14 and Fig.15. On column B the user must fill at the beginning of the campaign the block numbers and use the new blocks numbering seen before. On column A, there are the labels corresponding to the zones defined during the creation of the blocks numbering. The number written after the initials of the zone is the position of the block inside its zone. For example SWLC2 means that it is the second block of the zone "Side wall left center". On column C, are written the distances from the top of the tankwall at which the measurements are performed. Then from column D to Q, the original design of the tankwall at the beginning of the campaign is described. On the cell framed in red on Fig.14, is written the formula:

=’Cold data’!B2

It means that this cell is automatically filled with the value filled on the cell B2 of the sheet “Cold data” seen before. This value corresponds to the date of beginning of campaign so this is a good example of how a cold data can be reused several times even if the user write it only once. The format of this cell is the customized format : “Original design:” jj/mm/aaaa. This customized format allows to display in the cell “Original design:” before the initial date even if the value returned by the formula here is only the initial date. In the yellow cells, the user must indicate the original design of the tankwall with the material and the thickness of the different layers. From the inside to the outside, these layers are : the CIP (Cast In Place) which is a layer of casted concrete (optional), the main layer of the tankwall which has the higher thickness, and then the layers 1 to 5 which are overcoating layers and insulation layers. On the electrical furnaces an overcoating is installed right from the start of the campaign, that’s why the columns “Layer 1 material” and “Layer 1 mm” are already filled on these yellow cells. The materials of all these layers are choosen with a drop-down list thanks to the lists of overcoating and insulation materials on the “Cold data” sheet. This allow to have no differences on how to write these materials, like for example with or whithout spaces, or uppercase or lowercase. These differences would have complicated things, particularly for the analysis with the Python code. On the yellow cells of the row 5, there is another drop-down list thanks to which the user indicate if the layer is an overcoat or an insulation layer. This choice in the cells of row 5 impacts on which drop-down list will be available on the other cells of the columns. If “Ovecoat” is selected, then the list of the overcoating materials will be available, but if “Insulation” is selected, this is the list of the insulation materials which will be available. In the white cell just at the right of these yellow cells of row 5, the choice selected (Overcoat or Insulation) is copied automatically. For example in the cell framed in blue, it is done thanks to the formula:

=SI(ESTVIDE(H5);“”;H5)”

This formula doesn’t display anything if the cell H5 is empty, but copy the value written on H5 if there is a value. It was not possible to write only the formula “=H5” because, doing that, when nothing is choosen on the drop-down list of H5, the cell framed in blue displays “0” which is not wanted.

Then, starting from the column R, the user writes the characteristics of the three possible overcoatings in the green cells. When an overcoating is performed, one or more layers are added, but it is also possible to remove layers. That is why the idea is here to have a complete description of all the layers presents around the furnace after the overcoating and not only the new layers added. The tankwall layer and the first overcoating installed at the start of the campaign are the only layers which are never removed, so they are written in the yellow cells and the description of all the layers at each overcoating starts from layer 2. In the same way, for each layer, there is a column to write the thickness and a column to select the material in a drop-down list which depends on what is selected on th drop-down list on row 5. The user also have to write the date of the overcoating on row 2. A drawing is visible on Fig.16, to understand well what must be written in the original design part and in each overcoating part. The left drawing represents the initial situation (start of campaign), the right drawing represents a correction which occur later during the campaign, and a different color means a different material, so a different layer. Here, only the tankwall layer and the layer 1 are the same between the two drawings.

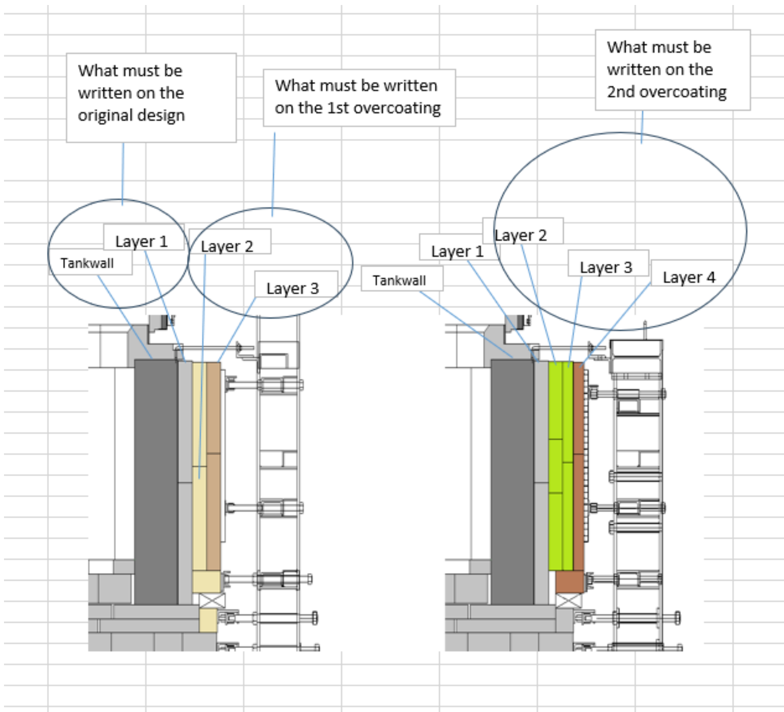


Fig.16 : Indication of which information must be written in the original design part or in each overcoating part

The right part of this sheet is dedicated to the wear measurements strictly speaking. As shown on Fig.15, on the column AP, the starting date is written directly from the value written in the “Cold data” sheet, and a the wear value of all the block is 0 just as a reminder that at this date there was no wear. Then, from the column AQ, the user must write the values of wear measured during the audit. For each date of audit there is a column for the wear, which correspond to the thickness lost in millimeters, and a column for the thickness remaining, also in millimeters, called here “Left”. The dates are filled by the user in the sheet “Synthesis”, which will be seen later, and are automatically written in the cells in row 2 of this sheet thanks to the formula, for example in the cell framed in green:

=Synthesis!C1

The user writes the wear calculated in the green cells of the column “Wear (mm)” and the thickness remaining is automatically calculated in the corresponding white cell of the column “Left (mm)” thanks to a formula. For example, in the cell framed in purple, this formula is:

```
=SI(ESTVIDE(AQ6);"";$E6+$G6+$I6+SI(AQ$2>$AH$2;SOMME(SI($AI$5="Overcoat";$AI6;0);SI($AK$5="Overcoat";$AK6;0);SI($AM$5="Overcoat";$AM6;0);SI($AO$5="Overcoat";$AO6;0));SI(AQ$2>$Z$2;SOMME(SI($AA$5="Overcoat";$AA6;0);SI($AC$5="Overcoat";$AC6;0);SI($AE$5="Overcoat";$AE6;0);SI($AG$5="Overcoat";$AG6;0));SI(AQ$2>$R$2;SOMME(SI($S$5="Overcoat";$S6;0);SI($U$5="Overcoat";$U6;0);SI($W$5="Overcoat";$W6;0);SI($Y$5="Overcoat";$Y6;0));0)))-AQ6)
```

In this formula, the first test “SI(ESTVIDE(AQ6);””;” is performed to write nothing if the cell directly to the left, which is the cell containing the wear, is empty. Indeed, at each audit, the wear measurements are performed only on some blocks and at some distances from the top, so if no wear measurement is performed on this block and at this distance, no thickness left is wanted. Then the goal of this formula is to add the thickness of all the layers presents and remove the wear measured. So, if the cell directly to the left is not empty, it starts by “$E6+$G6+$I6” to add the thickness of the CIP layer, the main layer of the tankwall, and the first layer, which are the three layers never removed, and so existing no matter the date.The part “SI(AQ$2>$AH$2;SOMME(SI($AI$5="Overcoat";$AI6;0);SI($AK$5="Overcoat";$AK6;0);SI($AM$5="Overcoat";$AM6;0);SI($AO$5="Overcoat";$AO6;0))” ensures that, if the date of the audit is later than the date of the third overcoating, the thickness of the layers existing after this third overcoating, and for which the user has selected “Overcoat” on the drop-down list, are added. Indeed, only the overcoat layers are wanted in this calculation, and not the insulation layers, because the thickness left is calculated only on the overcoat layer. The insulation layers have not the scope to prevent a glass leakage. On the following of the formula, if the date of the audit is earlier than the date of the third overcoating, it does the same thing comparing the date of the audit to the date of the second overcoating, and then to the first overcoating. If the date of the audit is earlier than the date of the first overcoating, 0 is added, so the only layers taken into account are the CIP layer, the tankwall layer and the first layer. At the end of the formula, “-AQ6” subtracts the value of the wear filled by the user. To sum up, the calculation of the thickness left is performed, considering the situation at the moment of the measurement and this calculation is updated with the elements added as the campaign goes.

5.2.2. Flame furnaces

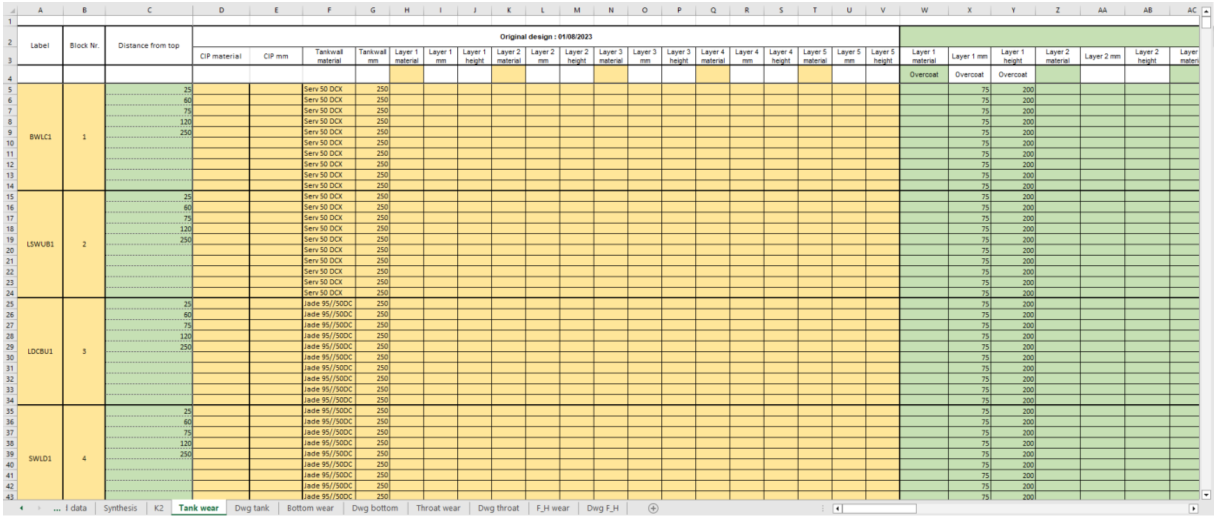


Fig.17 : Left part of the "Tank wear" sheet of the plant of Gliwice

The difference from the electrical furnaces is that there is a column for the height in addition to the columns of material and thickness. Indeed, for the flame furnaces, the overcoatings are sometimes installed only up to a certain height which is therefore indicated on the column "height". For example, it is shown in Fig.17, in column Y, that in Gliwice the first overcoating was performed up to 200 mm only. On the contrary, for the electrical furnaces, the overcoating are always performed on all the height of the tankwall, so there is no need for this column.The other difference is that, on flame furnaces, there is no overcoating installed right from the start of the campaign. That is why the overcoating layers start from layer 1, and only the main tankwall layer is described on the yellow cells of the original design. The last difference is that there are columns planned for four add of overcoating against only three for the electrical furnaces. Indeed, in the electrical furnaces, when an overcoating is installed, it is installed on all the blocks of the furnace, whereas in the flame furnace, it is possible to overcoat only some blocks. The consequence is that the number of interventions can be higher than the number of layers, because a layer can be installed at different dates in different zones. Since a new area in the sheet is needed each time an overcoat is provided, it was necessary to plan more area than the maximum number of overcoating theorically installed during a campaign.

These three differences are the only ones of the "Tank wear" sheet, the rest of the sheet is the same as for the electrical furnaces. The "Tank wear" sheet is the only sheet which is not exactly the same between electrical and flame furnaces, all the other sheets are identical.

5.3. The ”Bottom wear” sheet

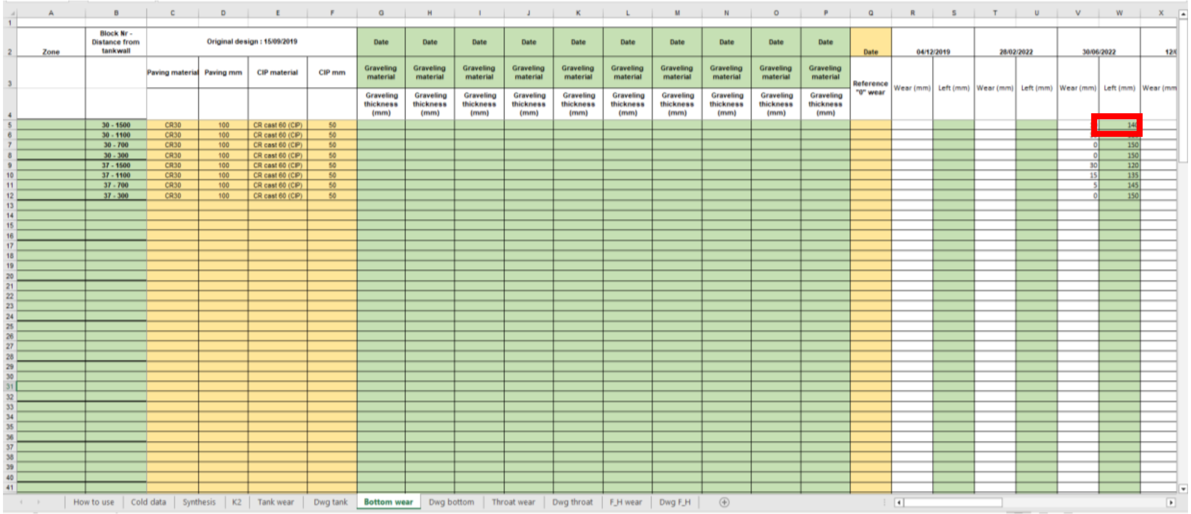


Fig.18 : “Bottom wear” sheet of the plant of Azuqueca

The bottom wear measurements are performed with several measurement points at differents distances from the tankwall in the axis of a specific block. To transcribe this way of doing in the file, in column B the user write the specific block and the distance from tankwall choosen to effectuate the measurements, as it is visible on Fig.18. In the column A, he can write the zone of the measurement points. It is not mandatory and there are no precise zones defined valid for all the furnaces, but it is useful if the user want to have a quick idea of where were performed the precedent measurements. The original design groups only the paving material and thickness and the CIP material and thickness. Like in the “Tank wear” sheet, the date of beginning of campaign is automatically written from the “Cold date” sheet, after “Original design” in row 2. Regarding the bottom, the add of thickness during the campaign is not performed by overcoatings but by an action called graveling. This consists of throwing on the furnace coarse grits on the more uniform way possible, which will agglomerate when they will be in contact with the bottom to increase the total thickness and prevent glass leakage by the bottom. These actions are reported on columns G to P and each time a graveling is performed, the user must fill the date, the material and the thickness added. Since the grits are not controlable once they are in the glass bath, the thickness is not always exactly equal on all the bottom, but the user write aproximatelly the average thickness added on all the bottom and it is sufficient for the application done because the differences are not very big. The graveling material, as well as the paving and the CIP materials are filled thanks to a drop-down list of the overcoating materials.

Like in the “Tank wear” sheet, the date of audits are automatically copied from the “Synthesis” sheet, starting from column R, in row 2. The bottom is the only part of the furnace where the value measured during a wear measurement is the thickness left, and not the wear. That is why, on this sheet, the green cells are on the column of the thickness left and the white cells are on the column of the wear. The user write the values measured on the column of the thickness left and the corresponding wear is automatically calculated. It is done, for example in the cell framed in red, thanks to the formula:

=SI(ESTVIDE(W5);"";$D5+$F5+SI(V$2>$P$2;SOMME($G5:$P5);SI(V$2>$O$2;SOMME($G5:$O5);SI(V$2>$N$2;SOMME($G5:$N5);SI(V$2>$M$2;SOMME($G5:$M5);SI(V$2>$L$2;SOMME($G5:$L5);SI(V$2>$K$2;SOMME($G5:$K5);SI(V$2>$J$2;SOMME($G5:$J5);SI(V$2>$I$2;SOMME($G5:$I5);SI(V$2>$H$2;SOMME($G5:$H5);SI(V$2>$G$2;$G5;0))))))))))-W5)

The first part, “SI(ESTVIDE(W5);"";” is done to write nothing if the cell containing the value measured is empty. Then, to know the wear, it is necessary to sum all the thickness composing the bottom and subtract the value of thickness left measured. “$D5+$F5” sum the thickness of the paving and the CIP. +SI(V$2>$P$2;SOMME($G5:$P5) add to that the sum of all the graveling thickness from the first one to the tenth, if the date of the audit is later than the date of the tenth graveling. If the date of the audit is earlier than the date of the tenth graveling, “SI(V$2>$O$2;SOMME($G5:$O5)” add the sum of all the graveling thickness from the first one to the ninth if the date of the audit is later than the date of the ninth graveling. If the date of the audit is earlier than the date of the ninth graveling but later than the date of the eighth graveling, the formula adds the sum of all the graveling thickness from the first one to the eighth, if it is not the case from the first one to the seventh and so on. In a nutshell, the formula add the paving thickness, the CIP thickness, and the thickness of all the gravelings performed between the beginning of the campaign and the date of the audit. Finally, “-W5” subtracts the wear measured. Here, for example no graveling was performed so only the thickness of the paving and the CIP are summed and the thickness left measured is 140mm so the wear is 100 + 50 – 140 = 10mm. Sometimes, at the beginning of the campaign, a “reference 0 wear” is done. This is some measurements of the thickness at the very beginning to have, experimentally, a starting point, before the glass corrosion begin to wear the material. The user can fill the date and the measurements of this “reference 0 wear” if he wants on the column Q. This is not taken into account in the calculation of the wear, but it gives the information of what was the real thickness at the beginning of the campaign on some specific points.

5.4. The “Throat wear” sheet

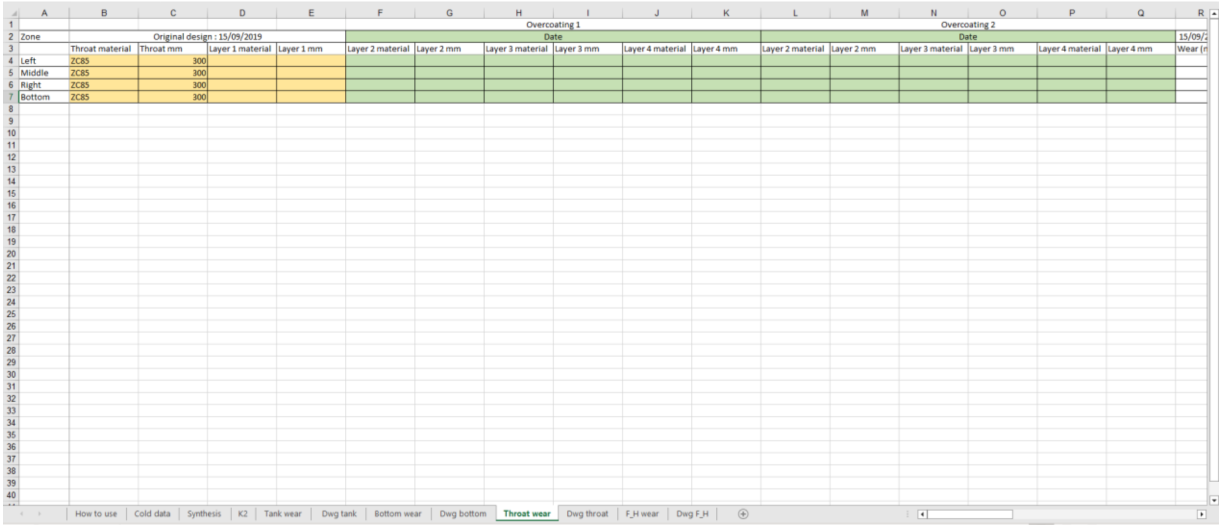


Fig.19 : Left part of the “Throat wear” sheet of the plant of Azuqueca

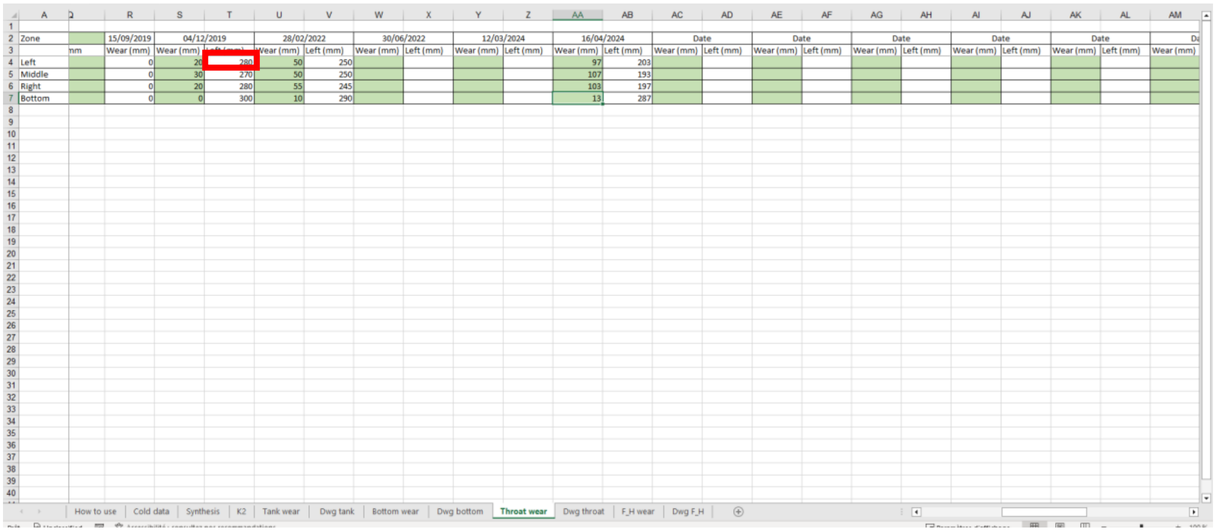


Fig.20 : Right part of the “Throat wear” sheet of the plant of Azuqueca

The throat is much smaller than the other parts where wear measurements are performed, that is why the wear measurements are always on the four same points : the right, the left, the middle and the bottom of the throat. These zones of the throat are written in advance in the column A, as it is shown on Fig.19. Then, like the tankwall of the electrical furnaces, it is possible to have an overcoating direclty installed during the building of the furnace, so in the original design of columns B to E contains the main throat layer and the layer 1. Similarly as before, the date of beginning of campaign is automatically filled in row 2. Whether an original overcoating is installed or not, the overcoatings start with the second layer from column F. As well as for the tankwall, a complete description at each date of overcoating is wanted so the user have to write the material and the thickness of all the layers presents after the date of overcoating, which also have to be written. All the material cells are filled thanks to the same drop-down list as before, with all the overcoating materials.

As it is shown on Fig.20, on the right part of this sheet, there is the starting date and the value of the wear of 0mm in all the zones at this date in column R, just as a reminder. Then the values of wear measured during the audit are filled in the green cells from column S. Like for the other sheets, the date of the audits are automatically filled in row 2. The thickness left is automatically calculated thanks to a formula, which is for example, in the cell framed in red:

=SI(ESTVIDE(S4);"";$C4+$E4+SI(S$2>$L$2;SOMME($M4;$O4;$Q4);SI(S$2>$F$2;SOMME($G4;$I4;$K4);0))-S4)

This is the same principle as for the tankwall, to calculate the thickness remaining, it is seeked to sum all the thickness existing at the date of the audit and subtract the wear measures. So the formula works in the same way. “SI(ESTVIDE(S4);"";” allows to write nothing if the cell of the corresponding wear is empty. “$C4+$E4” sums the thickness of the main throat layer and of the layer 1. “+SI(S$2>$L$2;SOMME($M4;$O4;$Q4);SI(S$2>$F$2;SOMME($G4;$I4;$K4);0))” adds the sum of all the layers presents after the second overcoating is the date of the audit is later than the date of the second overcoating, and the sum of all the layers of the first overcoating if the date of the audit is between the dates of the first and the second overcoatings. If the date is earlier than the date of the first overcoating it adds 0. In this case, there is no need to verify if the layers are overcoat layers like it was done for the tankwall, because the insulation layers of the throat are not written so, if a thickness is written, it corresponds necessarily to an overcoat layer. Finally, “-S4” subtracts the measured wear. So, here for example, there is no overcoating so the calculation is only 300 – 20 = 280mm.

