Workshop on Pickling Solutions Technology

Optimisation of pickling process control and management by model-based simulation tools

University of Oviedo
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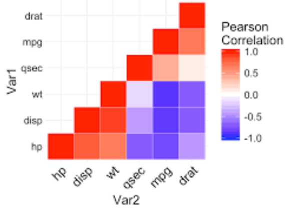
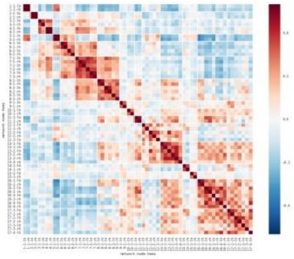
13th of November 2019, Düsseldorf

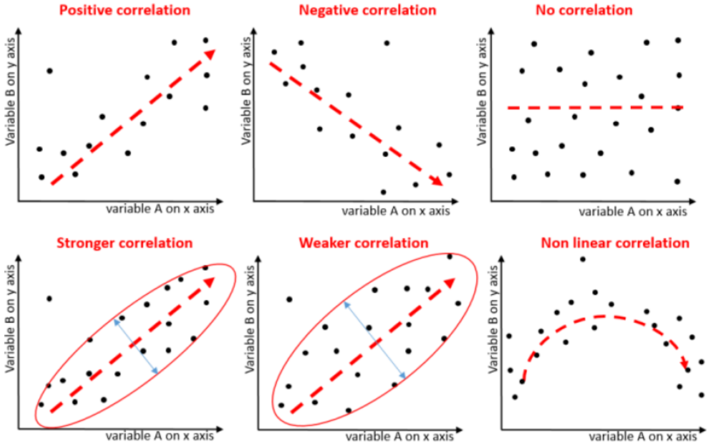
Optimisation of pickling process control and management by model-based simulation tools

Data correlations

- Analysis and/or verification of correlations
- Search of nonlinear or partial/local correlations by means of visualization algorithms