5.5. The “F_H wear” sheet

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1									Design 1								Design 2					
2	Date building	Date building	Date building	Date building	Date building	Area	Zone	Type	Design at beggining of campaign: 20/07/2015								30/01/2023					
3	1	2	3	4	5				Forehearth material	Forehearth mm	Layer 1 material	Layer 1 mm	Layer 2 material	Layer 2 mm	Layer 3 material	Layer 3 mm	Forehearth material	Forehearth mm	Layer 1 material	Layer 1 mm	Layer 2 material	Layer 2 m
4																						
5	20/07/2015					Working end 1	Working end	Furnace outlet	SERV 50 DCX	250							SERV 50 DCX	250	Serv 50 DCX	75		
6	20/07/2015					Working end 2	Working end	Furnace outlet	SERV 50 DCX	250							SERV 50 DCX	250	Serv 50 DCX	75		
7	20/07/2015					Working end 3	Working end	Furnace outlet	SERV 50 DCX	250							SERV 50 DCX	250	Serv 50 DCX	75		
8	20/07/2015					Working end 4	Working end	Furnace outlet	SERV 50 DCX	250							SERV 50 DCX	250	Serv 50 DCX	75		
9	20/07/2015					Working end 5	Working end	Furnace outlet	SERV 50 DCX	250							SERV 50 DCX	250	Serv 50 DCX	75		
10	20/07/2015					Z0 / Z1	Z0	Conditioning	ER1681	140							ER1681	140				
11	20/07/2015					Z1	Z1	Conditioning	ER1681	140							ER1681	140				
12	20/07/2015					Z1 below chimney	Z1	Conditioning	ER1681	140							ER1681	140				
13	20/07/2015					Z2	Z2	Conditioning	ER1681	140							ER1681	140				
14	20/07/2015					Z2	Z2	Conditioning	ER1681	140							ER1681	140				
15	20/07/2015					Z3	Z3	Conditioning	ER1681	140							ER1681	140				
16	20/07/2015					Z3	Z3	Conditioning	ER1681	140							ER1681	140				
17	20/07/2015					Z5	Z5	Fiberizing	ER1681	140							ER1681	140				
18	20/07/2015					Z5	Z5	Fiberizing	ER1681	140							ER1681	140				
19	20/07/2015					Z5	Z5	Fiberizing	ER1681	140							ER1681	140				
20	20/07/2015					Z9	Z9	Fiberizing	ER1681	140							ER1681	140				
21	20/07/2015					Z9	Z9	Fiberizing	ER1681	140							ER1681	140				

... l data | Synthesis | K2 | Tank wear | Dwg tank | Bottom wear | Dwg bottom | Throat wear | Dwg throat | F_H wear | Dwg F_H | Graphs tank | Graphs F_H

Fig.21 : Left part of the "F_H wear" sheet of the plant of Vamdrup

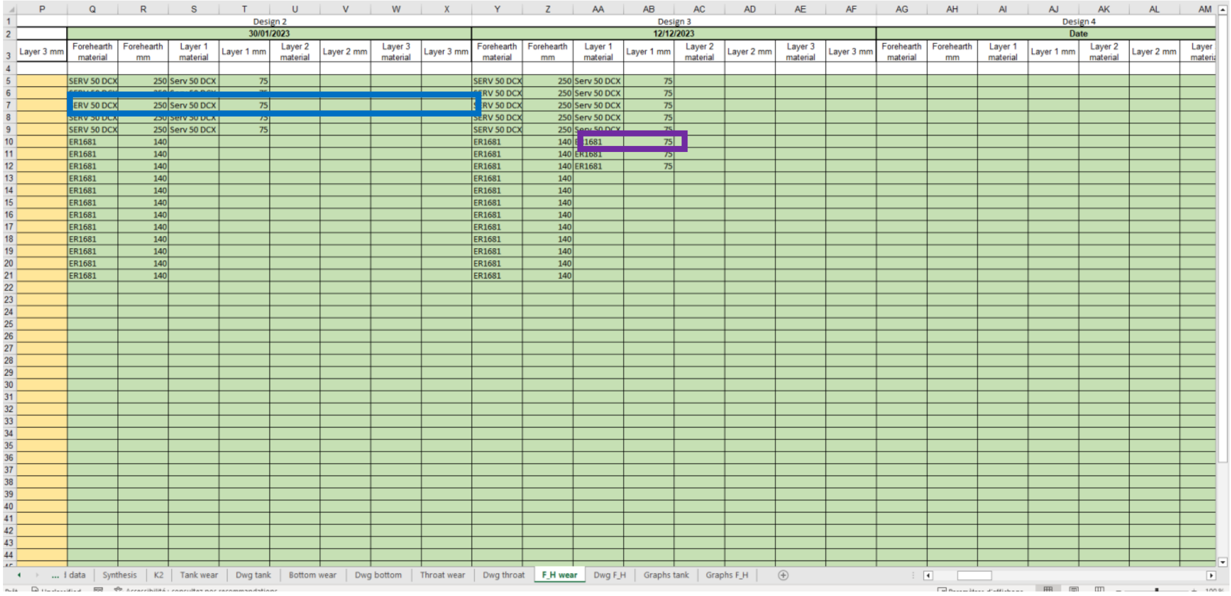


Fig.22 : Center part of the "F_H wear" sheet of the plant of Vamdrup

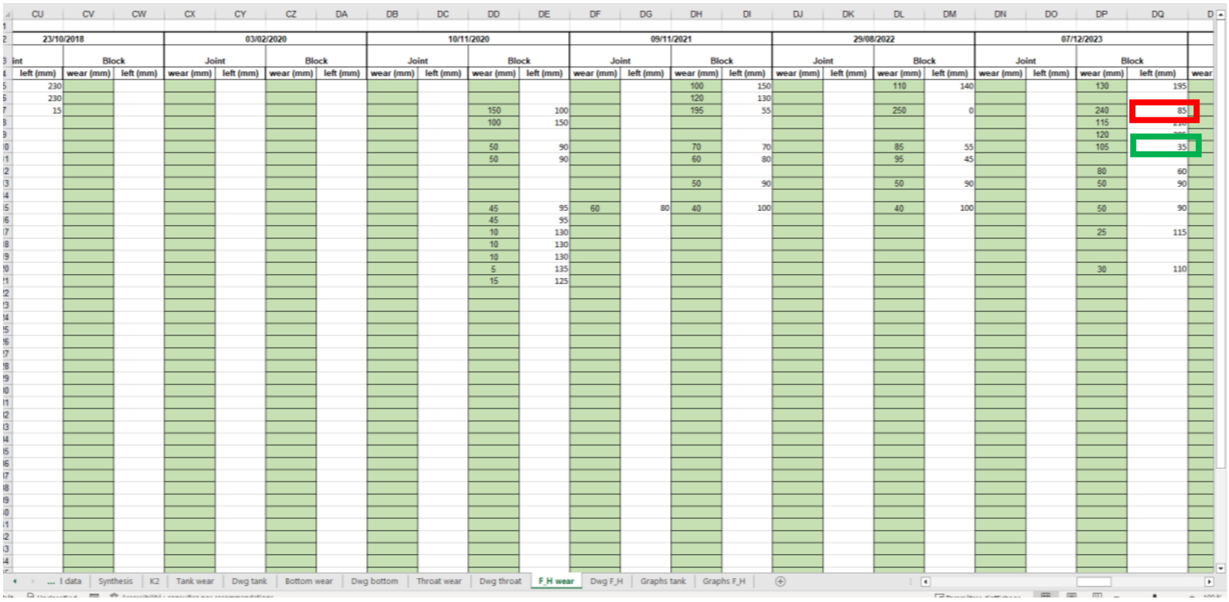


Fig.23 : Right part of the "F_H wear" sheet of the plant of Vamdrup

F_H is a short form for forehearth, so this sheet is about the wear measurements on the forehearth. As it is shown on Fig.21, it starts with five columns that were not in the other sheets, these columns are dedicated to the dates of building of the different parts of the forehearth. Indeed, the forehearth is not necessarily built at the same time as the furnace. The date of building of the furnace determines the start of the campaign but the forehearth is not necessarily demolished and rebuilt when there is a change of campaign. It is possible to keep the forehearth already existing. It is also possible to rebuilt all or some parts of the forehearth during the campaign without rebuilding the furnace. That is why there are five possible building date. Five is a number willingly large but this is to make sure that the user do not have to modify the file by adding columns for example. Indeed a forehearth is usually rebuilt less than five times during a campaign. It is possible to rebuilt only some parts of the forehearth at a time, so that is why it is possible to indicate differents dates on each row. Then, on column F, is written the area on which the measurement is performed. Thanks to this, the user will know where he must measure on the next audits. On column G, the user can choose, for each measurement point, the corresponding zone. This is done thanks to a drop-down list taking the zone previously written on column G of the “Cold data” sheet. On column H the user choose between three types which are “Furnace outlet”, “Conditioning” and “Fiberizing” thanks to a drop-down list using what is written in the column E of the “Cold data” sheet. These are the three main zones of all the forehearths and it was decided to indicate the zone of each measurement point, to perform separated calculations and comparisons between these zones in the future. As always, the date of beginning of campaign is automatically written above the yellow cells. But this time, by comparing Fig.21 and Fig.22, it is possible to see that the layers described with material and thickness are the same at the beginning of the campaign and for each overcoating. It was necessary to have many layers on the initial description because it is possible to have a forehearth which is already very overcoated at the beginning if the forehearth was not rebuilt with the furnace. Then in the green cells, it is more the change of design which are indicated than the overcoatings because if the forehearth is completely rebuilt, of course the user must indicate it in these cells. That is why, in these green cells, as well as in the yellow cells, is described also the main forehearth layer, because it can be rebuilt during the campaign. As usual all the materials columns are filled thanks to the drop-down list of the overcoat materials. There is enough space to have ten differents design because it is possible to add a layer only on a few blocks at a time, so that lead to a lot of possible design changes during a campaign, and even if it changes only a little bit the new design must be described in a new group of green cells with the date of this change.

Then, here again, the values of the wear measured are written on the right part of the sheet. Once the wear is filled in the green cells, the thickness left is automatically calculated in the white cells. This time, however, for each date of audit, there is a column for the joint and a column for the block itself, because the measurement can be performed on either of them. Here to calculate the thickness left, it is necessary to sum the thickness of all the layers of the design in place at the date of the audit and subtract the wear measured. For example, the formula to do that on the cell framed in red in Fig.23 is:

```
=SI(ESTVIDE(DP7);"";SI(DN$2>$CC$2;SOMME($CD7;$CF7;$CH7;$CJ7);SI(DN$2>$BU$2;SOMME($BV7;$BX7;$BZ7;$CB7);SI(DN$2>$BM$2;SOMME($BN7;$BP7;$BR7;$BT7);SI(DN$2>$BE$2;SOMME($BF7;$BH7;$BJ7;$BL7);SI(DN$2>$AW$2;SOMME($AX7;$AZ7;$BB7;$BD7);SI(DN$2>$AO$2;SOMME($AP7;$AR7;$AT7;$AV7);SI(DN$2>$AG$2;SOMME($AH7;$AJ7;$AL7;$AN7);SI(DN$2>$Y$2;SOMME($Z7;$AB7;$AD7;$AF7);SI(DN$2>$Q$2;SOMME($R7;$T7;$V7;$X7);SOMME($J7;$L7;$N7;$P7))))))))))-DP7)
```

As usual, “SI(ESTVIDE(DP7);"";” allows to write nothing if the cell of the corresponding wear is empty.“SI(DN$2>$CC$2;SOMME($CD7;$CF7;$CH7;$CJ7)” sums the thickness of the layers of the design 10 if the date of the audit is later than the date of the design 10. If the date of the audit is earlier than the date of the design 10, “SI(DN$2>$BU$2;SOMME($BV7;$BX7;$BZ7;$CB7)” sums the thickness of the layers of the design 9 if the date of the audit is later than the date of the design 9, and so on until “SOMME($J7;$L7;$N7;$P7)” which sums the thickness of the layers of the design at the beginning of campaign if the date of the audit is earlier than the dates of all the design changes during the campaign. Here, the design which has to be taken into account is the design 2, framed in blue in Fig.22, because the date of the audit (07/12/2023) is later than the date of design 2 but earlier than the date of design 3. Finally, “-DP7” subtracts the wear measured. So in this example the thickness left is 250 + 75 – 240 = 85mm. On another block, it is possible to see in the cell framed in green on Fig.23 that the remaining thickness at this date for this block was 35mm. This is very little and it is probably why the Melting TA team performed an overcoating of this zone five days later (on the 12/12/2023), visible on the cells framed in purple on Fig.22, to add 75mm of thickness.

5.6. The drawing sheets

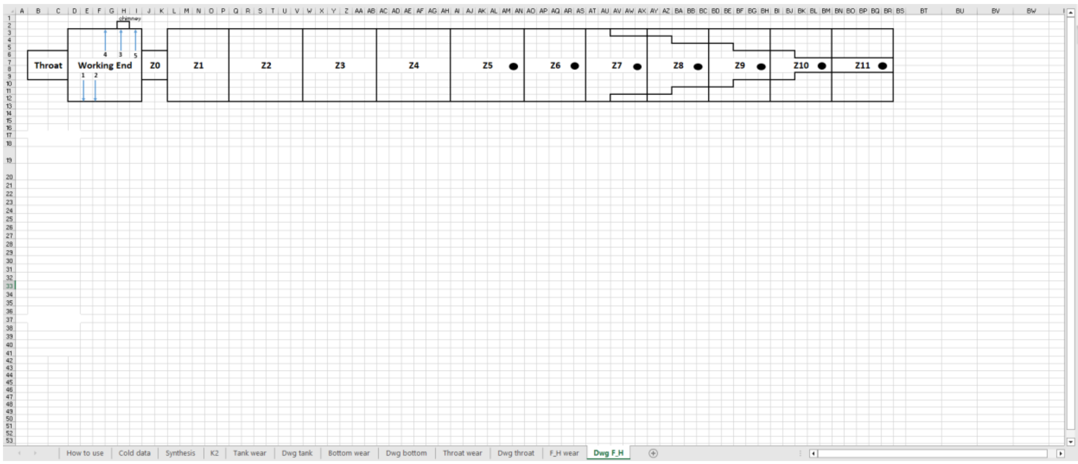
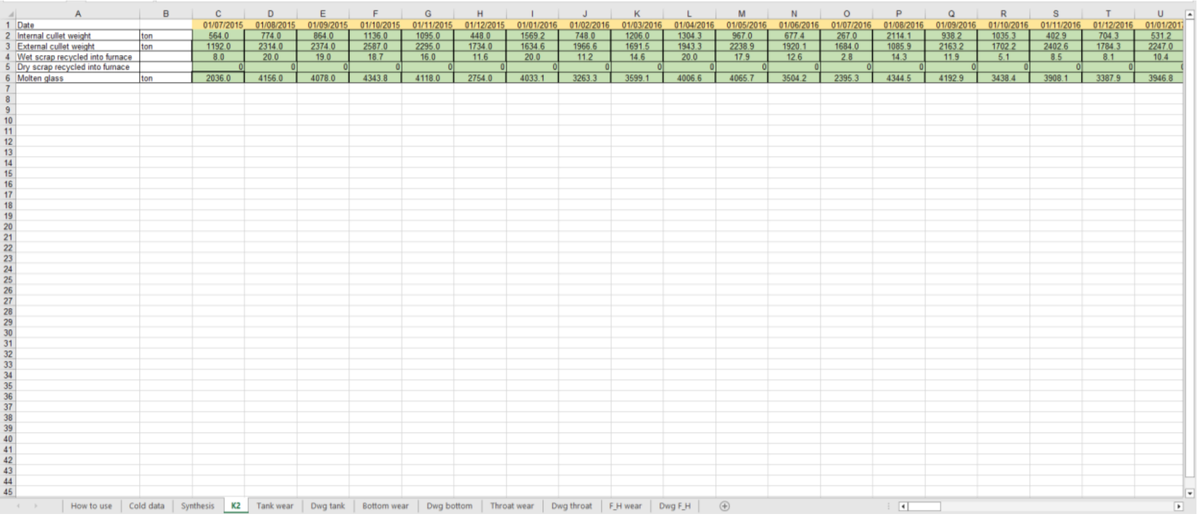


Fig.24 : “Dwg F_H” sheet of the plant of Vamdrup

The sheets “Dwg tank”, “Dwg bottom”, “Dwg throat” and “Dwg F_H” contain drawing of each part of the furnace and of the forehearth. They are helpful for the user to know exactly where the wear measurements are performed. The blocks or the zones indicated in the sheets containing the measurements refer to these drawing sheets. On Fig.24, is shown the “Dwg F_H” sheet of the plant of Vamdrup as an example. On this drawing, the glass flow from the left to the right. The areas written on the “F_H wear” sheet seen before are visible. It is also easier here to realize the three zones defined of the forehearth. Right after the throat, the working end correspond to the “Furnace outlet” zone. From Z0 to Z4, it is the “Conditioning” zone. And form Z5 to Z11, it is the “Fiberizing” zone. Indeed, the black circles represent the fiberizing holes.

5.7. The ”K2” sheet

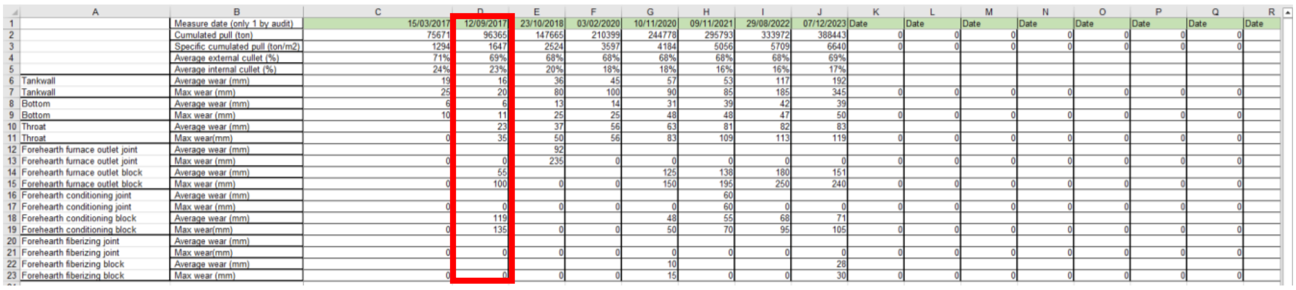


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
1	Date		01/07/2015	01/08/2015	01/09/2015	01/10/2015	01/11/2015	01/12/2015	01/01/2016	01/02/2016	01/03/2016	01/04/2016	01/05/2016	01/06/2016	01/07/2016	01/08/2016	01/09/2016	01/10/2016	01/11/2016	01/12/2016	01/01/201
2	Internal cullet weight	ton	564.0	774.0	864.0	1136.0	1095.0	448.0	1569.2	748.0	1206.0	1304.3	967.0	677.4	267.0	2114.1	938.2	1035.3	402.9	704.3	531.2
3	External cullet weight	ton	1192.0	2314.0	2374.0	2587.0	2295.0	1734.0	1634.6	1966.6	1691.5	1943.3	2238.9	1920.1	1684.0	1085.9	2163.2	1702.2	2402.6	1784.3	2247.0
4	Wet scrap recycled into furnace		8.0	20.0	19.0	18.7	16.0	11.6	20.0	11.2	14.6	20.0	17.9	12.6	2.8	14.3	11.9	5.1	8.5	8.1	10.4
5	Dry scrap recycled into furnace		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	Molten glass	ton	2036.0	4156.0	4078.0	4343.8	4118.0	2754.0	4033.1	3263.3	3599.1	4006.6	4065.7	3504.2	2395.3	4344.5	4192.9	3438.4	3908.1	3387.9	3946.8

Fig.25. : “K2” sheet of the plant of Vamdrup

K2 is the name of a group of process data mensually extracted from the plants. It was decided to copy these data in the file of wear measurement in order to make calculations using this data. The data which is copied in this sheet (Fig.25) are the internal cullet weight, the external cullet weight, the wet scrap recycled into furnace, the dry scrap recycled into furnace, and the molten glass. The cullet is the glass already formed which can be reused for the glass wool production. The use of cullet limits the waste of product and limits also the energy consumption. Indeed a glass already formed needs less heat than raw materials mixed to form glass, because it only needs heat to be fused but not to activate the chemical reaction to form glass. The internal cullet is the cullet coming from the plant. Its chemical composition is known and usually is the same as needed for the production. The external cullet is the cullet coming from other recycling sources. This cullet have an unknown chemical composition, and requires to do some adjustement in the proportions of the differents raw materials used, to match with the wanted chemical composition of the production. The wet and dry scrap recycled into furnace can give an idea of how much internal scrap is recycled in the plant each month. Finally, the molten glass is the quantity of glass produced each month. This data is also called the pull.

5.8. The ”Synthesis” sheet



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1		Measure date (only 1 by audit)	15/03/2017	12/09/2017	23/10/2018	03/02/2020	10/11/2020	09/11/2021	29/08/2022	07/12/2023	Date	Date	Date	Date	Date	Date	Date	Date
2		Cumulated pull (ton)	75671	96365	147665	210399	244778	295793	333972	388443	0	0	0	0	0	0	0	
3		Specific cumulated pull (ton/m2)	1294	1647	2524	3597	4184	5056	5709	6640	0	0	0	0	0	0	0	
4		Average external cullet (%)	71%	69%	68%	68%	68%	68%	68%	69%								
5		Average internal cullet (%)	24%	23%	20%	18%	18%	16%	16%	17%								
6	Tankwall	Average wear (mm)	19	16	36	45	57	53	117	192								
7	Tankwall	Max wear (mm)	25	20	80	100	90	85	185	345	0	0	0	0	0	0	0	
8	Bottom	Average wear (mm)	6	6	13	14	31	39	42	39								
9	Bottom	Max wear (mm)	10	11	25	25	48	48	47	50	0	0	0	0	0	0	0	
10	Throat	Average wear (mm)		23	37	56	63	81	82	83								
11	Throat	Max wear(mm)	0	35	50	56	83	109	113	119	0	0	0	0	0	0	0	
12	Forehearth furnace outlet joint	Average wear (mm)			92													
13	Forehearth furnace outlet joint	Max wear (mm)	0	0	235	0	0	0	0	0	0	0	0	0	0	0	0	
14	Forehearth furnace outlet block	Average wear (mm)		55			125	138	180	151								
15	Forehearth furnace outlet block	Max wear (mm)	0	100	0	0	150	195	250	240	0	0	0	0	0	0	0	
16	Forehearth conditioning joint	Average wear (mm)						60										
17	Forehearth conditioning joint	Max wear (mm)	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	
18	Forehearth conditioning block	Average wear (mm)		119			48	55	68	71								
19	Forehearth conditioning block	Max wear(mm)	0	135	0	0	50	70	95	105	0	0	0	0	0	0	0	
20	Forehearth fiberizing joint	Average wear (mm)																
21	Forehearth fiberizing joint	Max wear(mm)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	Forehearth fiberizing block	Average wear (mm)					10			28								
23	Forehearth fiberizing block	Max wear (mm)	0	0	0	0	15	0	0	30	0	0	0	0	0	0	0	

Fig.26 : "Synthesis" sheet of the plant of Vamdrup

The synthesis sheet can be seen like the final overview of all the date filled in the other sheets of the file. As said before, in the green cells of the row 1 of this sheet, the user must write the date when he is performing an audit. Once a green cell is filled in this page, the date is automatically copied in the sheets of wear measurements. It allows to write the date of an audit only one time rather than four times as it was done before, and it was redundant for the user.

Then, several automatic calculations are performed. These calculations are done for each audit date so that they can be correlated at the wear measurements performed on these audit. All the formulas taken in example in the following are the formulas of column D, framed in red on Fig.26, which correspond to the second audit performed on September the 12th 2017. On row 2, there is the cumulated pull which is the total quantity of glass produced until the date of the audit. The cumulated pull at a date D can be calculated like that:

$$Cumulated\ pull = \sum_{Starting date}^{DateD} Tons\ of\ glass\ produced \qquad (1)$$

On Excel, it is calculated thanks to the formula:

=SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)

This formula sums all the values of the row of the molten glass in the "K2" sheet, for which the corresponding date on row 1 of the "K2" sheet is earlier than the date of the audit on row 1 of the "Synthesis" sheet. So, here, the total quantity of glass produced since the beginning of the campaign until the 12/09/2017 is 96 365 tons. On row 3, the specific cumulated pull is calculated. This is the cumulated pull divided by the melting area of the furnace, calculated as:

$$Specific\ cumulated\ pull = \frac{Cumulated\ pull}{Melting\ area} \qquad (2)$$

The surface is known and is written in the "Cold data" sheet, so, on Excel, the specific cumulated pull is calculated with the formula:

=SI('Cold data'!$B$1=0;"";D2/'Cold data'!$B$1)

Nothing is written if no surface is filled in the "Cold data" sheet, so if the surface is equal to 0, and otherwise it effectuates the calculation. Here the specific cumulated pull at the date of the second audit is 1 647 ton/m^2.

On row 4 is calculated the average external cullet, which is the average of external cullet used in the production since the beginning of the campaign until the date of the audit. The average external cullet is given by the formula :

$$\frac{External\ cullet\ weight}{Molten\ glass - Internal\ cullet\ weight} \quad (3)$$

So, in the Excel file, to have the average external cullet since the beginning of the campaign, it is calculated with the formula:

```
=SI((SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)-
SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C2:$FT2))=0;"";SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C3:$
FT3)/(SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)-
SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C2:$FT2)))
```

If the difference between the molten glass and the internal cullet weight since the beginning of the campaign is equal to 0, it write nothing thanks to the part"SI((SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)-SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C2:$FT2))=0;"";" in order to have no problem with the division by 0. Otherwise it effectuate the calculation thanks to the other part of the formula : "SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C3:$FT3)/(SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)-SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C2:$FT2)))".

In the detail, "SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C3:$FT3)" sums all the values of the row of the external cullet weight in the "K2" sheet, for which the date on row 1 of the "K2" sheet is earlier than the date of the audit on row 1 of the "Synthesis" sheet, to have the total external cullet weight since the beginning of the campaign. "SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)" does the same thing with the molten glass values to have the total molten glass weight since the beginning of campaign (which is the cumulated pull). "SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C2:$FT2)" also does the same thing with the values of the internal cullet weight to have the total internal cullet weight since the beginning of the campaign.In this example, the average external cullet calculated is of 69%.

On row 5 is calculated the average internal cullet which is obtained thanks to the formula :

$$\frac{Internal\ cullet\ weight}{Molten\ glass} \quad (4)$$

So in Excel and in order to have the average internal cullet since the beginning of the campaign, it is calculated thanks to the formula:

=SI(SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)=0;"";SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C2:$FT2)/SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6))

Nothing is written if the sum of the molten glass values is equal to 0 thanks to the part “SI(SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)=0;"";” in order to have no problem with the division by 0. If this sum of the molten glass values is not equal to 0, the calculation is performed thanks to the other part of the formula : “SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C2:$FT2)/SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)”. In this part, “SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C2:$FT2)” sums all the values of the row of the internal cullet weight in the “K2” sheet,for which the date on row 1 of the “K2” sheet is earlier than the date of the audit on row 1 of the “Synthesis” sheet, to have the total internal cullet weight since the beginning of the campaign. “SOMME.SI('K2'!$C1:$FT1;"<"&D1;'K2'!$C6:$FT6)” does the same thing for the molten glass in order to have the total molten glass weight since the beginning of the campaign. In this example, the average internal cullet weight at the date of the second audit is 23%.

From row 6 to row 11 are calculated the maximum and the average of all the measures performed on the tankwall, the bottom and the throat at each date of audit. For the tankwall, the formula to calculate the average is:

=SI(SOMME('Tank wear'!AS6:AS475)=0;"";MOYENNE('Tank wear'!AS6:AS475))”

The part “SI(SOMME('Tank wear'!AS6:AS475)=0;"";” allows to write nothing if the sum of all the wear values at this date is 0. This time, on the contrary of what has been done for the calculation of the thickness left on the wear measurements sheets, it is necessary to verify if the sum is null and not only one cell because the formula needs to write nothing only if all the cells are empty. Indeed, since a wear measurement is necessarily a positive value, the only way to have a sum equal to 0 is to have all the values equals to 0. Then if at least one value is written, the function “MOYENNE” used in the following of the formula calculate the average of all the values written and ignores the empty cells. Here the average of all the measures performed on the tankwall on the 12/09/2017 is 16mm. The maximum of these measures is calculated thanks to the formula:

=MAX('Tank wear'!AS6:AS475)

This time there is no need to verify if values are written because, if no values are written, the maximum which is displayed is 0, and this is enough for the use wanted. In this example, the maximum of all the measured wear values on the tankwall on the 12/09/2017 is 20mm.

The maximum and the average of the measures on the bottom and on the throat are calculated thanks to similar formulas which are reported below:

- Average wear of the bottom: “=SI(SOMME('Bottom wear'!T5:T36)=0;"";MOYENNE('Bottom wear'!T5:T36))”
- Max wear of the bottom: “=MAX('Bottom wear'!T5:T36)”
- Average wear of the throat: “=SI(SOMME('Throat wear'!U4:U7)=0;"";MOYENNE('Throat wear'!U4:U7))”
- Max wear of the throat: “=MAX('Throat wear'!U4:U7)”

The results obtained are 6mm for the average wear of the bottom, 11mm for the maximum wear of the bottom, 23mm for the average wear of the throat and 35mm for the maximum wear of the throat.

Regarding, the forehearth, the same calculations are performed, but independently on each zone defined and, for each zone, independently on the block and the joint. The formula to calculate the average wear on the blocks belonging to the zone “Furnace outlet” is:

=SI(SOMME.SI('F_H wear'!$H$5:$H$54;"Furnace outlet";'F_H wear'!CR5:CR54)=0;"";MOYENNE.SI('F_H wear'!$H$5:$H$54;"Furnace outlet";'F_H wear'!CR5:CR54))

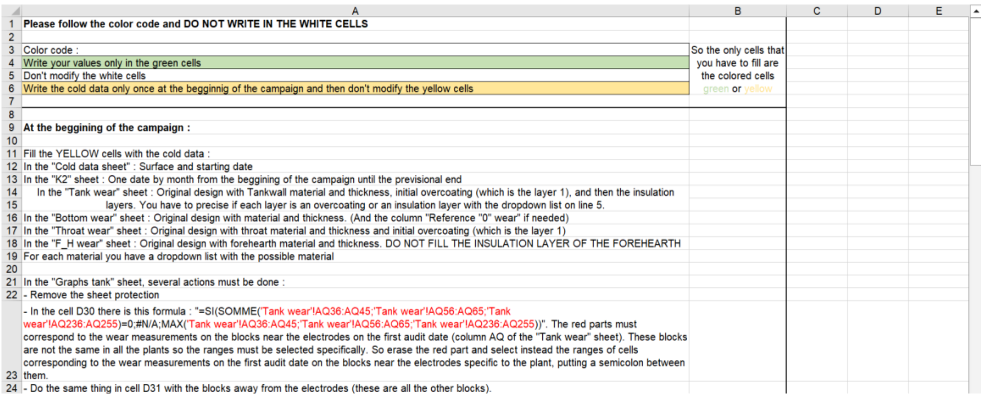
The part “=SI(SOMME.SI('F_H wear'!$H$5:$H$54;"Furnaceoutlet";'F_H wear'!CR5:CR54)=0;"";” allows to write nothing if all the cells containing the wear of the blocks belonging to the zone “Furnace outlet” at the date of the audit are empty, that is if their sum is null. Otherwise, “MOYENNE.SI('F_H wear'!$H$5:$H$54;"Furnace outlet";'F_H wear'!CR5:CR54)” calculate the average of all the wear values of the block at the date of the audit, for which the corresponding cell on column H of the ‘F_H wear” sheet is exactly filled with “Furnace outlet”.The formula to calculate the maximum wear in the blocks belonging to the zone “Furnace outlet” is:

=MAX.SI.ENS('F_H wear'!CR5:CR54;'F_H wear'!$H$5:$H$54;"Furnace outlet")

The function used here found the maximum between the wear values of the block at the date of the audit, for which the corresponding cell on column H of the ‘F_H wear” sheet is exactly filled with “Furnace outlet”. The point of implementing a drop-down list on this column H of the “F_H wear” is seen here. Indeed, without drop-down list, a simple typographical error when the user is writing the zone would lead for the wear value to not be considered in the calculation of the average and maximum wear on the “Synthesis” sheet.

The calculations on the other zones are performed with the same formulas by replacing “Furnace outlet” with “Conditioning” or “Fiberizing”. To have the maximum and the average on the joint it is enough to change the column.

5.9. The “How to use” sheet



	A	B	C	D	E
1	**Please follow the color code and DO NOT WRITE IN THE WHITE CELLS**				
2					
3	Color code :	So the only cells that			
4	Write your values only in the green cells	you have to fill are			
5	Don't modify the white cells	the colored cells			
6	Write the cold data only once at the begginnig of the campaign and then don't modify the yellow cells	green or yellow			
7					
8					
9	**At the beggining of the campaign :**				
10					
11	Fill the YELLOW cells with the cold data :				
12	In the "Cold data sheet" : Surface and starting date				
13	In the "K2" sheet : One date by month from the beggining of the campaign until the previsional end				
14	In the "Tank wear" sheet : Original design with Tankwall material and thickness, initial overcoating (which is the layer 1), and then the insulation				
15	layers. You have to precise if each layer is an overcoating or an insulation layer with the dropdown list on line 5.				
16	In the "Bottom wear" sheet : Original design with material and thickness. (And the column "Reference "0" wear" if needed)				
17	In the "Throat wear" sheet : Original design with throat material and thickness and initial overcoating (which is the layer 1)				
18	In the "F_H wear" sheet : Original design with forehearth material and thickness. DO NOT FILL THE INSULATION LAYER OF THE FOREHEARTH				
19	For each material you have a dropdown list with the possible material				
20					
21	In the "Graphs tank" sheet, several actions must be done :				
22	- Remove the sheet protection				
23	- In the cell D30 there is this formula : "=SI(SOMME('Tank wear'!AQ36:AQ45;'Tank wear'!AQ56:AQ65;'Tank wear'!AQ236:AQ255)=0;#N/A;MAX('Tank wear'!AQ36:AQ45;'Tank wear'!AQ56:AQ65;'Tank wear'!AQ236:AQ255))". The red parts must correspond to the wear measurements on the blocks near the electrodes on the first audit date (column AQ of the "Tank wear" sheet). These blocks are not the same in all the plants so the ranges must be selected specifically. So erase the red part and select instead the ranges of cells corresponding to the wear measurements on the first audit date on the blocks near the electrodes specific to the plant, putting a semicolon between them.				
24	- Do the same thing in cell D31 with the blocks away from the electrodes (these are all the other blocks).				

Fig.27 : “How to use” sheet of the plant of Vamdrup

Finally, a “How to use” sheet has been added to remind the team members how they must fill and read this file. It explains the color code, what must be written and where should it be written after an audit, an overcoating or at the beginning of the campaign.

6. Overcoating curves

Once a file like the one described before was implemented for each plant, it was possible to use the data to create curves. The first type of curves is the overcoating comparative curves. The aim of these curves is to be able to see quickly when an overcoating is installed on a furnace and how many overcoating are installed on this furnace. In order to effectuate comparisons between plants and to know if a plant have installed an overcoating earlier or later than the others, one curve by plant is displayed on the same chart. Be able to effectuate such comparison was the first motivation to create these curves. To reach this goal, two charts has been created. On the y-axis, is always represented the number of overcoating installed, which usually is between 0 and 4 maximum.For the first chart, the time is on the x-axis, but it was not possible to choose the date as the values for this x-axis because the campaigns do not start all at the same time so it would have created an offset horizontally between the curves and it would not have been relevant. So, to have an equal time scale for all the plants, it has been decided to represent on the x-axis the number of months from the beginning of campaign. On the second chart, the x-axis represents the specific cumulated pull. Indeed, it would be logical that,in a furnace with a higher productivity by square meters, the wear should be faster and the overcoatings should be installed earlier. To take this into account, representing the specific cumulated pull on the x-axis is a good solution. Finally, the aim of these curves is also to be ergonomic and fast to use. Indeed, the user must be able to easily choose the plants for whichhe wants to display the curves on the chart.

6.1. Electrical furnaces

To create these curves, a table with all the necessary data is done on a new sheet of the wear measurement file of each plant. On the electrical furnaces, in addition to the first layer of overcoating which is installed directly at the beginning of the campaign, three other overcoatings are installed at most, so the table contains four columns. The first one is to have a point that indicate that there is no overcoating at the beginning of campaign (at 0 months from beginning of campaign or at 0 ton/m^2 of specific cumulated pull): this is the origin. The three other columns are used to count the three possible overcoatings and know their correspondence with the x-axis. An example of this table called "Number of overcoating" is showed in Fig.28.

Number of overcoating				
Date	20/07/2015	30/01/2023	Date	Date
NOMFB	0	90	#VALEUR!	#VALEUR!
CP (ton)	0	351948	0	0
SCP (ton/m^2)	0	6016	0	0
Overcoatings	0	2	0	0

Fig.28 : Table used to plot the number of overcoatings of the plant of Vamdrup

On the first row are visible the dates at which an overcoating is performed. First, as said before, on the first column is represented the state at the beginning of campaign. The starting date of the campaign is still obtained with the formula:

='Cold data'!B2

In this example, it is the 20/07/2015. Then the three other dates correspond to the dates written by the user in the "Tank wear" sheet when an overcoating is performed. To be automatically written in this table the formulas used are:

='Tank wear'!R2

='Tank wear'!Z2

='Tank wear'!AH2

Here, an overcoating has been performed on the 30/01/2023 but this is the only one, that is why "Date" is written in the two other cells.

The other rows are the number of months from beginning (NOMFB) of campaign, the cumulated pull (CP), the specific cumulated pull (SCP) and the number of overcoating. On the first column, under the starting date of the campaign, "0" is written on all these rows because at the beginning of the campaign no month have passed from the beginning of campaign, no glass has been produced so the cumulated pull and the specific cumulated pull are null, and no overcoating have been installed. In reality, usually an overcoating is installed directly during the building of the electrical furnaces but, since it is common to all the electrical furnaces, it is not represented here and the only overcoatings represented on these curves are the ones installed during the campaign.

6.1.1. Calculation of the number of months from beginning of campaign

On Excel, it is possible to make calculations with dates, but the date is considered in this case as the number of days since the 1st of January 1900. So, if a difference between two dates is performed, the result is the number of days between these two dates. To calculate the number of months from the beginning of campaign, it is therefore necessary to calculate the difference between the date of interest and the starting date of campaign and to divide the result by the number of days in one month, to obtain the result in months. In a year there are 7 months containing 31 days and 4 months containing 30 days. The month of February contains 28 days three years over four and 29 days the fourth year. The average number of days in February is therefore:

$$Average\ number\ of\ days\ in\ February = \frac{3\times 28+29}{4} = 28{,}25 \text{ days} \quad (5)$$

And the average number of days in a month is:

$$Average\ number\ of\ days\ in\ a\ month = \frac{7\times 31 + 4\times 30 + 28{,}25}{12} = 30{,}4375\ days \quad (6)$$

So, on Excel, to calculate the number of months between a date D and the starting date of the campaign, the calculation to effectuate is:

$$Number\ of\ months\ from\ beginning\ of\ campaign = \frac{Date\ D - Starting\ date}{30{,}4375} \quad (7)$$

So, for example, the formula written in the second row of the table of the column framed in red (Fig.28) is:

=(E48-'Cold data'!$B2)/30.4375

It calculates the number of months between the starting date and the 30/01/2023. Here, E48 is the date of the same columns on the first row and 'Cold data'!$B2 is the starting date. The result is 90 months. It has been chosen to display all the results as integers to be clearer.

6.1.2. Calculation of the cumulated pull and of the specific cumulated pull

The cumulated pull and the specific cumulated pull are calculated in the same way as in the “Synthesis” sheet (1) and (2). The same type of formulas is therefore used. On the column framed in red, the cumulated pull is calculated thanks to the formula:

=SOMME.SI('K2'!$C1:$KW1;"<"&E48;'K2'!$C6:$KW6)

And the specific cumulated pull is calculated thanks to the formula:

=E50/'Cold data'!$B1

In this case, on the 30/01/2023, date at which the first overcoating has been performed, the cumulated pull is 351 948 tons, and the specific cumulated pull is 6 016 tons/m^2.

6.1.3. Calculation of the number of overcoating

Finally, to calculate the values which will be displayed on the y-axis of the plot, the number of overcoatings, it has been necessary to return 0, 1, 2, 3 or 4 in function of several cases. On the "Tank wear" sheet, when an overcoating is installed, the user writes the date on row 2, choose thanks to the drop-down list on row 5 for each layer if it is an overcoating layer or an insulation layer, and write from row 6 the material and the thickness of the layer. On the electrical furnaces, when an overcoating is installed, it is installed all around the furnace, so if "Overcoat" is written on the row 5 of a layer it is sure that this layer is an overcoating layer. Moreover, on a furnace, the overcoating layers are always positioned on the inside and then externally covered by the insulation layers. Therefore, since the layers are numbered from the inside to the outside, the first layers are the overcoating layers and the last ones are the insulation layers. It results that, to know the number of overcoating layers installed at a specific date, it is sufficient to know the position of the outermost overcoating layer, that is the position of the outermost layer for which "Overcoat" is written in row 5.

On Excel, to transcribe this, the formula used, for example in the column framed in red, to know the number of overcoatings installed on the 30/01/2023 is:

=SI('Tank wear'!X5="Overcoat";4;SI('Tank wear'!V5="Overcoat";3;SI('Tank wear'!T5="Overcoat";2;SI('Tank wear'!R5="Overcoat";1;0))))

There are four cells by date in the "Tank wear" sheet in which the user can choose between "Overcoat" and "Insulation" (one for each layer which is possible to add, remove or change during the campaign). So the part "SI('Tank wear'!X5="Overcoat";4" returns 4 if for the outermost layer at this date "Overcoat" is written. If it is not the case "SI('Tank wear'!V5="Overcoat";3" returns 3 if for the second outermost layer at this date "Overcoat" is written and so on until the innermost layer. If "Overcoat" is not written for any layer, the formula returns 0 because if this is the case, it means that no overcoating layer is present at this date. The order is important in this formula because when a condition is verified, the associated value is returned and the formula is stopped. By writing the conditions from the outermost to the innermost layer, the formula stops when the outermost overcoating layer is founded as it is wanted. In this example, two overcoating layers has been installed on the 30/01/2023 so the formula returns 2.

X, V, T and R are the letters of the columns of the different layers at the fist date in the “Tank wear” sheet. In the formulas corresponding to the second and third dates, these letters are replaced respectively by AF, AD, AB and Z, and by AN, AL, AJ and AH.

As it is visible it was not possible to simply count the number of dates of overcoating written in the “Tank wear” sheet because, on the Vamdrup furnace and on the big majority of the electrical furnaces, the overcoating layers are installed two at a time.

6.1.4. Grouping of the data and plotting of the curves

To plot the curves, it was necessary to have at the same place the date of all the plants. So, a new file has been created and links between this new file and the wear measurement file of each plant have been set up to have all the data on the same file. On this file, the “number of overcoating” table is separated in two tables. The first one contains the values of the y-axis which are the number of overcoating of each plant (Fig.29) and the second one contains the values of the x-axis which are the number of months from beginning and the specific cumulated pull at each date of overcoating installation for each plant (Fig.30).

PLANTS	n° of overcoat	n° of overcoat	n° of overcoat	n° of overcoat
CHALON 2	0	#N/A	#N/A	#N/A
VAMDRUP	0	2	#N/A	#N/A
LUCENS	0	2	#N/A	#N/A

Fig.29 : Table of the number of overcoating of several plants

X-AXIS					
Chalon 2 NOMFB		0	#VALEUR!	#VALEUR!	#VALEUR!
Chalon 2 SCP (ton/m^2)		0	0	0	0
Vamdrup NOMFB		0	90	#VALEUR!	#VALEUR!
Vamdrup SCP (ton/m^2)		0	6016	0	0
Lucens NOMFB		0	58	#VALEUR!	#VALEUR!
Lucens SCP (ton/m^2)		0	9058	0	0

Fig.30 : Table of the number of months from beginning and specific cumulated pull of several plants

The only values for which a link is not used is the first column of the first table, where “0” is written manually. In this first table, from the second column, a formula of this type is written:

=SI(link=0;#N/A;link)

For example in the cell framed in red in Fig.29, the formula is:

=SI('https://saintgobain.sharepoint.com/sites/Meltingdataproject/Documents partages/INSULATION/41_LOCAL_DICTIONARY_VAMDRUP/DOCUMENTS/[Vamdrup - campaign 2015 - electrical furnace wear measurement.xlsx]Graphs tank'!F$52=0;#N/A;'https://saintgobain.sharepoint.com/sites/Meltingdataproject/Documents partages/INSULATION/41_LOCAL_DICTIONARY_VAMDRUP/DOCUMENTS/[Vamdrup - campaign 2015 - electrical furnace wear measurement.xlsx]Graphs tank'!F$52)

Indeed, if 0 is returned in the second, third or fourth column of the first table, the curve has a point which take 0 as y value and which is not relevant. On Excel, if “#N/A” is written on a data set used to plot a curve, this point is not considered to plot the curve and it is possible to connect the previous and next points. The formula used in the first table allows to write #N/A instead of 0 if the link leads to a 0. If it leads to another value than 0, it returns this value.

The green cell in which is written “PLANTS” on the first table is a filter which allows for the user to choose the plants he wants to display on the plot. He just has to click on the arrow on the right of the cell and select, thanks to check boxes, which plants he wants to compare. This is an easy way to switch from a comparison to another, which was one of the goals of these curves. The color code is the same than in the wear measurement file. Indeed, the green cell is the only one which can be used by the user. The white cells are cells with automatic calculations which must not be modified.

Thanks to these tables it is possible to plot the number of overcoatings against the number of months from beginning of campaign (Fig.31) and against the specific cumulated pull (Fig.32) for all the plants, and effectuate comparisons between the plants of interest thanks to the filter.

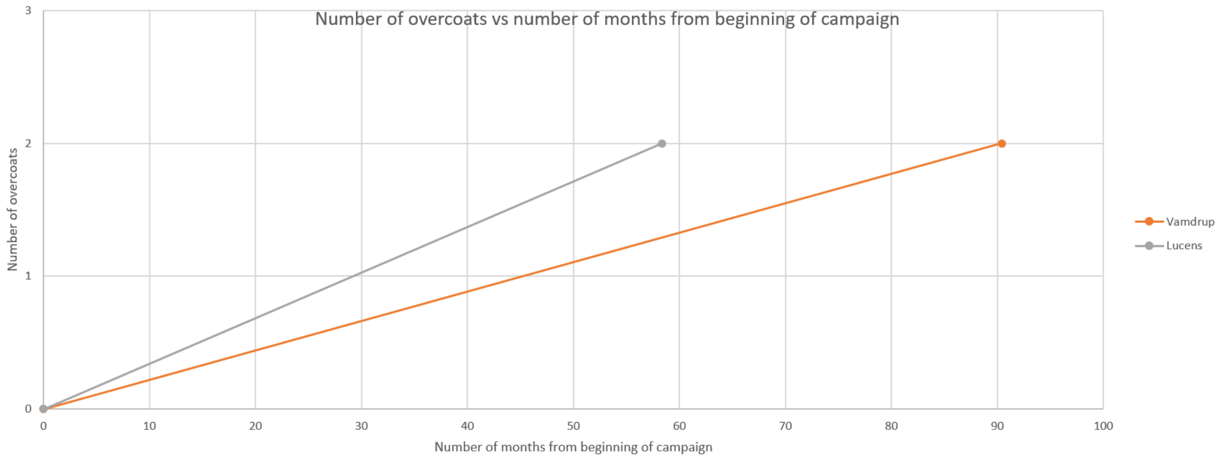


Fig.31 : Number of overcoatings vs number of months from beginning of campaign for the plants of Vamdrup and Lucens

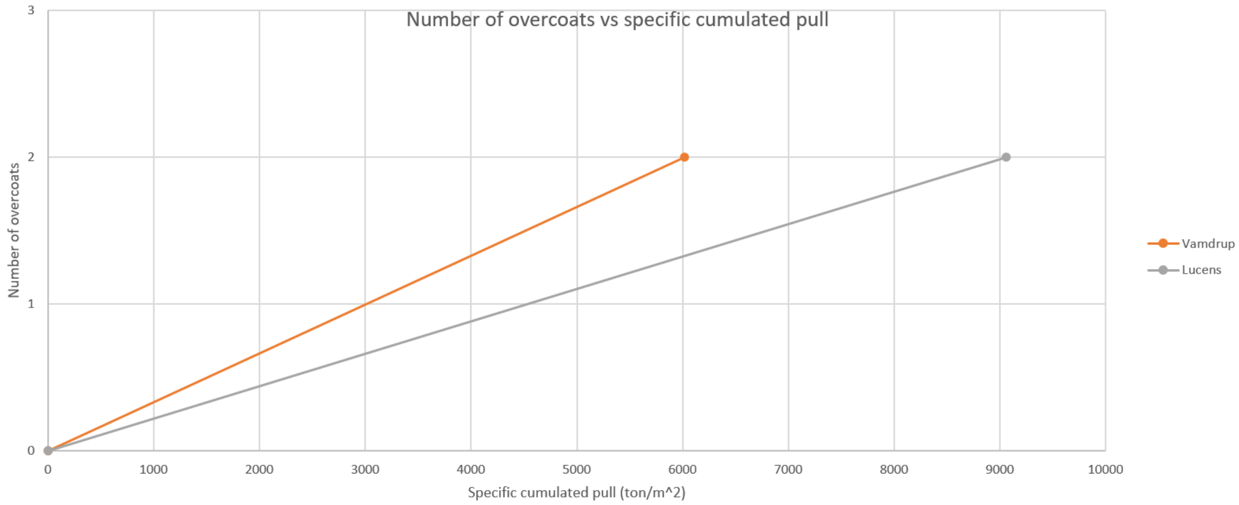


Fig.32 : Number of overcoatings vs specific cumulated pull for the plants of Vamdrup and Lucens

To realize these two plots, the filter has been used and only the plants of Vamdrup and Lucens have been selected.

On the first one, it is possible to see that the overcoatings in Lucens have been installed earlier than in Vamdrup. If Lucens needed an overcoating earlier than Vamdrup, it probably means that the first refractory layers were worn faster. On the contrary, looking at the second plot, the overcoatings in Lucens were installed when the furnace reached a higher value of specific cumulated pull with respect to Vamdrup. It is explainable by the fact that the plant of Lucens producesquicker than the plant of Vamdrup. So, this time, if the scale considered is not the time scale anymore but the production scale, these are the first refractory layers of Vamdrup which were probably worn faster. The faster installation of the overcoatings in Lucens showed in the first plot can be explained, among other, by a higher productivity. This example is a good way to show that the plot against the specific cumulated pull can be very useful to understand better phenomenon showed by the plot against the number of months from beginning of campaign, or simply to analyse the data from the point of view of the production. Find the right comparison to do and analyse these curves is now the job of the Melting TA team.

6.2. Flame furnace

For the flame furnaces, the general principle is the same as for the electrical furnaces but there are still some differences. Indeed, on the flame furnaces the overcoatings can be installed zone by zone, all the furnace is not overcoated at the same time like for the flame furnaces. Very often, the different zones are overcoated at different dates. Therefore, it is necessary to plot one curve by zone, using the zones defined previously. To plot one curve by zone, the “Number of overcoating” table of the wear measurement file must contain one row for each zone (Fig.33).

Number of overcoating					
Date	04/04/2017	11/01/2022	13/01/2024	Date	Date
NOMFB	0	57	81	#VALEUR!	#VALEUR!
CP (ton)	0	258903	341207	0	0
SCP (ton/m^2)	0	4308	5677	0	0
BWLC	0	0	0	0	0
LSWUD	0	0	0	0	0
LDCBU	0	0	0	0	0
SWLD	0	0	0	0	0
LDCBD	0	0	0	0	0
LSWDD	0	1	2	0	0
LSWUB	0	1	2	0	0
LSWB	0	1	2	0	0
LSWDB	0	0	1	0	0
FWLC	0	0	0	0	0
FWL	0	0	0	0	0
FWT	0	0	0	0	0
FWR	0	0	0	0	0
FWRC	0	0	0	0	0
RSWDB	0	0	1	0	0
RSWB	0	1	2	0	0
RSWUB	0	1	2	0	0
RSWDD	0	1	2	0	0
RDCBD	0	0	0	0	0
SWRD	0	0	0	0	0
RDCBU	0	0	0	0	0
RSWUD	0	0	1	0	0
BWRC	0	0	0	0	0
BWRS	0	1	2	0	0
BWC	0	1	2	0	0
BWLS	0	1	2	0	0

Fig.33 : "Number of overcoating" table of the plant of Tarsus

Since the "Tank wear" sheet includes four dates at most to add an overcoating during the campaign, it was necessary for this table to have four columns in addition to the first one which concerns the start of the campaign. Indeed, like in the "Number of overcoating" table of the electrical furnaces, one row is requested for each date of add of overcoating layer. Only the initials of the zones have been written in order to not have to long name and a huge cells dimension.

The date, the number of months from beginning of campaign, the cumulated pull and the specific cumulated pull are calculated exactly on the same way as it has been done for the electrical furnaces. The only calculations which vary are the calculations of the number of overcoating of each zone.

6.2.1. Calculation of the number of overcoating

This time, the overcoatings are not necessarily installed on all the blocks of the furnace so, at a given date, find the outermost layer for which "Overcoat" is written is not sufficient. In the case of the flame furnaces, the conditions to find the number of overcoating layers at this date are two. The first one is, nevertheless, the same as for the electrical furnaces: "Overcoat" must be written in top of the column of the layer. Thanks to this condition, it is possible to verify that it is an overcoating layer and not an insulation layer. The second condition must verify that this layer is actually an overcoating layer for the zone concerned. Indeed, when "Overcoat" is written in top of the column of a layer, it means that it is an overcoating layer for at least one block, but it does not mean that it is an overcoating layer for all the zones. To know that, the second condition must verify if something is written in the rows of the zone concerned in the columns of this layer. To verify that, it is possible to sum the values of the column of the thickness of this layer on the rows of the zone and watch the result. If this result is 0, it means that nothing is written on these cells and that this zone is not concerned by this overcoating layer. If, on the contrary, the result is not 0, it means that thickness are written and that this layer is actually an overcoating layer of this zone. So the second condition is to have a sum of the thickness of the zone different than 0 on the column of the layer. On Excel, this condition can be written “NON(SOMME('Tank wear'!AY215:AY304)=0)” for example in the cell framed in red in Fig.33. So the goal here is to found the outermost layer which meets both conditions and return the number of the corresponding layer. For that the function “ET” is used. This function return the logic value TRUE only if both of the conditions are true. In the cell framed in red, it gives:

ET('Tank wear'!AY$4="Overcoat";NON(SOMME('Tank wear'!AY215:AY304)=0))”. The whole formula in this cell is “=SI(ET('Tank wear'!AY$4="Overcoat";NON(SOMME('Tank wear'!AY215:AY304)=0));5;SI(ET('Tank wear'!AV$4="Overcoat";NON(SOMME('Tank wear'!AV215:AV304)=0));4;SI(ET('Tank wear'!AS$4="Overcoat";NON(SOMME('Tank wear'!AS215:AS304)=0));3;SI(ET('Tank wear'!AP$4="Overcoat";NON(SOMME('Tank wear'!AP215:AP304)=0));2;SI(ET('Tank wear'!AM$4="Overcoat";NON(SOMME('Tank wear'!AM215:AM304)=0));1;0)))))

As well as for the electrical furnaces the conditions are submitted from the outermost layer to the innermost and stop as soon as a layer has met the two conditions. Thanks to this method, the number returned is the number of the outermost layer which meet the two conditions. In the same way as the electrical furnaces, AY, AV, AS, AP and AM are the columns corresponding to the second date, and are adjusted in the other columns of the table to match with the right date.

6.2.2. Grouping of the data and plotting of the curves

As well as it was done for the electrical furnaces, the data of all the plants are grouped in a new file, using links with the “Number of overcoating” table of the wear measurement file of each plant. But this time, it is not possible to plot all the curves together because the maximum number of curves in an Excel plot is 255. Indeed, since one curve by zone is necessary, this number is largely exceeded. The solution founded was to separate the furnace in big zones and plot the curves of the concerned zones. These big zones are “Back wall”, “Front wall”, “Side wall” and “Doghouse”. It is not very disturbing to separate the curves like that because these curves are relevant if a same zone or similar zones are compared. One sheet for each big zone has been created, and on each sheet the same tables as for the electrical furnaces, with the values of the y-axis on the first one and the values of the x-axis on the second one, are present. The first table of the big zone “Back wall” is showed in Fig.34, the second table of the same big zone is showed in Fig.35.

PLANTS	ZONE	n° of overcoat	n° of overcoat	n° of overcoat	n° of overcoat	n° of overcoat
TARSUS	Back wall left corner	0	#N/A	#N/A	#N/A	#N/A
TARSUS	Back wall right corner	0	#N/A	#N/A	#N/A	#N/A
TARSUS	Back wall right side	0	1	2	#N/A	#N/A
TARSUS	Back wall center	0	1	2	#N/A	#N/A
TARSUS	Back wall left side	0	1	2	#N/A	#N/A
LLAVALLOL	Back wall left corner	0	1	#N/A	#N/A	#N/A
LLAVALLOL	Back wall right corner	0	1	#N/A	#N/A	#N/A
BERGISCH TEL	Back wall left corner	0	1	1	#N/A	#N/A
BERGISCH TEL	Back wall right corner	0	1	1	#N/A	#N/A
BERGISCH TEL	Back wall right side	0	1	1	#N/A	#N/A
BERGISCH TEL	Back wall center	0	1	1	#N/A	#N/A
BERGISCH TEL	Back wall left side	0	1	1	#N/A	#N/A
DANGJIN	Back wall left corner	0	1	#N/A	#N/A	#N/A
DANGJIN	Back wall right corner	0	1	#N/A	#N/A	#N/A
DANGJIN	Back wall right side	0	1	#N/A	#N/A	#N/A
DANGJIN	Back wall center	0	1	#N/A	#N/A	#N/A
DANGJIN	Back wall left side	0	1	#N/A	#N/A	#N/A

Fig.34 : Table of the number of overcoating of several plants

TARGET			0	4			
X-AXIS							
Target SCP (ton/m^2)			10000	10000			
Tarsus NOMFB			0	57	81	#VALEUR!	#VALEUR!
Tarsus SCP (ton/m^2)			0	4308	5677	0	0
Llavallol NOMFB			0	47	#VALEUR!	#VALEUR!	#VALEUR!
Llavallol SCP (ton/m^2)			0	3878	0	0	0
Bergisch TEL NOMFB			0	53	57	#VALEUR!	#VALEUR!
Bergisch TEL SCP (ton/m^2)			0	6040	6234	0	0
Dangjin NOMFB			0	57	#VALEUR!	#VALEUR!	#VALEUR!
Dangjin SCP (ton/m^2)			0	7386	0	0	0

Fig.35 : Table of the number of months from beginning and specific cumulated pull of several plants

On the same way as for the electrical furnaces, on the first table, the formulas written from the second column are of the type "=SI(link=0;#N/A;link)" to return #N/A instead of 0 if the value is 0. The second table uses the links as they are, without further formula.

It is visible that, on the first table there is one column more which concerns the zone of the furnace. On the top of this column, on the green cell where "ZONE" is written, a filter is set up and it works on the same way than the filter on the "PLANTS" cell. The user clicks on the arrow at the right of the cell and choose thanks to check boxes the zone he wants to display on the plot. These two filters work together, so the user can choose which plants he wants to compare and on which zone he wants to compare them.

In the second table, in addition to the values of the x-axis of the different plants, there are two rows concerning the "Target". Indeed, for the flame furnaces, it has been observed that their lifetime allows to reach more or less 10 000 ton/m^2 of specific cumulated pull. Obviously, some plants finish the campaign over this value and other finish it under this value but 10 000 ton/m^2 is an average value which has been chosen to be a target value to reach for the flame furnaces. So, it is interesting to display a vertical bar on the plot of the number of overcoating against the specific cumulated pull to represent this target and be able to see quickly what is the overcoating situation of the different plants with respect to this target. To create this horizontal bar, on the third row "Target SCP (ton/m^2)" of the second table are present the values of the x-axis of this bar which are two times 10 000. On the first row of this table, there are the values of the y-axis of the target bar which are 0 and 4. These values are written as they are, without any formula because they are not intended to change in function of the values written in the wear measurement file. 4 has been chosen because this is a value a little bit greater than the maximum number of overcoating of the flame furnaces. In this way, there are two points (10 000 ; 0) and (10 000 ; 4) which are connected, creating a vertical bar. The values of the y-axis are written on the second table, normally dedicated to the x-axis values because this bar is not intended to be filtered and should always appear on the plot. Since, the filters act on the first table, it was better not to put it in the first table. The row of the y-axis values has been, however, put on the first row, before the indiction "X-AXIS" to indicate that these values are different than the other values of the table. Since the specific pull rate is different for all the plants, it was not possible to calculate a common target lifetime in months to display it on the plot against the number of months from beginning of campaign.

The curves which can be plotted thanks to the values of these two tables are showed in Fig.36(against the number of months from beginning) and Fig.37. (against specific cumulated pull).

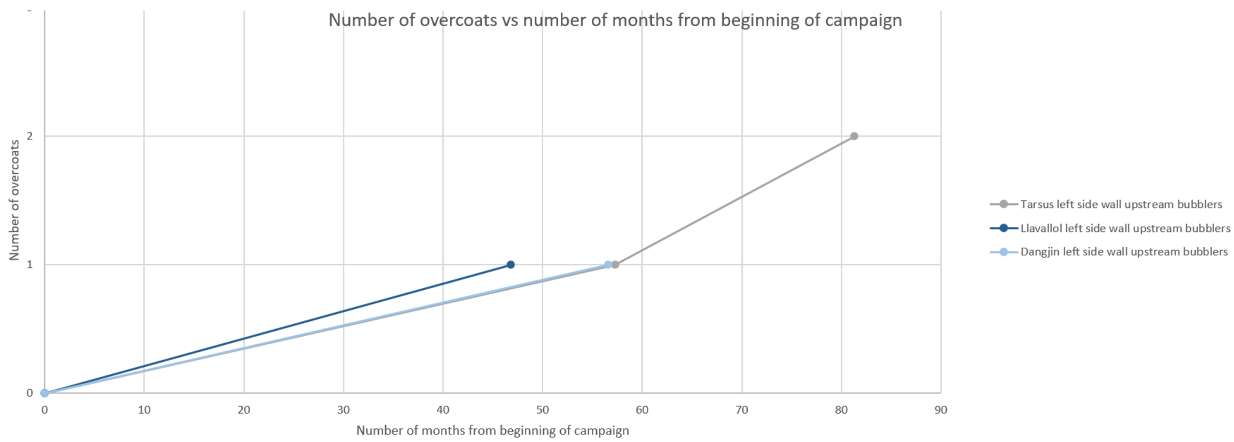


Fig.36 : Number of overcoating on the zone "Left side wall upstream bubblers" vs number of months from beginning of campaign for the plants of Tarsus, Llavallol and Dangjin

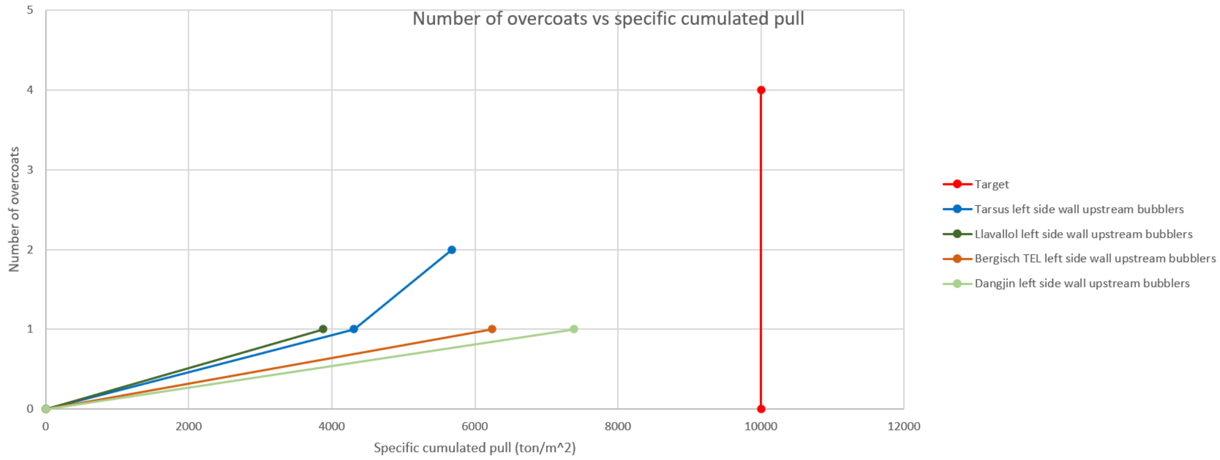


Fig.37 : Number of overcoating of the zone "Left side wall upstream bubblers" vs specific cumulated pull for the plants of Tarsus, Llavallol, Bergisch and Dangjin

On these two plots the same zone (left side wall upstream bubblers) is compared. On the first one, it is visible that the plants of Tarsus and Dangjin are following quite the same overcoating scenario with a first overcoating installed after almost the same number of months after the campaign start. Llavallol, however, has been overcoated earlier. With these informations, it is possible to guess that the scenarios of Tarsus and Dangjin are more standard than the overcoating scenario of Llavallol which could request further investigations to know what are the reasons of this premature overcoating and so, usually, of this faster wear.

On the second plot, the curve of Bergisch has been added to the plot. From the point of view of the specific cumulated pull, Llavallol is always the furnace which is overcoating the most early. But the curves of Tarsus and Dangjin are now well separated. Indeed, Dangjin has been overcoated much later than Tarsus at the production scale. This is the same phenomenon as the one observed for the electrical furnaces, when two plants have not the same specific cumulated pull rate, their curves have not the same disposition the one with respect to the other in the plot against the number of months from beginning and the one against the specific cumulated pull. Here, the four plants are separated in two groups. The ones which have their curves the more at the top left (Llavallol and Tarsus) are the ones which are overcoated earlier from the point of view of the production, and the ones which have their curves the more at the bottom right (Dangjin and Bergisch) are the ones which are overcoated later.

7. Single plant wear curves

The second type of curves that are plotted thanks to the data written in the wear measurement file are curves which are representing the wear of each plant zone by zone. To do that, for each zone, is plotted the evolution of the wear, using the wear values measured during the audits by the team and written in the "Tank wear" sheet. The other curve plotted here is a curve representing the total thickness of refractory available. Indeed, this thickness have an initial value at the beginning of the campaign, and then evolve at each overcoating, with additive layers. Here again, these curves are plotted against the specific cumulated pull, but for the plot in time, it was not necessary to have the number of months from beginning of campaign on the x-axis because they are not curves for comparison between plants. So, for the plot against time, the x-axis is simply the date. The values used to plot these curves and the curves themselves are located on the wear measurement file to be directly accessible for the user after having filled new data on the “Tank wear” sheet. They are on the same sheet than the “Number of overcoating” table. This sheet is called “Graphs tank” because it concerns the tankwall.

7.1. Electrical furnaces

The blocks of the electrical furnaces have been separated in two categories. There are the blocks near the electrodes and the blocks away from the electrodes. Indeed, a difference in the wear rate is observed between these two categories so it is relevant to separate them, but apart from that separation, the wear rate is quite homogeneous. For each category, the point taken as value for the curve is the maximum wear measured on this category of block for each audit date. In addition of these two curves, a “Total” curve is also plotted and take as values the maximum wear measured on all the blocks of the furnace at each date of audit.

Once again, tables containing the values used to plot the curves have been created. The table containing the y-axis values is showed in Fig.38 and the table containing the x-axis values is showed in Fig.39.

ZONE									
Total	0	25	20	80	100	90	85	150	345
Blocks near the electrodes	0	20	#N/A	#N/A	75	#N/A	#N/A	#N/A	270
Blocks away from the electrodes	0	25	20	80	100	90	85	150	345
Total thickness	400	400	575	#N/A	#N/A	#N/A	#N/A	575	

Fig.38 : Table of the y-axis values for the plant of Vamdrup

X-AXIS										
Date wear		20/07/2015	15/03/2017	12/09/2017	23/10/2018	03/02/2020	10/11/2020	09/11/2021	29/08/2022	07/12/2023
Date total thickness		20/07/2015	30/01/2023	31/01/2023	#N/A	#N/A	#N/A	#N/A	07/12/2023	
NOMFB wear		0	20	26	39	55	64	76	85	101
SCP wear (ton/m^2)		0	1294	1647	2524	3597	4184	5056	5709	6640
SCP total thickness (ton/m^2)		0	6016	6016	0	0	0	0	6640	

Fig.39 : Table of the x-axis values for the plant of Vamdrup

On the table of the y-axis values, the green cell on the top left is a filter which allows to choose which zone will be displayed on the plot. Then, the rows “Total”, “Blocks near the electrodes” and “Blocks away from the electrodes”, in which are calculated the maximum values of the wear measured at each audit date, are visible. On the row “Total thicknes” are calculated the values of the total thickness of overcoat material at several key moments.

On the table of the x-axis value, the row “Date wear” correspond to the audit dates. These values are the x-axis values of the wear curves on the plot against the date. The row “Date total thickness” correspond to the date of overcoating or the day just after. These values are the x-axis value of the curve of total thickness on the plot against the date. The row “SCP wear (ton/m^2)” correspond to the values of the specific cumulated pull at the audit date. These values are the x-axis values of the wear curves on the plot against the specific cumulated pull. The row “SCP total thickness (ton/m^2)” correspond to the values of the specific cumulated pull at the dates of the row “Date total thickness”. These values are the x-axis values of the curve of total thickness on the plot against the specific cumulated pull. Finally, the row “NOMFB wear” correspond to the number of months passed from the beginning of campaign at each audit date. It is calculated with the same method used in the tables of the overcoating curves. This row is useless to plot these wear curves for a single plant but it will be used to plot comparisons wear curves between plants.

7.1.1. Calculation of the values of the “Date wear” row

The value on the first column must be the starting date of campaign. So this cell is filled thanks to the formula:

=SI(ESTNUM('Cold data'!B$2);'Cold data'!B$2;#N/A)

In this formula, “'Cold data'!B$2” is the starting date, to return the starting date if it is indicated in the “Cold data” sheet, and “#N/A” otherwise.

Then, since the audit date are already filled in the “Synthesis” sheet, in the other columns it is possible to write a formula like:

=SI(ESTNUM(Synthesis!C1);Synthesis!C1;#N/A)

This is the example in the column framed in red in Fig.39, where “Synthesis!C1” is the first date of audit. Always in order not to have values which will be considered by Excel as 0 if there is no value, this formula returns “#N/A” if the audit date is not indicated.

7.1.2. Calculation of the values of the “SCP wear (ton/m^2)” row

On the first column of this row, “0” is written because at the starting date of the campaign, the specific cumulated pull is zero.

Then, as well as the audit dates, the specific cumulated pull at each audit date is already calculated in the “Synthesis” sheet. So, in the other columns it is enough to write a formula like:

=SI(Synthesis!C3=0;#N/A;Synthesis!C3)

It is the example in the column framed in red. On the same way this formula returns “#N/A” if the specific cumulated pull at this date is equal to 0.

7.1.3. Calculation of the values of the “Date total thickness” row

On the first column of this row, there is the starting date of the campaign which is written thanks to the same formula than in the row “Date wear”.

Then, starting from the second column, on one cell over two are written the overcoating dates thanks, for example in the column framed in red where is written the first date of overcoating, to the formula:

=SI(ESTNUM('Tank wear'!R2);'Tank wear'!R2;#N/A)

On the cell just at the right of the overcoating date are calculated the day after the each overcoating date thanks, for example in the cell framed in blue, to the formula:

=D39+1

Here “D39” is the first overcoating date so the day after this date is returned. There is no need to write in the formula to return “#N/A” if this date does not exist because if the overcoating date is not indicated its cell in this table will already be “#N/A”, so the formula will become “=#N/A+1” and “#N/A” will be returned.

Finally, the last value of this row needs to be the maximum of all the dates (audit dates and overcoating dates). Indeed, if the later existing date is an audit date, the total thickness curve can be extended until this date if this date is returned in this last cell of the row. But, if the later date is an overcoating date, the total thickness will already have a point with this maximum date and will go back to an earlier date (which is not wanted) if the maximum audit date is returned in this cell (because in this case it is the maximum audit date but not the maximum date overall). That is why, the date written in this cell must be the later date overall (audit and overcoating combined). To obtain it, the formula is:

=MAX(MAX.SI.ENS(C38:AA38;C38:AA38;"<>#N/A");MAX.SI.ENS(C39:I39;C39:I39;"<>#N/A"))”

“MAX.SI.ENS(C38:AA38;C38:AA38;"<>#N/A")” returns the later audit date without considering the “#N/A” values. “MAX.SI.ENS(C39:I39;C39:I39;"<>#N/A")” returns the later overcoating date without considering the “#N/A” values. The whole formula returns the later date between these two dates.

7.1.4. Calculation of the values of the “SCP total thickness (ton/m^2)” row

On the first column of this row, “0” is written because at the start of the campaign the specific cumulated pull is equal to 0.

On all the other columns, the values are calculated on the same way than the cumulated pull has been calculated on the “Synthesis” sheet. To obtain the specific cumulated pull at a date D, it is just necessary to adapt the equation (1) :

$$Specific\ cumulated\ pull = \sum_{Starting\ date}^{Date\ D} Tons\ of\ glass\ produced\ by\ m^2 \qquad (7)$$

In this case, the dates considered are the ones from the row “Date total thickness” so, in the column framed in red for example, the Excel formula to traduce the equation (7) is:

=SOMME.SI('K2'!$C1:$KW1;"<"&D39;'K2'!$C6:$KW6)/'Cold data'!$B1”

7.1.5. Calculation of the values of the “Total” row

Switching now to the y-values table, the values of the first column of the “Total”, “Blocks near the electrodes” and “Blocks away from the electrodes” rows are 0 because, at the start of the campaign, the wear is zero.

Regarding the other columns, the maximum wear on all the tankwall at each audit date is already calculated on the “Synthesis” sheet, so these cells can be filled, for example in the column framed in green in Fig.38, thanks to a formula like:

=SI(Synthesis!C7=0;#N/A;Synthesis!C7)

7.1.6. Calculation of the values of the “Blocks near the electrodes” row

The formula used to calculate the maximum wear of the blocks near the electrodes at each audit date is, for example in the column framed in green:

=SI(SOMME('Tank wear'!AQ196:AQ215;'Tank wear'!AQ276:AQ305;'Tank wear'!AQ326:AQ355;'Tank wear'!AQ416:AQ435;'Tank wear'!AQ646:AQ665;'Tank wear'!AQ736:AQ755;'Tank wear'!AQ816:AQ835;'Tank wear'!AQ906:AQ925)=0;#N/A;MAX('Tank wear'!AQ196:AQ215;'Tank wear'!AQ276:AQ305;'Tank wear'!AQ326:AQ355;'Tank wear'!AQ416:AQ435;'Tank wear'!AQ646:AQ665;'Tank wear'!AQ736:AQ755;'Tank wear'!AQ816:AQ835;'Tank wear'!AQ906:AQ925))

The condition “SOMME('Tank wear'!AQ196:AQ215;'Tank wear'!AQ276:AQ305;'Tank wear'!AQ326:AQ355;'Tank wear'!AQ416:AQ435;'Tank wear'!AQ646:AQ665;'Tank wear'!AQ736:AQ755;'Tank wear'!AQ816:AQ835;'Tank wear'!AQ906:AQ925)=0” verifies if the sum of the wear measured on the blocks near the electrodes is equal to 0. If it is the case, the formula returns “#N/A” because it would mean that no value of wear on these blocks is indicated at this date. If it is not the case, the formula returns the maximum of these values thanks to the part “MAX('Tank wear'!AQ196:AQ215;'Tank wear'!AQ276:AQ305;'Tank wear'!AQ326:AQ355;'Tank wear'!AQ416:AQ435;'Tank wear'!AQ646:AQ665;'Tank wear'!AQ736:AQ755;'Tank wear'!AQ816:AQ835;'Tank wear'!AQ906:AQ925)”. The cells ranges written in the “SOMME” and “MAX” functions are the cells corresponding to the wear of the blocks near the electrodes in the “Tank wear” sheet.

7.1.7. Calculation of the values of the “Blocks away from the electrodes” row

The calculation of the values of this row is performed with the same formulas as for the values of the “Blocks near the electrodes” row. The only difference is that the cells ranges written inside the functions are the cells corresponding to the wear of all the other blocks.

7.1.8. Calculation of the values of the “total thickness” row

This row must contain the values of the total overcoat material thickness at the dates of the row “Date total thickness”, without considering the wear. The layers considered to calculate this total thickness are the CIP layer, the main tankwall layer, the initial overcoating layer if there is one, and all the overcoating layers installed during the campaign if the studied date is later than the date of their installation. So the equation of the total thickness is :

$$Total\ thick. = CIP + Tankwall + Initial\ overcoating + \sum Overcoating\ installed \qquad (8)$$

The formula to translate it in Excel is, for example in the column framed in green:

=SI(ESTNUM(C39);'Tank wear'!$E6+'Tank wear'!$G6+SI('Tank wear'!$I5="Overcoat";'Tank wear'!$I6;0)+SI(C39>'Tank wear'!$AH2;SOMME(SI('Tank wear'!$AO5="Overcoat";'Tank wear'!$AO6;0);SI('Tank wear'!$AM5="Overcoat";'Tank wear'!$AL6;0);SI('Tank wear'!$AK5="Overcoat";'Tank wear'!$AK6;0);SI('Tank wear'!$AI5="Overcoat";'Tank wear'!$AI6;0));SI(C39>'Tank wear'!$Z2;SOMME(SI('Tank wear'!$AG5="Overcoat";'Tank wear'!$AG6;0);SI('Tank wear'!$AE5="Overcoat";'Tank wear'!$AE6;0);SI('Tank wear'!$AC5="Overcoat";'Tank wear'!$AC6;0);SI('Tank wear'!$AA5="Overcoat";'Tank wear'!$AA6;0));SI(C39>'Tank wear'!$R2;SOMME(SI('Tank wear'!$Y5="Overcoat";'Tank wear'!$Y6;0);SI('Tank wear'!$W5="Overcoat";'Tank wear'!$W6;0);SI('Tank wear'!$U5="Overcoat";'Tank wear'!$U6;0);SI('Tank wear'!$S5="Overcoat";'Tank wear'!$S6;0));0)));#N/A)

To check if an initial overcoating is installed, a condition verifies if “Overcoat” is written in the cell on top of the column dedicated to this initial overcoating in the “Tank wear sheet. This is done in the part “SI('Tank wear'!$I5="Overcoat";'Tank wear'!$I6;0)”. If the condition is true, it adds the thickness of this layer, and if it is false it adds 0. In the following of this formula, there are conditions to find the last overcoating date which is still earlier than the date considered in the “Date total thickness” row. Once this date is found, conditions verify for each layer at this date if “Overcoat” is written on the top of the column of this layer and add its thickness if it is true and 0 if it is false.

7.1.9. The “Overcoat materials” row

Another requirement for these curves is to write on the total thickness curve the material used for each overcoating. In this way, when an overcoating is installed, the total thickness increase and it is possible to know which is the material of the layer added, just looking at the curve. The main tankwall material should also be displayed at the beginning of the curve.

Overcoat materials		Serv 50 DCX	ER1681				

Fig.40 : "Overcoat material" row of the plant of Vamdrup

On Excel, it is possible to do that thanks to data labels. These data labels get their values from a new row called "Overcoat materials" (Fig.40). To work correctly, each material must be on the exact same column than its installation date. That is why, on the first column corresponding to the starting date of the campaign, the formula used to write the main tankwall material if it is indicated, is:

=SI(ESTVIDE('Tank wear'!F6);"";'Tank wear'!F6)

On the second column, which correspond to the first date of overcoating, the function "SI.CONDITIONS" is used. This function allows to verify several conditions, to return the value associated to the first true condition, and to stop the function. Here, the conditions check, for each layer written on the first overcoating date, if "Overcoat" is written on top of their columns to verify if this layer exists and is not an insulation layer. If this is true, it returns the material of this layer. The conditions and their associated values are written starting from the outermost layer and going more and more to the inside. In this way, the formula returns, for each date, the material of the outermost overcoating layer, which is the last one installed, and so the one installed at the relevant date. The formula written in the second column is:

=SI.CONDITIONS('Tank wear'!X5="Overcoat";'Tank wear'!X6;'Tank wear'!V5="Overcoat";'Tank wear'!V6;'Tank wear'!T5="Overcoat";'Tank wear'!T6;'Tank wear'!R5="Overcoat";'Tank wear'!R6;VRAI;"")

Then, the same formula is written on one column over two for the second and third overcoating date because these dates are present on one column over two on the "Date total thickness" row which determines the x-axis value of the total thickness curve. The only thing which changes in the formula is the columns considered in the "Tank wear" sheet, which are adapted to each date.

7.1.10. Plotting of the curves

Once all these data are calculated, it is possible to plot the curves. The plot of the wear of the blocks near and away from the electrodes and of the total thickness against the date is showed on Fig.41. The same plot against the specific cumulated pull is showed on Fig.42.

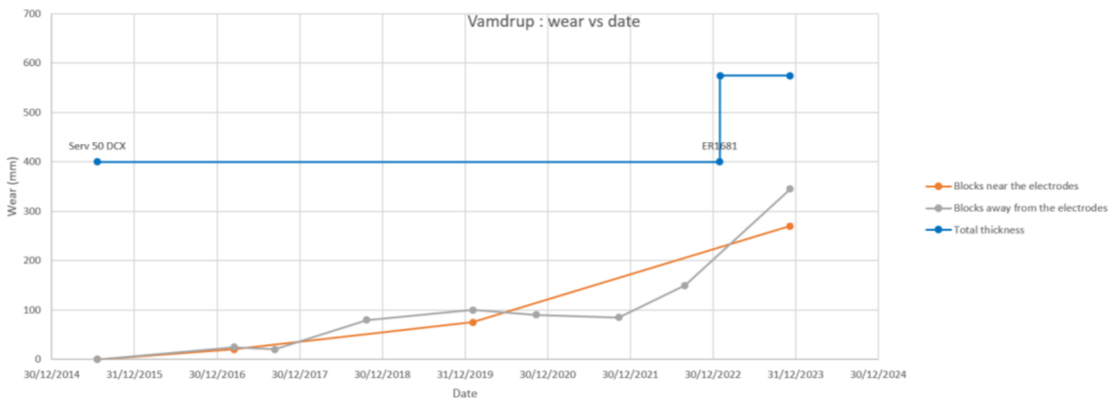


Fig.41 : Wear and total thickness curves vs date for the plant of Vamdrup

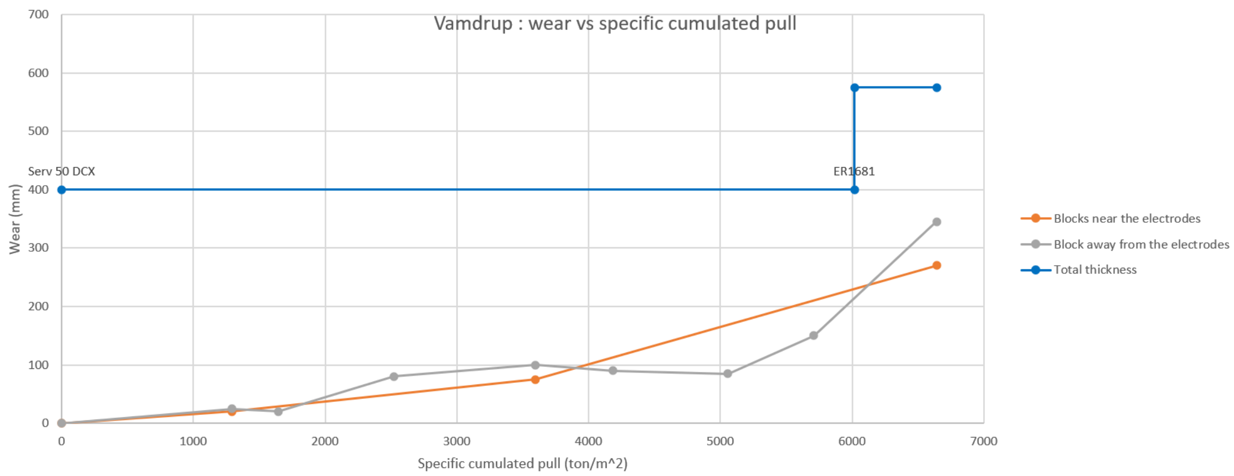


Fig.42 : Wear and total thickness curves vs specific cumulated pull for the plant of Vamdrup

These plots show the wear which is increasing in time and the date at which a overcoating layer is installed, but it is also possible to see the remaining thickness which take into account the wear. Indeed, the remaining thickness of the tankwall correspond to the space between the total thickness curve and the wear curves. At the beginning of the campaign the space corresponds to the initial thickness of the tankwall, then the wear increases and this space decreases because the wear reduce the thickness of the blocks. When an overcoat is installed, the total thickness curve increases suddenly and so is doing the space between the curves. This space is the more important data of this plot for the Melting TA team because if it is too small, it means that a glass leakage could happen soon and that an overcoating should be installed quickly. The main goal is that the wear curves must not reach the total thickness curve. To summarize, these plots can be seen like a section plane of the tankwall with the material located between the total thickness and the wear curves, the glass which touch the tankwall under the wear curves, and the outside of the furnace above the total thickness curve. This section plan evolves in time and is updated at each audit or overcoating date.

The point of having the overcoating date and the day after as x-axis value of the total thickness curve is seen here. Indeed, if only the overcoating date was present, the plot would have connected the two points (Starting date ; Initial thickness) and (Overcoating date ; Thickness after the overcoating) by an oblique bar which would not have been relevant to represent the total thickness of the tankwall. Indeed, the thickness does not increase regularly between the starting date and the overcoating date, but stays equal from the starting date until the overcoating date, and increases suddenly, by the value of the thickness of the layer added, at the overcoating date. So a point is needed at the overcoating date to obtain an horizontal bar between the starting date and the overcoating date, and another point is required just on the day after the overcoating date to obtain a vertical bar between the thickness value before the overcoating and the thickness value after the overcoating.

The results given by the data labels are also visible on these plots. Thanks to them, it is easy to see that the main material of the tankwall is SERV 50 DCX and the material of the layer added at the first overcoating is ER 1681.

7.2. Flame furnaces

The same type of curves is plotted for the flame furnaces but there are some differences. First, on the flame furnaces, there are several zones which have different wear rate so one wear curve by zone must be plotted. The zones used here are the ones already defined. Also, each one of these zones can be overcoated at a different date on a flame furnace, so one total thickness curve by zone also must be plotted. Another difference is that a curve of the average value of wear for each zone at each audit date is plotted in addition to the curve of the maximum value. Moreover, as well as in the overcoating plots, a red vertical bar representing the target is displayed on the plot against the specific cumulated pull at 10 000 ton/m². This time, it is also possible to calculate the date at which 10 000 ton/m² is reached because only one plant is considered, so an estimation based on its specific cumulated pull rate is achievable. Finally, prediction curves regarding the future maximum and average wear, and the total thickness are also created. These prediction curves have not been done for the electrical furnaces because the Melting TA already have a file that calculate the future predictive wear of the electrical furnaces thanks to a model which considers several parameters.

The add of average and prediction curves, in addition to the fact that there are a lot of zones, lead to tables much bigger to calculate the data used to plot the curves.Because it can not be displayed in a single figure and for a better understanding, it will be showed part by part with the explanations of the calculations of the different parts. The table of the y-axis values contains for each zone six different rows for the maximum wear measured at each audit date, the average wear measured at each audit date, the total thickness updated at each overcoating date, the maximum wear prediction, the average wear prediction, and the total thickness prediction. In addition to that, there are also four rows for the maximum and the average wear measured on the total of the blocks of the furnace, and for the prediction of these maximum and average wear. On the x-axis table, there are rows for the audit dates, the overcoating dates, the specific cumulated pull at each audit dates, the specific cumulated pull at each overcoating date, and the number of months from beginning corresponding to each audit dates which will be used later for comparison curves. In addition to that, there are also one row to calculate the x-axis values of the maximum wear prediction curves, and one row for the average, for each zone and for the total of the blocks, of the plot against the date and the date and the plot against the specific cumulated pull. Moreover, there are one row to calculate the x-axis value of the total thickness prediction curve for each zone, for the plot against the date and for the one against the specific cumulated pull. In addition to these two tables, there are also a table to calculate the data useful to plot the target bar and a table filled with the materials of each overcoating, used to display it on the data labels on the plot.

To begin, the five first rows of the x-axis table showed in Fig.43 are calculated in the exact same way than for the electrical furnaces. The only thing which varies is the name of the column. Indeed, the x-axis of the wear curves are now named “Date max/mean”, “NOMFB max/mean” and “SCP max/mean (ton/m²)” to indicate that they are used for the average wear curves as well as for the maximum wear curves.

X-AXIS										
Date max/mean			04/04/2017	05/04/2019	18/10/2019	13/02/2020	19/06/2020	23/11/2020	12/02/2021	0
Date total thickness			04/04/2017	11/01/2022	12/01/2022	13/01/2024	14/01/2024	#N/A	#N/A	
NOMFB max/mean			0	24	30	34	39	44	46	
SCP max/mean (ton/m^2)			0	2030	2421	2666	2884	3267	3487	
SCP total thickness (ton/m^2)			0	4308	4308	5677	5677	0	0	

Fig.43 :Five first rows of the table of the x-axis values for the plant of Tarsus

7.2.1. Calculation of the y-axis values of the maximum wear, average wear and total thickness curves

	Prediction		ZONES	CRITERION WEAR (mm)					
mm/year before	Pivot date	mm/year after	Total	Max	0	105	135	150	1
	#N/A		Total	Max prediction	292	292	#N/A		
mm/year before	Pivot date	mm/year after	Total	Mean	0	49	57	68	
	#N/A		Total	Mean prediction	192	250	#N/A		
mm/year before	Pivot date	mm/year after	Back wall left corner	Max	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Back wall left corner	Max prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Back wall left corner	Mean	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Back wall left corner	Mean prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Left side wall upstream doghouse	Max	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Left side wall upstream doghouse	Max prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Left side wall upstream doghouse	Mean	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Left side wall upstream doghouse	Mean prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Left doghouse corner block upstream	Max	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Left doghouse corner block upstream	Max prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Left doghouse corner block upstream	Mean	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Left doghouse corner block upstream	Mean prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Side wall left doghouse	Max	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Side wall left doghouse	Max prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Side wall left doghouse	Mean	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Side wall left doghouse	Mean prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Left doghouse corner block downstream	Max	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Left doghouse corner block downstream	Max prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Left doghouse corner block downstream	Mean	0	#N/A	#N/A	#N/A	#N/A
	#N/A		Left doghouse corner block downstream	Mean prediction	#N/A	#N/A	#N/A		
mm/year before	Pivot date	mm/year after	Left side wall downstream doghouse	Max	0	#N/A	#N/A	70	
	#N/A		Left side wall downstream doghouse	Max prediction	255	255	#N/A		
mm/year before	Pivot date	mm/year after	Left side wall downstream doghouse	Mean	0	#N/A	#N/A	50	
	#N/A		Left side wall downstream doghouse	Mean prediction	215	250	#N/A		
mm/year before	Pivot date	mm/year after	Left side wall upstream bubblers	Max	0	89	117	100	1
	#N/A		Left side wall upstream bubblers	Max prediction	287	287	#N/A		
mm/year before	Pivot date	mm/year after	Left side wall upstream bubblers	Mean	0	48	57	68	
	#N/A		Left side wall upstream bubblers	Mean prediction	226	250	#N/A		
mm/year before	Pivot date	mm/year after	Left side wall bubblers	Max	0	61	72	50	

Fig.44 : Upper part of the y-axis values table of the plant of Tarsus

As it is showed in Fig.44, the rows regarding the y-axis values of the max and mean wear curves are located alternating with their y-axis data for the prediction curves.

The way of calculating the y-axis values of the max wear curves is the same than the one used for the electrical furnaces, only taking care of calling the cells corresponding to the good zone in the functions. To calculate the y-axis values of the mean wear curve, alwaysthe formula is used but substituting the function “MAX” by the function “MOYENNE”. This gives for example in the cell framed in red in Fig.44:

=SI(SOMME('Tank wear'!CF215:CF304)=0;#N/A;MOYENNE('Tank wear'!CF215:CF304))

As well as the tankwall total max wear, the tankwall total mean wear is already calculated in the “Synthesis” sheet, so it is possible to fill these cells with a formula like, for example in the cell framed in blue in Fig.44:

=SI(Synthesis!C6="";#N/A;Synthesis!C6)

Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Front wall left corner	Total thickness	250	250	250	250	2
			Front wall left corner	Total thickness prediction	250	250	250	250	2
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Front wall left	Total thickness	250	250	250	250	2
			Front wall left	Total thickness prediction	250	250	250	250	2
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Front wall throat	Total thickness	250	250	250	250	2
			Front wall throat	Total thickness prediction	250	250	250	250	2
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Front wall right	Total thickness	250	250	250	250	2
			Front wall right	Total thickness prediction	250	250	250	250	2
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Front wall right corner	Total thickness	250	250	250	250	2
			Front wall right corner	Total thickness prediction	250	250	250	250	2
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Right side wall downstream bubblers	Total thickness	250	250	250	250	3
			Right side wall downstream bubblers	Total thickness prediction	250	250	250	250	3
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Right side wall bubblers	Total thickness	250	250	325	325	4
			Right side wall bubblers	Total thickness prediction	250	250	325	325	4
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Right side wall upstream bubblers	Total thickness	250	250	325	325	4
			Right side wall upstream bubblers	Total thickness prediction	250	250	325	325	4
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Right side wall downstream doghouse	Total thickness	250	250	325	325	4
			Right side wall downstream doghouse	Total thickness prediction	250	250	325	325	4
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Right doghouse corner block downstream	Total thickness	250	250	250	250	2
			Right doghouse corner block downstream	Total thickness prediction	250	250	250	250	2
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Side wall right doghouse	Total thickness	250	250	250	250	2
			Side wall right doghouse	Total thickness prediction	250	250	250	250	2
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Right doghouse corner block upstream	Total thickness	250	250	250	250	2
			Right doghouse corner block upstream	Total thickness prediction	250	250	250	250	2
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Right side wall upstream doghouse	Total thickness	250	250	250	250	3
			Right side wall upstream doghouse	Total thickness prediction	250	250	250	250	3
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Back wall right corner	Total thickness	250	250	250	250	2
			Back wall right corner	Total thickness prediction	250	250	250	250	2
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Back wall right side	Total thickness	250	250	325	325	4
			Back wall right side	Total thickness prediction	250	250	325	325	4
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Back wall center	Total thickness	250	250	325	325	4
			Back wall center	Total thickness prediction	250	250	325	325	4
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Back wall left side	Total thickness	250	250	325	325	4
			Back wall left side	Total thickness prediction	250	250	325	325	4

Fig.45 : Lower part of the y-axis values table of the plant of Tarsus

Again, the rows of the y-axis values of the total thickness curves of each zone are alternating with the rows dedicated to the total thickness prediction (Fig.45). These values are calculated in the same way than for the electrical furnaces, except that there is no initial overcoating at the beginning of the campaign, so it is not necessary to add it in the formula, and that in the part which sum the thickness of the overcoating layers, it is needed to take care that the cells called are corresponding to the zone of interest. Without the initial overcoating, the formula of the total thickness for a flame furnace becomes:

$$Totalthick.\text{(flame furnace)} = CIP + Tankwall + \sum Overcoatinginstalled \quad (9)$$

7.2.2. Intermediate tables

To organize a little bit the calculations and to help further calculations, two intermediate tables have been created. The values located in these tables are not considered to plot the curves, but they are used to calculate the data to plot the prediction curves and the target bars. The first of these intermediate tables is showed in Fig.46 and Fig.47 and contains values in front of each y-axis row of max wear, mean wear or total thickness, just filled before.

Last date with measure	Last SCP with measure (ton/m^2)	Last value of the row (mm)
29/04/2024	5853	292
29/04/2024	5853	192
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
#N/A	#N/A	#N/A
29/04/2024	5853	255
29/04/2024	5853	215
29/04/2024	5853	287
29/04/2024	5853	226
29/04/2024	5853	160

Fig.46 : Upper part of the first intermediate table

25/08/2021	3932	250
25/08/2021	3932	250
25/08/2021	3932	250
25/08/2021	3932	250
25/08/2021	3932	250
25/08/2021	3932	325
25/08/2021	3932	400
25/08/2021	3932	400
25/08/2021	3932	400
25/08/2021	3932	250
25/08/2021	3932	250
25/08/2021	3932	250
25/08/2021	3932	325
25/08/2021	3932	250
25/08/2021	3932	400
25/08/2021	3932	400
25/08/2021	3932	400

Fig.47 : Lower part of the first intermediate table

The data corresponding to the max and mean wear rows are on the upper part of this table, whereas the data corresponding to the total thickness rows are on the lower part of this table.

The last value of the row corresponds to the maximum or average of the last values of wear measured for the wear rows, and to the total thickness after the last overcoating date for the total thickness rows. To find the last value of the row and obtain these values, for example in the row framed in red in Fig.46, the formula is:

=INDEX(TRIERPAR(F51:AD51;COLONNE(F51:AD51);-
1);EQUIV(VRAI;INDEX((TRIERPAR(F51:AD51;COLONNE(F51:AD51);-1)<>0);0);0))

Here, the mean calculated the last time that measures were performed is 215 mm so 215 is returned.

The last date with measure is the date corresponding to the last value of the row just calculated. Indeed, wear measurement are not performed on every blocks(and so on every zones) at each audit date, so, for a given zone, the last audit date may not be the last date with measure. Therefore, a formula, which returns the value of the cell of the "Date max/mean" row which is in the same column than the last value of the row, is needed. This formula is, for example in the row framed in red:

=INDEX(TRIERPAR($F$25:$AD$193;COLONNE($F$25:$AD$193);-
1);166;EQUIV(INDEX(TRIERPAR(F51:AD51;COLONNE(F51:AD51);-
1);EQUIV(VRAI;INDEX((TRIERPAR(F51:AD51;COLONNE(F51:AD51);-
1)<>0);0);0));TRIERPAR(F51:AD51;COLONNE(F51:AD51);-1);0))

Here the average wear of 215 mm has been calculated on the measurements performed on the 29/04/2024. For the total thickness rows, the principle is the same but the formula is modified to return a value from the "Date total thickness" row.

In the same way, the last SCP with measure is the specific cumulated pull value corresponding to the last value of the row. For the wear rows, the formula to return the value of the row "SCP max/mean (ton/m²)" which is in the same column than the last value of the row, is for the row framed in red:

=INDEX(TRIERPAR($F$25:$AD$193;COLONNE($F$25:$AD$193);-
1);169;EQUIV(INDEX(TRIERPAR(F51:AD51;COLONNE(F51:AD51);-
1);EQUIV(VRAI;INDEX((TRIERPAR(F51:AD51;COLONNE(F51:AD51);-
1)<>0);0);0));TRIERPAR(F51:AD51;COLONNE(F51:AD51);-1);0))

For the total thickness rows, the value returned is located in the row "SCP total thickness (ton/m²)".

The second intermediate table (Fig.48) contains several data which will be used to calculate the values necessary to plot the prediction curves, but they are also combined together to calculate the "Date to reach 10 000 ton/m²" which is used to plot the target bar on the plot against the date.

Max date	29/04/2024
Number of days missing to reach 10000 ton/m^2	2119
Date to reach 10000 ton/m^2	16/02/2030
Average SP by day on last year ((ton/m^2)/day)	1.96
SCP at max date (ton/m^2)	5853
Number of dates of overcoating	2

Fig.48 : Second intermediate table of the plant of Tarsus

The max date is the last date of audit. To obtain it the formula used is:

=MAX.SI.ENS(F190:AD190;F190:AD190;"<>#N/A")

It returns the maximum of the row "Date max/mean", in which are written the audit dates, without considering the "#N/A". For the plant of Tarsus, this date is 29/04/2024.

The SCP at max date is the specific cumulated pull value at the last audit date. The principle is the same so the formula to return in this cell the maximum of the row "SCP max/mean" without considering the "#N/A" is:

=MAX.SI.ENS(F193:AD193;F193:AD193;"<>#N/A")

In Tarsus, this value is 5 853 ton/m².

Then, it has been decided to calculate the average specific pull (SP) by day on the last year, in order to make an estimation of the specific cumulated pull evolution, considering that this average value will be the same in the future. The monthly pull is available in the "K2" sheet, the melting area is written in the "Cold data" sheet. Naming M the last month for which values are available, the average specific pull by day on the last year can be calculated as following:

$$Average\ SP\ by\ day\ on\ the\ last\ year = \frac{\left(\frac{\left(\frac{\sum_{M-12}^{M} Monthly\ specific\ pull}{12}\right)}{Melting\ area}\right)}{Average\ number\ of\ days\ in\ one\ month} \tag{10}$$

It is necessary to divide by the average number of days in one month to obtain the average specific pull by days instead of by month. This value has already been calculated (6) and is equal to 30,4375. In Excel, the sum of the monthly specific pull divided by 12 can be replaced by the function “MOYENNE” so the complete formula is:

=(MOYENNE(INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0));INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+1);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+2);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+3);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+4);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+5);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+6);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+7);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+8);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+9);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+10);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1)<>0);0);0)+11);INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-
1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-1)<>0);0);0)+12))/'Cold
data'!$B$1)/30.4375”

In this formula, “INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-1)<>0);0);0))” returns the pull on the last month for which data are available. Then, by writing “+n” at the end of this part, the value for the n-th month, starting by the last one, is returned. For example “INDEX(TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-

1);EQUIV(VRAI;INDEX((TRIERPAR('K2'!C6:JZ6;COLONNE('K2'!C6:JZ6);-1)<>0);0);0)+4)" returns the pull on the fourth month, starting from the last one, for which the data are available.For Tarsus the average specific pull by days on the last year is 1,96 (ton/m²)/day.

Once this value is known, it is possible to calculate the number of days missing to reach 10 000 ton/m² of specific cumulated pull. The equation to obtain it is:

$$Number\ of\ days\ missing\ to\ reach\ 10\,000\,\frac{ton}{m^2} = \frac{(10\,000 - SCP\ at\ \max date)}{Average\ SP\ by\ day\ on\ last\ year} \quad (11)$$

On Excel, this formula is written:

=(10000-AK32)/AK30

In Tarsus, 2 119 days are missing to reach 10 000 ton/m² of specific cumulated pull.

Now, the max date and the number of days missing to reach 10 000 ton/m² are summed. In this way, the date at which 10 000 ton/m² will be reached, if the average pull rate remains stable until this moment, is calculated:

$$Date\ to\ reach\ 10\,000\,\frac{ton}{m^2} = Max\ date + Number\ of\ days\ missing\ to\ reach\ 10\,000\,\frac{ton}{m^2} \quad (12)$$

In Tarsus, the target of 10 000 ton/m² should be reached the 16/02/2030. This date will be used to plot the target bar in the plot against the date.

The last value calculated in this second intermediate table is the number of dates of overcoating. This data will be used to plot the total thickness prediction curves. To calculate that, the function is:

=SI.CONDITIONS(ESTNUM('Tank wear'!BP2);4;ESTNUM('Tank wear'!BA2);3;ESTNUM('Tank wear'!AL2);2;ESTNUM('Tank wear'!W2);1)

It verifies if each cell which can contain a date of overcoating is a number, which would mean that an overcoating has been performed. It starts from the cell dedicated to the last overcoating and returns 4 if this cell is a number, otherwise 3 if the cell dedicated to the third overcoating is a number and so on. In Tarsus, two overcoatings has been performed so the formula has returned 2.

7.2.3. Calculation of the target data

The data used to plot the target bar are the target date and the target SCP which will be used as x-axis values, and the target value which will be used as y-axis values. Once again, these target data are calculated in a separate table (Fig.49) because the target bar must be always displayed on the plot and should not be affected by the filter.

Date target			16/02/2030	16/02/2030
SCP target (ton/m^2)			10000	10000
Target value			0	500

Fig.49 : Target data table of the plant of Tarsus

The classic target for a flame furnace is 10 000 ton/m² of specific cumulated pull, and the date at which this target will be reached has been calculated. But, if the user, thanks to his experience, thinks that the end date of campaign will be another, or if he wants to see how it goes with another target date, he can modify it in the third row of a dedicated table displayed in Fig.50.

Change slope of prediction when it remain	150	mm
Overcoat to be installed when it remains	75	mm
Target date (if different from 10k ton/m^2)		

Fig.50 : Table to change the parameters

In the "Date target" row of the target data table the same date is returned two time to have two points. If a date is written in the green cell of the third row of the table in Fig.50, this date is returned, otherwise the predictive date calculated before, at which 10 000 ton/m² of specific cumulated pull will be reached, is returned. To verify it the function "ESTNUM" is used and the formula is:

=SI(ESTNUM(E22);E22;AK28)

In the "SCP target (ton/m²)" row, the predictive specific cumulated pull at the target date displayed in the "Date target" row, no matter if another target date is written in the third row of the table in Fig.50 or not. The formula to calculate it is:

$$SCP\ target = SCP\ at \max date + Average\ SP\ by\ day\ on\ last\ year \times (Target\ date - \mathrm{Max}\, date) \quad (13)$$

So, if no other target date is written, 10 000 is returned because the date at which 10 000 ton/m² will be reached is the date in the "Date target" row. Otherwise, if a new target date is written, this date is returned in the "Date target" row, and the predictive specific cumulated pull at this date is returned in the "SCP target (ton/m²)" row, like in the example showed in Fig.51. In this example, "25/06/2033" has been chosen as the new target date and the predictive specific cumulated pull at this date, which is 12 397 ton/m², is returned in the "SCP target (ton/m²)" row.

Date target			25/06/2033	25/06/2033
SCP target (ton/m^2)			12397	12397
Target value			0	500

Fig.51 : Target data table if "25/06/2033" is written as the new target date for the plant of Tarsus

Regarding the "Target value" row, "0" and "500" have been directly written. 500 has been arbitrarily chosen because it is a little bit above the maximum wear measured in a whole campaign.

7.2.4. Calculation of the wear prediction curves data

The y-axis values of the wear prediction curves are displayed in Fig.44, alternating with the data of the measured wear curves. The x-axis values of the wear prediction curves for the plot against the date are showed in Fig.52.

Date total max prediction			29/04/2024	#N/A	16/02/2030
Date total mean prediction			29/04/2024	#N/A	16/02/2030
Date BWLC max prediction			#N/A	#N/A	16/02/2030
Date BWLC mean prediction			#N/A	#N/A	16/02/2030
Date LSWUD max prediction			#N/A	#N/A	16/02/2030
Date LSWUD mean prediction			#N/A	#N/A	16/02/2030
Date LDCBU max prediction			#N/A	#N/A	16/02/2030
Date LDCBU mean prediction			#N/A	#N/A	16/02/2030
Date SWLD max prediction			#N/A	#N/A	16/02/2030
Date SWLD mean prediction			#N/A	#N/A	16/02/2030
Date LDCBD max prediction			#N/A	#N/A	16/02/2030
Date LDCBD mean prediction			#N/A	#N/A	16/02/2030
Date LSWDD max prediction			29/04/2024	#N/A	16/02/2030
Date LSWDD mean prediction			29/04/2024	#N/A	16/02/2030
Date LSWUB max prediction			29/04/2024	#N/A	16/02/2030
Date LSWUB mean prediction			29/04/2024	#N/A	16/02/2030
Date LSWB max prediction			29/04/2024	#N/A	16/02/2030
Date LSWB mean predicition			29/04/2024	#N/A	16/02/2030
Date LSWDB max prediction			29/04/2024	#N/A	16/02/2030
Date LSWDB mean prediction			29/04/2024	#N/A	16/02/2030
Date FWLC max prediction			#N/A	#N/A	16/02/2030
Date FWLC mean prediction			#N/A	#N/A	16/02/2030
Date FWL max prediction			#N/A	#N/A	16/02/2030
Date FWL mean prediction			#N/A	#N/A	16/02/2030
Date FWT max prediction			#N/A	#N/A	16/02/2030
Date FWT mean prediction			#N/A	#N/A	16/02/2030
Date FWR max prediction			#N/A	#N/A	16/02/2030
Date FWR mean prediction			#N/A	#N/A	16/02/2030
Date FWRC max prediction			#N/A	#N/A	16/02/2030
Date FWRC mean prediction			#N/A	#N/A	16/02/2030
Date RSWDB max prediction			29/04/2024	#N/A	16/02/2030
Date RSWDB mean prediction			29/04/2024	#N/A	16/02/2030
Date RSWB max prediction			29/04/2024	#N/A	16/02/2030
Date RSWB mean prediction			29/04/2024	#N/A	16/02/2030

Fig.52 : Table of the x-axis values of the wear prediction curves for the plot against the date of the plant of Tarsus

Since there is a curve for each zone, there are values for each zone with both the max and the mean curves. Each time, there are three values per axis. In the x-axis table, the initials of the zones has been written to prevent having too large cells.

The first values of the x and y-axis are respectively the last date with measure and the last value of the row of the corresponding measured wear curve, in order for the predictive curve to start at the last point of the measured wear curve. These data are available in the first intermediate table. So, for example, in the row framed in red in Fig.52, the formula used to return the last date with measure is:

=AF53

This date is the 29/04/2024. In the row framed in green in Fig.44, the formula used to return the last value of the corresponding row, which is the row just above, is:

=AH51

The calculation of the predictive wear for the flame furnace is based on the following principle: the predictive future wear is linear until the moment at which 150 mm of thickness is remaining, and starting from this point, the wear is still linear but with a smaller rate (approximately divided by 2 but it is not an obligation). This reduction is explained by the fact that, when the remaining thickness is small enough (empirically 150 mm), the ventilation effect can be felt on the inner surface of the tankwall and decrease the wear rate. This explain, in part, why the overcoatings should not be installed too early, to benefit this ventilation effect. This parameter of 150 mm is written in the green cell of the first row of the table in Fig.50. In this manner, if, in the future, a more accurate value is founded, the user can change it only by writing it in this cell.

The second values calculated in the predictive wear tables are dedicated to this point of slope change. Its y-axis value is therefore calculated by:

$$y\ axis\ value\ of\ the\ point\ of\ slope\ change = total\ thickness - 150 \qquad (14)$$

To obtain the right total thickness to use in the calculation, the last value of the row of the total thickness of the zone is called in the formula. 150 is not written directly but in the green cell of the table in Fig.50 is called in order to adapt the calculation if the value of 150 mm is modified. Nevertheless, if the last point measured is already located under 150 mm of remaining thickness, only the wear rate with the ventilation effect must be considered. In this case, the second point must coincide with the first one, so its y-axis value must be the same as the y-axis value of the first point. To check if the last measured point is already under the 150 mm of remaining thickness, a condition verifies if the y-axis value of the first point is greater than the result of the equation (14). If it is the case, the y-axis of the first point is returned, otherwise the result of the equation (14) is returned. In the row framed in green in Fig.44, the formula is:

=SI(F52>AH143-$E$20;F52;AH143-$E$20)

Here the total thickness of this zone is 400 mm so 250 is returned because it is greater than 215 which is the first y-axis value.

On Fig.44, it is possible to see on the left two green cells. The user writes the estimated predictive wear rates (based on his experience) in these cells in mm/year. The one at the left corresponds to the wear rate before reaching 150 mm of remaining thickness and the one at the right corresponds to the wear rate after reaching 150 mm of remaining thickness. The x-axis value of the second point of the wear prediction curves is the date at which the second y-value calculated before is reached. To calculate this date, the predictive wear rate before reaching 150 mm of remaining thickness is used:

$$Date\ to\ reach\ the\ 2nd\ y\ axis\ value = \frac{2nd\ y\ axis\ value - last\ measured\ wear}{\left(\frac{prediction\ wear\ rate\ before\ reaching\ 150mm}{365{,}25}\right)} + last\ date\ with\ measure \qquad (15)$$

The last measured wear is the last value of the row of the corresponding wear curve and 365,25 is used as the average number of days in a year to convert the mm/year into mm/day. In the row framed in red, this formula is written:

=SI(ESTNUM(A54);(G54-AH53)/(A54/365.25)+AF53;#N/A)

The function "ESTNUM" checks if a value is written in the green cell dedicated to the predictive wear rate. If it is not the case, "#N/A" is written to not plot the predictive curve. This value is, then, returned between the two green cells dedicated to the predictive wear rates thanks to the formula, for example in the cell framed in purple in Fig.44:

=G209

This date at this place must help the user to know at which date the transition is effectuated between the two wear rates he writes. It is called "Pivot date".

The third x-axis value must be the target date to stop the prediction curve at this date. So, the exact same formula than for the x-axis of the target date is used to return the target date chosen by the user if there is one, and the date at which 10 000 ton/m² should be reached otherwise.

The third y-axis value must be the predictive wear reached at the target date. This time, this is the predictive wear rate after the pivot date which is considered. The wear at the target date is calculated as:

$$Wear\ at\ target\ date = \frac{predictive\ wear\ rate\ after\ pivot\ date}{365{,}25} \times (target\ date - pivot\ date) + 2nd\ y\ axis\ value \quad (16)$$

Here again, the predictive wear rate is divided by 365,25 to convert it from mm/year into mm/day. The formula written in the row framed in green to obtain this is:

=(C52/365.25)*(H209-G209)+G52

If no predictive wear rate is written in the dedicated cells, "#N/A" is written in the cell of the pivot date and "#N/A" will be also written in this cell of third y-axis value. So, as it is wanted, the predictive wear curve will not be plotted.

Regarding now the x-axis values of the predictive wear curves of the plot against the specific cumulated pull, they are calculated in another table (Fig.53) with a row for each zone max and for each zone mean. The y-axis values are the same than for the plot against the date.

SCP total max prediction (ton/m^2)			5853	#N/A	10000
SCP total mean prediction (ton/m^2)			5853	#N/A	10000
SCP BWLC max prediction (ton/m^2)			#N/A	#N/A	10000
SCP BWLC mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP LSWUD max prediction (ton/m^2)			#N/A	#N/A	10000
SCP LSWUD mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP LDCBU max prediction (ton/m^2)			#N/A	#N/A	10000
SCP LDCBU mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP SWLD max prediction (ton/m^2)			#N/A	#N/A	10000
SCP SWLD mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP LDCBD max prediction (ton/m^2)			#N/A	#N/A	10000
SCP LDCBD mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP LSWDD max prediction (ton/m^2)			5853	#N/A	10000
SCP LSWDD mean prediction (ton/m^2)			5853	#N/A	10000
SCP LSWUB max prediction (ton/m^2)			5853	#N/A	10000
SCP LSWUB mean prediction (ton/m^2)			5853	#N/A	10000
SCP LSWB max prediction (ton/m^2)			5853	#N/A	10000
SCP LSWB mean predicition (ton/m^2)			5853	#N/A	10000
SCP LSWDB max prediction (ton/m^2)			5853	#N/A	10000
SCP LSWDB mean prediction (ton/m^2)			5853	#N/A	10000
SCP FWLC max prediction (ton/m^2)			#N/A	#N/A	10000
SCP FWLC mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP FWL max prediction (ton/m^2)			#N/A	#N/A	10000
SCP FWL mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP FWT max prediction (ton/m^2)			#N/A	#N/A	10000
SCP FWT mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP FWR max prediction (ton/m^2)			#N/A	#N/A	10000
SCP FWR mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP FWRC max prediction (ton/m^2)			#N/A	#N/A	10000
SCP FWRC mean prediction (ton/m^2)			#N/A	#N/A	10000
SCP RSWDB max prediction (ton/m^2)			5853	#N/A	10000
SCP RSWDB mean prediction (ton/m^2)			5853	#N/A	10000
SCP RSWB max prediction (ton/m^2)			5853	#N/A	10000
SCP RSWB mean prediction (ton/m^2)			5853	#N/A	10000

Fig.53 : Table of the x-axis values of the predictive wear curves for the plot against the specific cumulated pull of the plant of Tarsus

The first value must correspond to the last value of the measured wear curve so the last SCP with measure of the corresponding row is returned in these cells. This data is available in the first intermediate table. So, for example, in the row framed in red in Fig.53, it is done thanks to the formula:

=AG57

Here the last SCP with measure is 5 853 ton/m², so it is the value returned.

The second x-axis value of these curves must be the specific cumulated pull that will be reached at the pivot date, in order to convert the pivot date into a specific cumulated pull. This value is obtained by the equation:

$$SCP\ at\ pivot\ date = SCP\ at\ \max date + average\ SP\ by\ day\ on\ last\ year \times (pivot\ date - \max date) \quad (17)$$

So, for example, in the row framed in red, the Excel formula is:

=$AK$32+$AK$30*(G212-$AK$24)

Here again, if no predictive wear rate is written, "#N/A" is written in the cell of the pivot date and "#N/A" will be also written in this cell, so the curve will not be plotted.

Finally, the third x-axis value of these curves is the specific cumulated pull at the target date. This data has already been calculated for the x-axis values of the target bar, so the same equation (13) and the same formula are used here. Here 10 000 is returned (Fig.53) because no different target date has been written so the target date considered is the date at which 10 000 ton/m² should be reached.

7.2.5. Additional column of the "Number of overcoating" table

To plot the predictive total thickness curves, it is necessary to know the number of overcoating installed by zone. These data are calculated in a new column added to the "Number of overcoating" table (Fig.54).

	Number of overcoating					
Date	04/04/2017	11/01/2022	13/01/2024	Date	Date	Last value of the row
NOMFB	0	57	81	#VALEUR!	#VALEUR!	
CP (ton)	0	258903	341207	0	0	
SCP (ton/m^2)	0	4308	5677	0	0	
BWLC	0	0	0	0	0	0
LSWUD	0	0	0	0	0	0
LDCBU	0	0	0	0	0	0
SWLD	0	0	0	0	0	0
LDCBD	0	0	0	0	0	0
LSWDD	0	1	2	0	0	2
LSWUB	0	1	2	0	0	2
LSWB	0	1	2	0	0	2
LSWDB	0	0	1	0	0	1
FWLC	0	0	0	0	0	0
FWL	0	0	0	0	0	0
FWT	0	0	0	0	0	0
FWR	0	0	0	0	0	0
FWRC	0	0	0	0	0	0
RSWDB	0	0	1	0	0	1
RSWB	0	1	2	0	0	2
RSWUB	0	1	2	0	0	2
RSWDD	0	1	2	0	0	2
RDCBD	0	0	0	0	0	0
SWRD	0	0	0	0	0	0
RDCBU	0	0	0	0	0	0
RSWUD	0	0	1	0	0	1
BWRC	0	0	0	0	0	0
BWRS	0	1	2	0	0	2
BWC	0	1	2	0	0	2
BWLS	0	1	2	0	0	2

Fig.54 : "Number of overcoating" table with an additional column of the plant of Tarsus

The "Number of overcoating" table being a table which count the overcoating installed at each overcoating date, to have the number of overcoating installed at the present moment, it is enough to calculate the last value of each row, without considering the "0" values to not taking into account the dates which are not filled yet. The formula to return that, in the cell framed in red in Fig.54 for example, is:

=SIERREUR(INDEX(TRIERPAR(H404:K404;COLONNE(H404:K404);-1);EQUIV(VRAI;INDEX((TRIERPAR(H404:K404;COLONNE(H404:K404);-1)<>0);0);0));0)

Here 2 is returned because it is the last value of the row which is not 0. As wanted, it corresponds to the number of overcoating at the present moment.

7.2.6. Calculation of the y-axis values of the predictive total thickness curves

The y-axis of the predictive total thickness curve of each zone is displayed in Fig.45, alternating with the y-axis values of the total thickness curves based on the overcoatings already installed. The method used to plot these prediction curves is to have the same points for them than for the initial total thickness curves until the point at which it is not anymore a curve based on actual known values of the passed overcoatings, but a curve of prediction of the future overcoatings. The row framed in red in Fig.45 will be taken as an example in the following.

The first value of the row is the value at the beginning of the campaign, so this is the same first value as the initial curve. It corresponds to the main tankwall thickness, and the cell is filled by the formula “=F143” which returns the first value of the initial curve.

Then, in order to obtain a horizontal bar, the second value must be equal to the first one. So, the formula which return the first value of the row is:

=F144

For a flame furnace, the recommendation of the Melting TA is to install an overcoating on a zone when 75 mm of thickness remains. Like the 150 mm at which the ventilation effect starts to decrease the wear rate, this parameter of 75 mm is written in the green cell of the second row of the table in Fig.50, to be able to modify it easily if a new recommendation appears. This date at which 75 mm of thickness is remaining will be automatically calculated to plot the predictive total thickness curves. The user must indicate in the green cells at the left in Fig.45, what will be the thickness that he plans for the futureovercoatings. The cell the most at the left regards the first overcoating, the one in the middle regards the second overcoating and the one at the right regards the third overcoating.

The third point of the total thickness curves is the point which corresponds to the first possible increase of thickness due to an overcoating installation. The predictive total thickness must be calculated if no overcoating have already been installed and if a value is written in the cell dedicated to the first overcoating thickness prediction. Indeed, if at least one overcoating has already been installed, this point must not be a prediction point but must coincide with the point of the initial total thickness curve. To check if no overcoating have already be installed, the value of the number of dates of overcoating, calculated in the second intermediate table, is checked. The number of dates of overcoating is checked instead of the number of overcoating of the zone because the x-axis values are all the overcoating dates (already existing and future). So, the predictive curve starts to have its own points from the moment at which there is no overcoating date existing yet. If the number of overcoating dates is greater than 0, no matter the value of the number of overcoating of the zone, it means that at least one overcoating has been installed, no matter if it is on this zone or not, and so the x-axis value of the third point is the first overcoating date, as for the initial total thickness curve. For this reason, if the number of overcoating dates is greater than 0, the third y-axis value of the predictive total thickness curve must coincide with the third y-axis value of the initial overcoating curve. If, on the contrary, the number of overcoating date is equal to 0 and a value is written in cell dedicated to the thickness of the first predictive overcoating, this third point must be equal to:

$$Total\ thickness\ = previous\ total\ thickness + predictive\ thickness\ of\ the\ overcoating \quad (18)$$

Here the previous total thickness is the y-axis value just before and the predictive thickness of the overcoating is the value written in the cell dedicated to the thickness of the first predictive overcoating. The formula to verify the conditions and to return the wanted value is:

=SI(ET($AK$34=0;ESTNUM(A144));G144+A144;H143)

Again, to have a horizontal bar, the fourth value must be equal to the third one. Therefore, the formula is:

=H144

For the same reason the sixth, eighth and tenth cells are equals to the previous ones and their formulas are similar.

The fifth value (which is not visible anymore on Fig.45) is the total thickness value after its increase in the second overcoating date. For the same reason as for the third value, if the number of overcoating date is greater than 1, the value of the initial total thickness curve must be returned. If the number of overcoating dates is equal to the number of overcoating of the zone (calculated in the additional column of the "Number of overcoating" table), it would mean that no overcoating have been installed or that one overcoating has been performed and that it was on this zone. In the first case, the first overcoating would have been predictive and calculated on the third cell, and in the second case, the first overcoating is already existing and it corresponds to the third cell also. In both cases, if the number of overcoating dates is equal to the number of overcoating of the zone, this is the predictive second overcoating which must be calculated in this fifth cell. The third possibility is to have the difference between the number of overcoating dates and the number of overcoating of the zone which is equal to 1. This would mean that the number of overcoating date is 1 and the number of overcoating of the zone is 0. In this case, the predictive overcoating which must be added in the fifth cell is the first one (because no overcoating are already installed on this zone). The number of the overcoating added is important to know which green cell must have its value called in the calculation. In each case, the fact that a value is written in the cell dedicated to the thickness of the predictive is also verified. To check these three conditions the function "SI.CONDITIONS" is used and the complete formula is:

=SI.CONDITIONS($AK$34>1;J143;ET($AK$34=L402;ESTNUM(B144));I144+B144;ET($AK$34-L402=1;ESTNUM(A144));I144+A144)

In the seventh cell, the values of the third overcoating date must be added. With the same reflexion than before, several conditions are checked. If the number of overcoating dates is greater than 2, the value of the initial total thickness curve must be returned. If the number of overcoating dates is equal to the number of overcoating of the zone, the thickness of the predictive third overcoating must be added. If the difference between the number of overcoating dates and the number of overcoating of the zone is equal to 1, the thickness of the predictive second overcoating must be added. If the difference between the number of overcoating dates and the number of overcoating of the zone is equal to 2, the thickness of the predictive first overcoating must be added. The formula in this seventh cell is:

=SI.CONDITIONS($AK$34>2;L143;ET($AK$34=L402;ESTNUM(C144));K144+C144;ET($AK$34-L402=1;ESTNUM(B144));K144+B144;ET($AK$34-L402=2;ESTNUM(A144));K144+A144)

Finally, in the ninth cell, the thickness of the fourth overcoating date must be added. If the number of overcoating dates is greater than 3, the value of the initial total thickness curve must be returned. If the number of overcoating dates is equal to the number of overcoating of the zone, it would mean that three overcoatings had already been installed (in reality plus in prediction) so no more overcoating is possible in this zone and the value of the previous cell (the eighth of this row) must be returned to continue the curve. If the difference between the number of overcoating dates and the number of overcoating of the zone is equal to 1, the thickness of the predictive third overcoating must be added. If the difference between the number of overcoating dates and the number of overcoating of the zone is equal to 2, the thickness of the predictive second overcoating must be added. Finally, if the difference between the number of overcoating dates and the number of overcoating of the zone is equal to 3, the thickness of the predictive first overcoating must be added. The formula here is:

=SI.CONDITIONS($AK$34>3;N143;$AK$34=L402;M144;ET($AK$34-L402=1;ESTNUM(C144));M144+C144;ET($AK$34-L402=2;ESTNUM(B144));M144+B144;ET($AK$34-L402=3;ESTNUM(A144));M144+A144)

7.2.7. Calculation of the x-axis values of the predictive total thickness curves for the plot against the date

The x-axis values of the predictive total thickness curves for the plot against the date are calculated with one data set by zone in the table showed in Fig.55.

Date BWLC total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date LSWUD total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date LDCBU total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date SWLD total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date LDCBD total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date LSWDD total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date LSWUB total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date LSWB total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date LSWDB total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date FWLC total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date FWL total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date FWT total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date FWR total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date FWRC total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date RSWDB total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date RSWB total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date RSWUB total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date RSWDD total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date RDCBD total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date SWRD total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date RDCBU total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date RSWUD total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date BWRC total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date BWRS total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date BWC total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A
Date BWLS total thickness prediction			04/04/2017	12/01/2022	12/01/2022	14/01/2024	14/01/2024	#N/A	#N/A

Fig.55 : Table of the x-axis values of the predictive total thickness curves for the plot against the date of the plant of Tarsus

In these data the first value is the starting date of the campaign which is returned thanks to the formula:

='Cold data'!$B$2

Then, only the third, fifth, seventh and nine values are calculated and the other ones are equals to the cell just after.

On the third cell, the date must be the first overcoating date if it has been installed in reality, otherwise, if no overcoating have been performed already, it must be the date of the first predictive overcoating. This date should be the date at which 75 mm of thickness remains, considering the predictive wear curves with the wear rates written by the user. To obtain it, the first predictive wear rate must be considered until the pivot date and the second one must be considered starting from this pivot date. To be more concise let's define some letters for each parameter which participate to this calculation:

- D is the date at which 75 mm of remaining thickness will be reached, this is the wanted date.
- T is the current total thickness value.
- W is the maximum of the last wear measurements, so it is the last value of the maximum row of the zone.
- L is the date of the measurement of W, so it is the last date with measure of the zone.
- 1stR is the first predictive wear rate, before the pivot date.
- 2ndR is the second predictive wear rate, after the pivot date.
- P is the pivot date.

With all these parameters, the equation to calculate D is:

$$D = \frac{T - 75 - W - \left(\frac{1stR}{365{,}25}\right) \times (P - L)}{\left(\frac{2ndR}{365{,}25}\right) + P} \tag{18}$$

To obtain the current total thickness value, the maximum of the y-axis value until the column just at the left of the third column is calculated.Indeed, the total thickness can only increase so the current value is the maximum of all the previous values. To check if a first overcoating has been performed, the function "ESTNUM" verifies if a date is written in the cell dedicated to it in the "Tank wear" sheet. The formula which verify this condition and return the first overcoating date if it is true, or the result of the equation (18) otherwise is, for example in the cell framed in red in Fig.55:

"=SIERREUR(SI(ESTNUM('Tank wear'!W2);$H$191;(MAX.SI.ENS(F156:G156;F156:G156;"<>#N/A")-$E$21-AH73-(A74/365.25)*(G220-AF73))/(C74/365.25)+G220);#N/A)

The function "SIERREUR" is used to return "#N/A" if there is an error due to a value not written for example.

In the fifth, seventh and ninth cells, the exact same equation (18) is used to calculate the predictive date at which 75 mm of remaining thickness is reached. The only value which can possibly not be the same is the current total thickness value which may evolve. So the formula used is this cells is the same as in the third one. Only the range on which is calculated the maximum total thickness value is updated to go until the right column, the cell of the "Tank wear" sheet to verify if an overcoating date exists is modified, as well as the cell retuned (representing the n-th overcoating date) if this condition is true.

On the last cell of these x-axis values, must appears the target date, which is calculated thanks to the same formula as before, for the x-axis values of the target bar for example.

7.2.8. Calculation of the x-axis values of the predictive total thickness curves for the plot against the specific cumulated pull

The x-axis values of the predictive total thickness curves for the plot against the specific cumulated pull are the specific cumulated pull which correspond to the dates of the x-axis values for the plot against the date. They are showed in Fig.56.

SCP BWLC total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP LSWUD total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP LDCBU total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP SWLD total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP LDCBD total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP LSWDD total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP LSWUB total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP LSWB total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP LSWDB total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP FWLC total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP FWL total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP FWT total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP FWR total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP FWRC total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP RSWDB total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP RSWB total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP RSWUB total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP RSWDD total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP RDCBD total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP SWRD total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP RDCBU total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP RSWUD total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP BWRC total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP BWRS total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP BWC total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	
SCP BWLS total thickness prediction (ton/m^2)			0	4308	4308	5677	5677	#N/A	#N/A	

Fig.56 : Table of the x-axis values of the predictive total thickness curves for the plant against the specific cumulated pull of the plant of Tarsus

In the first column, “0” is written because at the beginning of the campaign the specific cumulated pull is equal to 0.

On all the other rows, if the overcoating date of interest exists, the specific cumulated pull at this overcoating date is returned, otherwise the specific cumulated pull at the date written in the x-axis table of the plot against the date is calculated with the same equation than for the specific cumulated pull at the pivot date (17) but using the date of the x-axis table instead of the pivot date. Considering a predictive overcoating date, its corresponding specific cumulated pull will be then:

$$SCP\ OC = SCP\ \mathrm{M} + AVG\ SP \times (OCD - \mathrm{M\ D}) \quad (19)$$

With :

- SCP OC the specific cumulated pull at the predictive overcoating date
- SCP M the specific cumulated pull at max date
- AVG SP the average specific pull by day on last year
- OC D the predictive overcoating date
- M D the max date

Therefore, the formula used in the cell framed in red in Fig.56for example is:

=SI(ESTNUM('Tankwear'!$W$2);G$194;$AK$32+$AK$30*(G262-$AK$24))

In the last column of the table, the specific cumulated pull at the target date is calculated in any case. Indeed, this value must be considered, no matter which overcoating date exist or not, to continue the prediction total thickness curve until the target bar.

7.2.9. Materials table

Finally, as well as for the electrical furnaces, a materials table is implemented (Fig.57) (which correspond to the “Overcoat materials” row of the electrical furnaces) to be able to write the material of each overcoating on the total thickness curves, thanks to data labels. The difference with the electrical furnaces is that the materials can be different between each zone and not installed at the same time, so one row by zone is created and each row will be the values of the data labels of the total thickness curve of the corresponding zone. Therefore, it is also important to take care that the cells of the “Tank wear” sheet called in the formula correspond to cells of the zone. For the main tankwall material at the beginning of campaign the formula is the same than for the electrical furnace.

Then for the overcoatings, there is a little difference. Indeed, in addition to verify if “Overcoat” is written on the top of the column, it is necessary to verify also if the cells of the zone are not empty, because it is possible to overcoat only some zones at a time for the flame furnace. Therefore the formula used in the cell framed in red in Fig.57, for example, is:

```
=SI.CONDITIONS(ET('Tank wear'!$AX$4="Overcoat";NON('Tank wear'!$AX$257=""));'Tank
wear'!$AX$257;ET('Tank wear'!$AU$4="Overcoat";NON('Tank wear'!$AU$257=""));'Tank
wear'!$AU$257;ET('Tank wear'!$AR$4="Overcoat";NON('Tank wear'!$AR$257=""));'Tank
wear'!$AR$257;ET('Tank wear'!$AO$4="Overcoat";NON('Tank wear'!$AO$257=""));'Tank
wear'!$AO$257;ET('Tank wear'!$AL$4="Overcoat";NON('Tank wear'!$AL$257=""));'Tank
wear'!$AL$257;VRAI;"")
```

BWLC materials			ZC30						
LSWUD materials			Wool 50						
LDCBU materials			Wool 50						
SWLD materials			Wool 50						
LDCBD materials			Wool 50						
LSWDD materials			Wool 50	ZC60		ZC60			
LSWUB materials			ZC30	ZC60		ZC60			
LSWB materials			Wool 50	ZC60		ZC60			
LSWDB materials			Wool 50			ZC60			
FWLC materials			Wool 50						
FWL materials			Wool 50						
FWT materials			Wool 50						
FWR materials			Wool 50						
FWRC materials			Wool 50						
RSWDB materials			Wool 50			ZC60			
RSWB materials			Wool 50	ZC60		ZC60			
RSWUB materials			ZC30	ZC60		ZC60			
RSWDD materials			Wool 50	ZC60		ZC60			
RDCBD materials			Wool 50						
SWRD materials			Wool 50						
RDCBU materials			Wool 50						
RSWUD materials			Wool 50			ZC60			
BWRC materials			ZC30						
BWRS materials			ZC30	ZC60		ZC60			
BWC materials			ZC30	ZC60		ZC60			
BWLS materials			ZC30	ZC60		ZC60			

Fig.57 : Materials table of the plant of Tarsus

7.2.10. Plotting of the curves

Once all these data are calculated, it is possible to plot the curves. First, as an example, the wear and total thickness curves of the zone "Left side wall bubblers" of Tarsus are plotted against the date with the parameters written in Fig.58.

			Change slope of prediction when it remain	150	mm
			Overcoat to be installed when it remains	75	mm
			Target date (if different from 10k ton/m^2)	01/03/2034	
		Prediction	ZONES	CRITERION WEAR (mm)	
mm/year before	Pivot date	mm/year after	Left side wall bubblers	Max	0
40	29/07/2026	20	Left side wall bubblers	Max prediction	160
mm/year before	Pivot date	mm/year after	Left side wall bubblers	Mean	0
40	22/09/2027	20	Left side wall bubblers	Mean prediction	114
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Left side wall bubblers	Total thickness	250
		75	Left side wall bubblers	Total thickness prediction	250

Fig.58 : Parameters to plot the curve of the "Left side wall bubblers" in the plant of Tarsus

The target date is set to the 01/03/2034. The predictive wear rates of the max and mean wear curves are set to 40 mm/year before reaching 150 mm of remaining thickness and 20 mm/year after that. The predictive thickness of the third overcoating, which is the only one still possible because two overcoating have already been installed in this zone, is set to 75 mm. It is already possible to see that the pivot date, at which the predictive wear decrease is, the 29/07/2026 for the maximum wear and the 22/09/2027 for the mean wear.

These are the dates at which the remaining thickness reaches 150 mm and so the ventilation effect starts to impact. The curves resulting of this are showed in Fig.59.

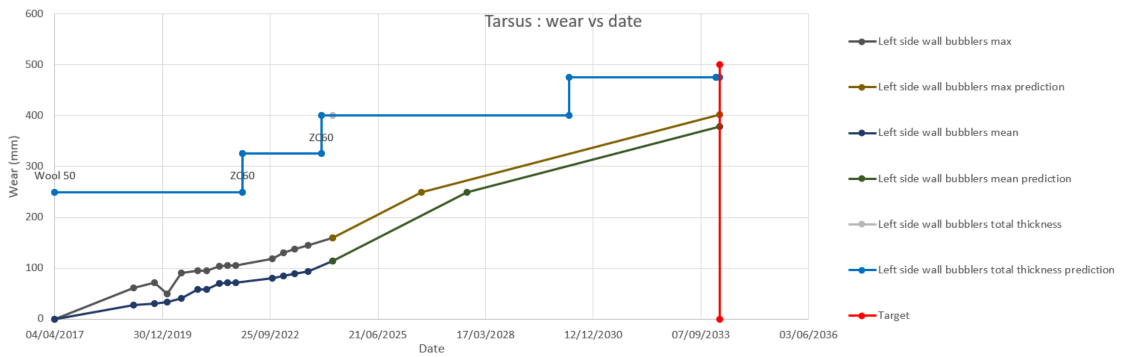


Fig.59 : Measured and predictive wear and total thickness of the "Left side wall bubblers" of the plant of Tarsus against the date

In the first part of this plot are visible the measured wear values and the total thickness based on the overcoating already installed. In the second part, the wear curves increase by 40 mm/year as a first step, until the pivot date, and then increase by 20 mm/year until the target bar. When the predictive max wear curve is 150 mm from the total thickness curve, the total thickness curve increases suddenly by 75 mm and then continues with a horizontal bar. So, by reading the date of the predictive third overcoating on the x-axis, the Melting TA team can know that, in these conditions, the third overcoating of this zone must be installed in 2030. By passing the mouse over the total thickness curve, they can even read the exact date which is the 29/04/2030 in this case. This information of when the future overcoatings should be installed is very useful to the Melting TA team to plan the in-plant interventions.

As a second example, the wear and total thickness curves of the zone "Left side wall downstream bubblers" of Tarsus are plotted against the specific cumulated pull with the parameters showed in Fig.60.

			Change slope of prediction when it remain	150	mm
			Overcoat to be installed when it remains	75	mm
			Target date (if different from 10k ton/m^2)	18/11/2035	
		Prediction	ZONES	CRITERION WEAR (mm)	
mm/year before	Pivot date	mm/year after	Left side wall downstream bubblers	Max	0
30	29/04/2024	15	Left side wall downstream bubblers	Max prediction	188
mm/year before	Pivot date	mm/year after	Left side wall downstream bubblers	Mean	0
30	31/03/2025	15	Left side wall downstream bubblers	Mean prediction	147
Overcoat 1 mm	Overcoat 2 mm	Overcoat 3 mm	Left side wall downstream bubblers	Total thickness	250
	75	75	Left side wall downstream bubblers	Total thickness prediction	250

Fig.60 : Parameters to plot the curve of the "Left side wall downstream bubblers" in the plant of Tarsus

The target date is set to the 18/11/2035. The predictive wear rates of the max and mean wear curves are set to 30 mm/year before the pivot date and 15 mm/year after the pivot date. On this zone, only one overcoating has been installed, so the cells of the second and third predictive overcoating are filled. The predictive thickness of the second and third overcoatings is 75 mm. It is already possible to see that the pivot date for the max wear curve is the 29/04/2024, which is the last date with measure on this zone. This is because already less than 150 mm is remaining on this zone. The average of the measured points is lower and is outside of these 150 mm so the pivot date is in the future and is the 31/03/2025. The curves resulting of this are showed in Fig.61.

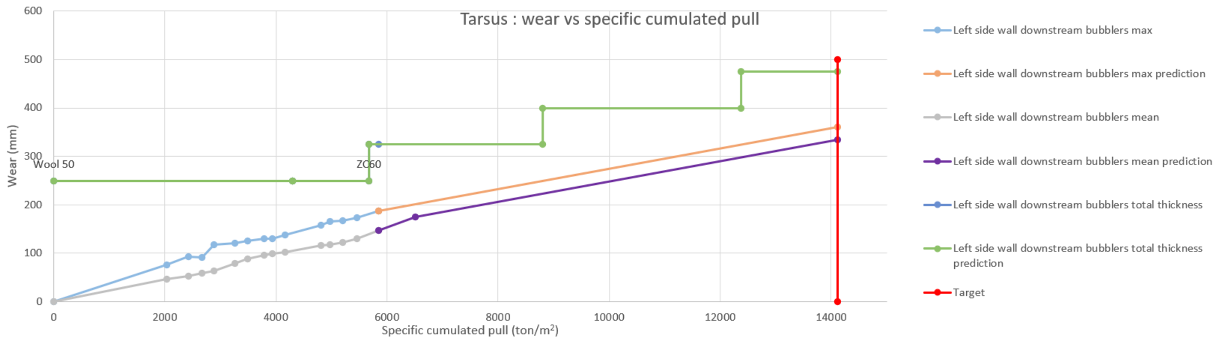


Fig.61 : Measured and predictive wear and total thickness of the "Left side wall downstream bubblers" of the plant of Tarsus against the specific cumulated pull

Like seen on Fig.60, the pivot date of the max wear curve is the last date with measure, so the max wear curve increases only by 15 mm/year and does not consider the predictive wear rate after the pivot date. Meanwhile, the mean wear curve works like the wear curves of the first example. The other difference which is interesting to see in this second example is that only one overcoating has been installed. So, the second and the third ones are predictive. The second is installed when the max wear curve is at 150 mm from the total thickness curve. For a flame furnace the overcoatings have a thickness of 75 mm and are installed when 75 mm of thickness remains. So, when an overcoating is installed the thickness is 150 mm and it is not necessary to change the wear rate, the wear rate after the pivot date can be used. So, the max wear curve continues to increase with the same wear rate and when, once again, this curve is at 150 mm from the new value of the total thickness, the third overcoating is installed. So, it is possible for the Melting TA team to plan several overcoatings in advance. In this case, it is recommended to install the overcoatings at 8 807 ton/m² and 12 381 ton/m². The scale of the specific cumulated pull is not the better one to know when the overcoatings should be installed, so it better to look at the plot against the date for that.

Two examples of use have been seen but the Melting TA team can now use these curves on several ways, on several plants and several zones, to see the current wear and total thickness and their predictive evolution in the future. For example, it is also possible to compare the wear of several zones of the furnace, by plotting them together.

8. Multiple plants wear curves

In order to compare the wear of several plants, these wear curves have also been plotted in a new file which group the data of all the plants. A plot is done against the number of months from beginning and another one is done against the specific cumulated pull.

8.1. Electrical furnaces

As well as it has been done for the ovecoating curves, the data of all the plants are grouped, using links. The data used are the ones used to plot the wear curves just seen in the "Tank wear" sheet. A table for the x-axis values (Fig.62) and a table for the y-axis values (Fig.63) have been created.

X-AXIS												
Chalon 2 NOMFB			0	16	40	50	58	59	67	78	86	9
Chalon 2 SCP (ton/m^2)			0	2319	6558	8626	10589	10678	11273	11273	11273	1127
Vamdrup NOMFB			0	20	26	39	55	64	76	85	101	#VALEUR!
Vamdrup SCP (ton/m^2)			0	1294	1647	2524	3597	4184	5056	5709	6640	#N/A
Lucens NOMFB			0	10	38	52	57	69	81	94	#VALEUR!	#VALEUR!
Lucens SCP (ton/m^2)			0	1683	6782	8295	8928	10413	11865	13148	#N/A	#N/A

Fig.62 : X-axis values table of the comparison wear curves of the electrical furnaces

The x-axis values are the number of months from beginning of campaign and the specific cumulated pull of each plant.

PLANTS	ZONE	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
CHALON 2	Blocks near the electrodes	0	#N/A	95	160	#N/A	#N/A	190	145	280	250	#N/A	#N/A
CHALON 2	Blocks away from the electrodes	0	#N/A	190	220	240	#N/A	250	275	330	400	#N/A	#N/A
VAMDRUP	Blocks near the electrodes	0	20	#N/A	#N/A	75	#N/A	#N/A	#N/A	270	#N/A	#N/A	#N/A
VAMDRUP	Blocks away from the electrodes	0	25	20	80	100	90	85	150	345	#N/A	#N/A	#N/A
LUCENS	Blocks near the electrodes	0	#N/A	70	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
LUCENS	Blocks away from the electrodes	0	#N/A	100	#N/A	195	315	295	320	#N/A	#N/A	#N/A	#N/A

Fig.63 : Y-axis values table of the comparison wear curves of the electrical furnaces

The y-axis values are the maximum of the measured wear values of the blocks near the electrodes and the blocks away from the electrodes for each plant. Two filter are available on the green cells to choose which plants and which zone will be compared. For example, on Fig.64 are compared, thanks to these curves the wear on the blocks away from the electrodes on the plants of Chalon 2, Vamdrup and Lucens, against the number of months from beginning of campaign.

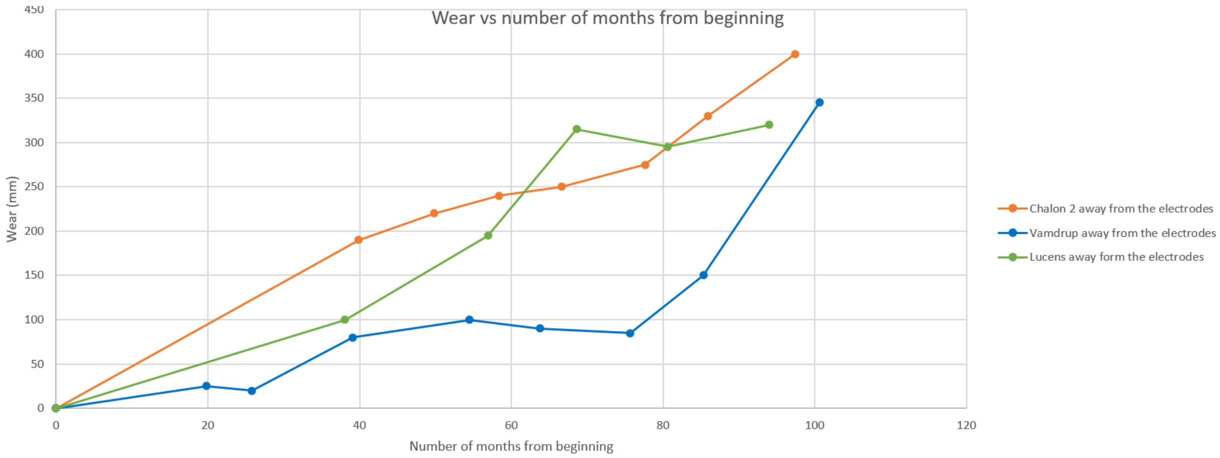


Fig.64 : Wear comparison curves of the blocks away from the electrodes of the plants of Chalon 2, Vamdrup and Lucens against the number of months from beginning

It is possible to see on this plot that Chalon is the plant which have the faster wear, except in one point around 70 months after beginning of campaign, where Lucens was the most worn. On the contrary, the Vamdrup curve is always below so this is the plant with the slower wear.

The curves of the same zone of the same plants are plotted against the specific cumulated pull on Fig.65.

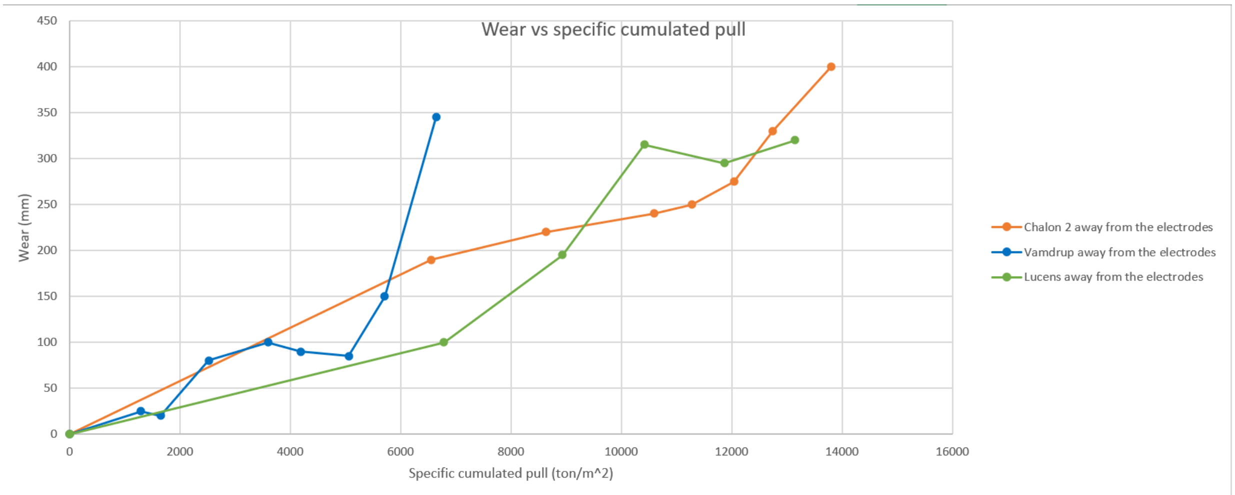


Fig.65 : Wear comparison curves of the blocks away from the electrodes of the plants of Chalon 2, Vamdrup and Lucens against the specific cumulated pull

On this second plot the curves of Chalon and Lucens are still a little bit intertwined, but the plants of Vamdrup, which was the less worn on the first plot, seems here, on the contrary the most worn. Indeed, after a first part where its curve is between the two others, it increases suddenly far above the curves of the two other plants. So, this plant, which have the slower wear on the time scale, have the faster one on the production scale, probably because its specific pull rate is lower than the ones of the others.

8.2. Flame furnaces

As well as for the electrical furnaces, links are used to take the data used to plot the single plant curves from the "Graphs tank" sheet of the wear measurement file. But this time, as well as for the overcoating curves, one sheet (and so one plot) by big zone is created because, otherwise, the limit of 255 curves that it is possible to plot at a time in Excel would have been exceeded. In addition to the big zones defined for the overcoating curves, there is, this time, also a "Total" sheet, where is plotted the maximum wear on all the furnace of each plant. Indeed, even if for the single plant curves, the average has been calculated, for the comparison curves only the maximum is considered. Once again, for each big zone, there is a table for the x-axis values (Fig.66) and a table for the y-axis values (Fig.67) with filters to choose the plants and the zone. On the x-axis values table, the data necessary to plot the target bar at 10 000 ton/m² on the plot against the specific cumulated pull are also included.

TARGET			0	500								
X-AXIS												
Target SCP (ton/m^2)			10000	10000								
Tarsus NOMFB			0	24	30	34	39	44	46	50	51	53
Tarsus SCP (ton/m^2)			0	2030	2421	2666	2884	3267	3487	3788	3788	3932
Llavallol NOMFB			0	14	19	21	34	39	43	50	54	57
Llavallol SCP (ton/m^2)			0	1677	2049	2194	2952	3222	3543	4199	4565	4864
Bergisch TEL NOMFB			0	57	#VALEUR!	#VALEUR!	#VALEUR!	#VALEUR!	#VALEUR!	#VALEUR!	#VALEUR!	#VALEUR!
Bergisch TEL SCP (ton/m^2)			0	6234	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Dangjin NOMFB			0	36	45	58	67	71	91	#VALEUR!	#VALEUR!	#VALEUR!
Dangjin SCP (ton/m^2)			0	5101	6573	7542	8224	8527	10039	#N/A	#N/A	#N/A

Fig.66 : X-axis values table of the "Back wall" sheet of the flame furnaces comparative wear curves

Also here, the x-axis values are the number of months from beginning and the specific cumulated pull of each plant. The target data are written directly, without any formula, because they are not intended to change.

PLANTS	ZONE	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	n
TARSUS	Back wall left corner	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
TARSUS	Back wall right corner	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
TARSUS	Back wall right side	0	#N/A	78	70	#N/A	125	125	127	#N/A	128	135	160	
TARSUS	Back wall center	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
TARSUS	Back wall left side	0	#N/A	69	75	#N/A	86	#N/A	86	#N/A	132	132	#N/A	
LLAVALLOL	Back wall left corner	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
LLAVALLOL	Back wall right corner	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BERGISCH TEL	Back wall left corner	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BERGISCH TEL	Back wall right corner	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BERGISCH TEL	Back wall right side	0	30	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BERGISCH TEL	Back wall center	0	30	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
BERGISCH TEL	Back wall left side	0	30	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
DANGJIN	Back wall left corner	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
DANGJIN	Back wall right corner	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
DANGJIN	Back wall right side	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	
DANGJIN	Back wall center	0	115	#N/A	185	170	#N/A	245	#N/A	#N/A	#N/A	#N/A	#N/A	
DANGJIN	Back wall left side	0	55	#N/A	#N/A	105	#N/A	240	#N/A	#N/A	#N/A	#N/A	#N/A	

Fig.67 : Y-axis values table of the "Back wall" sheet of the flame furnaces comparative wear curves

The y-axis values are the maximum wear of each zone at each audit date for each plant. As well as for the overcoating, the comparisons are performed on similar zones, so it is relevant to split the curves in big zones which correspond to the different walls of the furnace. With the data of the two tables, it is now possible to plot the curves. On Fig.68 and Fig.69 , are showed the plot of the comparison wear curves of the zone "Right side wall upstream bubblers" of Tarsus, Llavallol, Bergisch and Dangjin, against the number of months form beginning of campaign and against the specific cumulated pull.

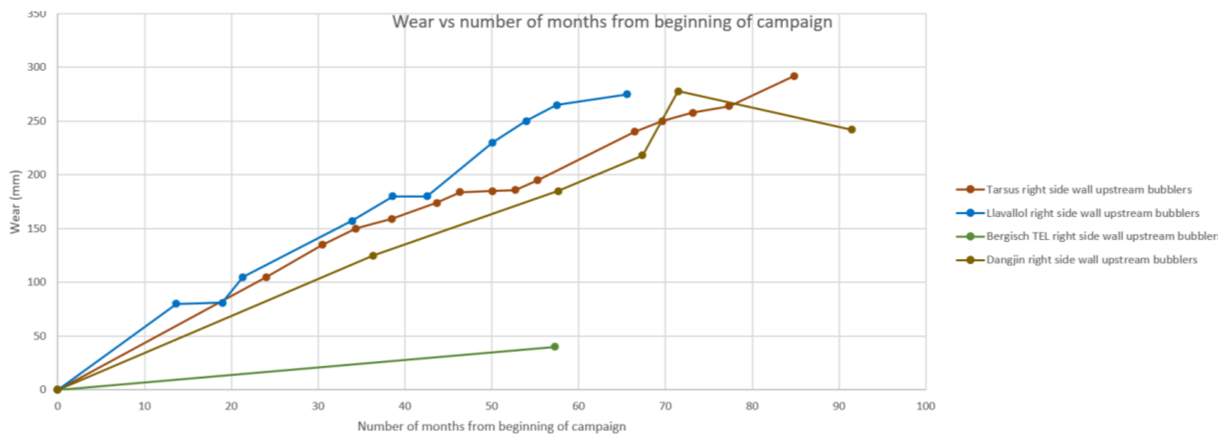


Fig.68 : Comparison wear curves of the zone "Right side wall upstream bubblers" of the plants of Tarsus, Llavallol and Dangjin against the number of months from beginning

On this plot, the curve of Bergisch is far below the other curves, which means that this plant in this zone have a slower wear than the other plants. But only one measurement has been performed, so it is not very relevant. To be able to make reliable comparison, more measurements would be better. The wear on the three other plants seems almost equivalent, with, maybe, a greater wear, nevertheless, in Llavallol because its curve is above the others.

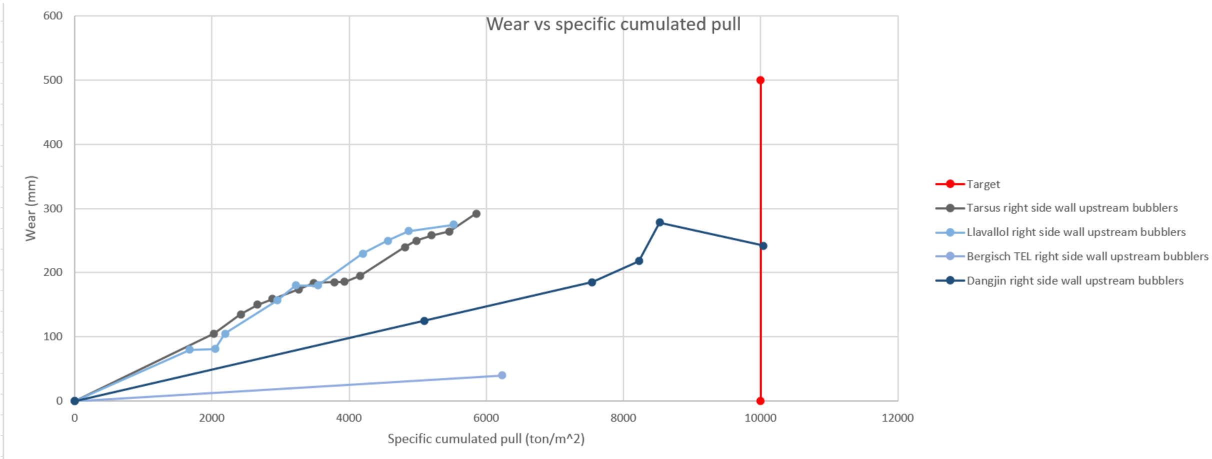


Fig.69 : Comparison wear curves of the zone "Right side wall upstream bubblers" of the plants of Tarsus, Llavallol and Dangjin against the specific cumulated pull

On the plot against the specific cumulated pull, Bergisch still is the less worn plant. The wear on this zone on the plants of Tarsus and Llavallol is even closer. However, the wear in Dangjin is slower from the production scale with respect to Tarsus and Lavallol. It is also possible to see that Dangjin has already reached the target of 10 000 ton/m², and with a wear which is not excessive. This is a good thing because it means that this plant can continue to produce over this target, and will have a final production above what is expected, without rebuilding the furnace which costs a lot.

With these curves, regarding the electrical furnaces as well as the flame furnaces, the Melting TA team will be able to see quickly and easily which are the plants the more and the less worn, on every zone, and on the time or on the production scale.

9. Forehearth curves

On the model of what has been done for the tankwall wear curves, it has been decided to plot forehearth wear curves. These curves are not comparison curves between plants but are only for a single plant. Since the forehearth does not depends on the type of furnace, these curves are the same for the electrical and the flame furnaces. The goal is to have curves based on the wear measurements performed during the audits, and the total thickness curve evolving with the forehearth overcoatings installed, like in the tankwall wear curves. A prediction curve is also wanted but there is no model taking into account the ventilation effect or other modification of the wear rate in the time. Therefore, this prediction curve is only wanted to be linear, with only one value of wear rate. Like in the tankwall, the forehearth have several zones so there is one curve by zone. Measurements are performed on the block and on the joint so for each zone, there is also one curve regarding the block and another one regarding the joint. These curves and the data used to plot them are on a new sheet of the wear measurement file called “Graphs F_H”.

In contrast to the tankwall, in the forehearth, the zones are not the same in all the plants. Indeed each forehearth is specific and that is why, for each plant, the user must write the forehearth zones in the “Cold data” sheet. These zones are, then, written in the “F_H wear” sheet in front of each measurement locations, thanks to a drop-down list. These zones are also copied in the y-axis values table (Fig.70, Fig.71 and Fig.72) thanks to the formula, for example in the cell framed in red in Fig.70:

=SI('Cold data'!G7="";"null";'Cold data'!G7)

This formula returns “null” if nothing is written in the corresponding cell of the “Cold data” sheet.

Prediction	ZONE	JOINT/BLOCK/TOTAL THICKNESS	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
mm/year	Working end	Joint	0	#N/A	#N/A	235	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Working end	Joint prediction	0	#N/A	#N/A	235	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z0	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z0	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z1	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z1	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z2	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z2	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z3	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	60	#N/A	#N/A	#N/A
	Z3	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	60	#N/A	#N/A	#N/A
mm/year	Z4	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z4	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z5	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z5	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z6	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z6	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z7	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z7	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z8	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z8	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z9	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z9	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z10	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z10	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z11	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z11	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	null	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	null	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	null	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	null	Joint	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Joint prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Fig.70 : “Joint part” of the y-axis values table of the forehearth curves of the plant of Vamdrup

mm/year	Working end	Block	0	#N/A	100	#N/A	#N/A	150	195	250	240	#N/A
	Working end	Block prediction	0	#N/A	100	#N/A	#N/A	150	195	250	240	#N/A
mm/year	Z0	Block	0	#N/A	100	#N/A	#N/A	50	70	85	105	#N/A
	Z0	Block prediction	0	#N/A	100	#N/A	#N/A	50	70	85	105	#N/A
mm/year	Z1	Block	0	#N/A	120	#N/A	#N/A	50	60	95	80	#N/A
	Z1	Block prediction	0	#N/A	120	#N/A	#N/A	50	60	95	80	#N/A
mm/year	Z2	Block	0	#N/A	135	#N/A	#N/A	#N/A	50	50	50	#N/A
	Z2	Block prediction	0	#N/A	135	#N/A	#N/A	#N/A	50	50	50	#N/A
mm/year	Z3	Block	0	#N/A	128	#N/A	#N/A	45	40	40	50	#N/A
	Z3	Block prediction	0	#N/A	128	#N/A	#N/A	45	40	40	50	#N/A
mm/year	Z4	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z4	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z5	Block	0	#N/A	#N/A	#N/A	#N/A	10	#N/A	#N/A	25	#N/A
	Z5	Block prediction	0	#N/A	#N/A	#N/A	#N/A	10	#N/A	#N/A	25	#N/A
mm/year	Z6	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z6	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z7	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z7	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z8	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z8	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z9	Block	0	#N/A	#N/A	#N/A	#N/A	15	#N/A	#N/A	30	#N/A
	Z9	Block prediction	0	#N/A	#N/A	#N/A	#N/A	15	#N/A	#N/A	30	#N/A
mm/year	Z10	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z10	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	Z11	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	Z11	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	null	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	null	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	null	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	null	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Block prediction	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
mm/year	null	Block	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Fig.71 : "Block part" of the y-axis values table of the forehearth curves of the plant of Vamdrup

mm/year	Working end	Total thickness	250	250	325	325	325	#N/A	#N/A	#N/A	#N/A	#N/A
	Z0	Total thickness	140	140	140	140	215	#N/A	#N/A	#N/A	#N/A	#N/A
	Z1	Total thickness	140	140	140	140	215	#N/A	#N/A	#N/A	#N/A	#N/A
	Z2	Total thickness	140	140	140	140	140	#N/A	#N/A	#N/A	#N/A	#N/A
	Z3	Total thickness	140	140	140	140	140	#N/A	#N/A	#N/A	#N/A	#N/A
	Z4	Total thickness	0	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A
	Z5	Total thickness	140	140	140	140	140	#N/A	#N/A	#N/A	#N/A	#N/A
	Z6	Total thickness	0	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A
	Z7	Total thickness	0	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A
	Z8	Total thickness	0	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A
	Z9	Total thickness	140	140	140	140	140	#N/A	#N/A	#N/A	#N/A	#N/A
	Z10	Total thickness	0	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A
	Z11	Total thickness	0	0	0	0	0	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
	null	Total thickness	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A

Fig.72 : "Total thickness part" of the y-axis values table of the forehearth curves of the plant of Vamdrup

As it is possible to see on the figures, the y-axis tables consist in three parts for the joints, the blocks, and the total thickness. In the first two parts, the zone is written two times for the measurements and the prediction. In the third part, it is written only one time because there is no total thickness prediction curve. A lot of rows have been implemented be sure that all the forehearth zones can be plotted. Indeed, it is better to be careful because all the forehearth have not the same number of zones. On the top of this table, two filters are available to choose the zones to plot and which curves must be plotted between the blocks, the joints, the total thickness and the prediction curves.

The x-axis values (Fig.73) are the audit dates ("Date block/joint") and the forehearth change of design dates ("Date total thickness").

X-AXIS												
Date block/joint			20/07/2015	15/03/2017	12/09/2017	23/10/2018	03/02/2020	10/11/2020	09/11/2021	29/08/2022	07/12/2023	#N/A
Date total thickness			20/07/2015	30/01/2023	31/01/2023	12/12/2023	13/12/2023	#N/A	#N/A	#N/A	#N/A	#N/A

Fig.73 : X-axis values table of the forehearth curves of the plant of Vamdrup

The audit dates row is filled on the same way than it has been done for the tankwall.

9.1. Calculation of the forehearth change of design dates

The first value of this row is the starting date of campaign and is calculated in the same way than in the tankwall curves. The other values are the forehearth change of design dates, one over two, alternating with the day after these dates. The values are taken from the "F_H wear" sheet. In the cells framed in red in Fig.73 for example, the change of design date is obtained with the formula:

=SI(ESTNUM('F_H wear'!Y2);'F_H wear'!Y2;#N/A)

And the day after is obtained with:

=G290+1

Thanks to these formula, if no change of design date is written in the dedicated cell in the "F_H wear" sheet, "#N/A" is written.

In order to know the date at which the prediction curves stop, it is asked to the user to write a "Date of end of prediction" in a dedicated cell (Fig.74). This is the only difference between the electrical and the flame furnaces. Indeed, for the flame furnaces, the target date calculated in the "Graphs tank" sheet in considered as the date of end of prediction. This date is the last value of the x-axis rows obtained thanks to the formula:

=D26

Date of end of prediction :	01/01/2031

Fig.74 : Cell dedicated to the date of end of prediction

9.2. Calculation of the block and joint measured wear values

The data wanted in the measured wear curves, are the maximum of each zone at each audit date. The first column is "0" because there is no wear at the beginning of the campaign. For the other cells, the function "MAX.SI.ENS" is used. This function allows to return the maximum of a range of data which correspond to the cell of a specific zone only. For example, in the cell framed in red in Fig.71, the formula is:

=SI(MAX.SI.ENS('F_H wear'!CR$5:CR$54;'F_H wear'!$G$5:$G$54;$B135)=0;#N/A;MAX.SI.ENS('F_H wear'!CR$5:CR$54;'F_H wear'!$G$5:$G$54;$B135))

Here the function "MAX.SI.ENS" returns the maximum value of the column CR of the "F_H wear" sheet, for which the value on the same row on the column G of the "F_H wear" sheet is equal to the cell B135 of the "Graphs F_H" sheet. On this cell B135 is written the name of the zone (here Z1), so the maximum of the values on the zone Z1 is returned by the function. The formula introduced here returns "#N/A" if the maximum of the zone is 0 and the maximum value otherwise.

9.3. Calculation of the total thickness values

The total thickness of a zone at a date D is the sum of all the layers present in the design of the last date before the date D. So the function "SI.CONDITIONS" is used to check if each date is earlier than the date of the same column on the row "Date total thickness". The date checked are placed in decreasing order in the function. In this way the function stops as soon as the last date earlier the date D is found, and returns the associated value. The associated value is the sum of all the layers thickness at this date. In addition to the main forehearth thickness, there are three possible overcoatings. So, once the right date has been found, the total thickness at this date is:

$$Total\ thickness = Forehearth\ thickness + \sum_{i=0}^{3} Thickness\ of\ layer\ i \qquad (20)$$

Once again, to sum the thickness of the specific zone, the function "MAX.SI.ENS" is used to found the layers thickness corresponding to this zone. The first condition and the associated value to return used in the cell framed in red in Fig.72 is:

SI.CONDITIONS(G$290>'F_H wear'!$CC$2;SOMME(MAX.SI.ENS('F_H wear'!$CD$5:$CD$67;'F_H wear'!$G$5:$G$67;$B235);MAX.SI.ENS('F_H wear'!$CF$5:$CF$67;'F_H wear'!$G$5:$G$67;$B235);MAX.SI.ENS('F_H wear'!$CH$5:$CH$67;'F_H wear'!$G$5:$G$67;$B235);MAX.SI.ENS('F_H wear'!$CJ$5:$CJ$67;'F_H wear'!$G$5:$G$67;$B235))

The columns CC which corresponds to the design change date and CD, CF, CH and CJ which correspond to the layers thickness are, then, adapted, and the condition and the associated value are repeated for the ten design change dates.

9.4. Calculation of the prediction wear curves values

To be able to calculate the prediction wear curves values a table containing the last date with measure and the last value of the row of each zone has been created, with the same method and formulas as for the tankwall curves. As it is visible in Fig.70 and Fig.71, to plot the prediction wear curves, the user must write at the left the predictive wear rate in mm/year in the green cells. The method followed here consists in havingexactly the same points than the measured wear curves except the last point. Therefore, the calculation is the same for all the point except the last one. The last point is the y-axis value which correspond to the date of end of prediction as x-axis value. This value is therefore calculated like this:

$$P = \frac{R}{365{,}25} \times (D - L) + W \qquad (21)$$

With:

- P, the predictive last wear value
- W, the maximum of the last wear measurements, so it is the last value of the row of the zone.
- L, the date of the measurement of W, so it is the last date with measure of the zone.
- R, the predictive wear rate
- D, the date of end of prediction

This equation, on Excel, is written for example for the joint of the zone “Working end”:

=SI(ESTNUM(A30);(A30/365.25)*($AC$289-AE29)+AF29;#N/A)

9.5. Plotting of the curves

Once all these data are calculated, it is possible to plot the curves and choose the zones and the block or the joint thanks to the filters. On Fig.75 is showed the plot of the blocks wear of the zones Z0 and Z1 with a predictive wear rate of 20 mm/year.

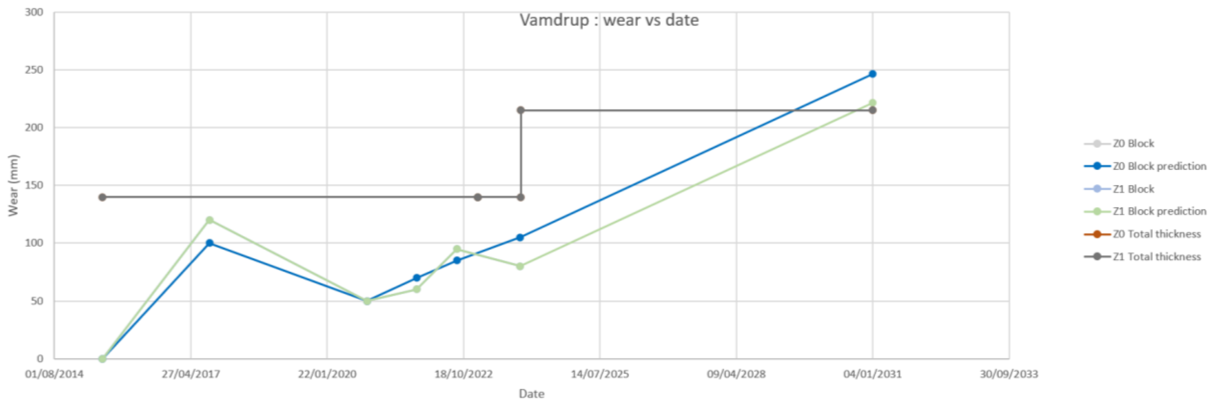


Fig.75 : Wear and total thickness curves of the blocks of the zones Z0 and Z1 of the forehearth of Vamdrup

The first outstanding point here is that these two zones have the same overcoating scheme, that is why only one total thickness curve is visible. The second point is that these two zones have a little bit the same level of wear. However, the last measured wear is higher for the zone Z0 than for the zone Z1. That explains why, switching to the prediction curves, the prediction curve of Z0 is higher than the one of Z1. Indeed, they increase linearly by 20 mm/year starting from the last measured point, so if the last measured point of Z0 is higher, its predictive curve will be higher until the date of end of prediction. Thanks to these prediction curves, it is possible to know that, with a wear rate of 20 mm/year, if nothing is done, there will be a glass leakage in the beginning of 2029 on Z0 and a little bit later, in the end of 2030 on Z1. To prevent that, the Melting TA team should install an overcoating before these dates on these zones.

10. Conclusion

The aim of this internship was to simplify the work of the Melting TA team in their studies of the refractory wear in the furnaces and forehearth in several plants of Saint-Gobain Isover. In particular, a lot of things were done manually before. It was a big loss of time for the team and a source of error because of the possible typographical errors. So the new tools provided by this work had to be the more automatic possible.

To achieve this goal and make automatic calculations and curves about the wear of the different furnaces, the first thing to do was to homogenize the wear measurement file, to have the same structure between the plants. This allows to find the layers design and the wear values, as well as the cold data or the K2 data, at the exact same place in each file. At the same time, taking advantage of this homogenization, the new file created has been thought to be the more automatic possible, with automatic calculations of the thickness left or maximum and average wear at each audit date for example, which were performed manually before.

Once this new file was implemented for all the plants, it has been possible to plot several curves. These curves are regarding the tankwall and forehearth wear as well as the tankwallovercoatings. A part of these curves is focused on a single plant only, and help the Melting TA team to have an history of the wear of the furnace and to make predictions, which will help them to know which maintenance actions must be performed on each plant and when they must be performed. Another part of these curves are comparison curves which allow to make a benchmark between the plants, about the overcoating strategy and the tankwall wear.

Thanks to this work, the user just has to write the data about the furnace (measured wear, original tankwall layers design, date and thickness of overcoating…) and see appear the different curves. He can use these curves easily by simply choosing the plants or the zones of interest thanks to the filters implemented.

The electrical and the flame furnaces are the two principal types of furnaces to produce glass wool. In this work they have been, most of the time, dealt with separately, because they work differently and the Melting TA team does not deal with them in the same way (in terms of overcoating strategy for example).

Once these files and these curves are implemented, they work automatically, but their creation had to be done manually. So, the duplication of the files and the writing of the data of all the plants, as well as the filling of all the data series in the Excel plots has taken a lot of time and may have prevented the creation of other tools to help an easy analysis of the Melting TA team. In addition to the work described here, other little tasks have been performed during this internship, regarding mainly the data storage (with the storage of several files in a SharePoint for example), the homogenization of other files or the implementation of automatic calculations, on topics like the chemical composition of the glass or the electrodes wear for example.

The work described here has been performed on Excel, even if it is not the better software to automate calculations and curves, because the Melting TA team is familiar with this software, so the use is easier for them. Nevertheless, in the long term, the team will learn to use a software more suitable for this automatic data processing of a large amount of data, like Power BI for example. At this moment, this work will be transferred in this software and the result should be even more convincing.

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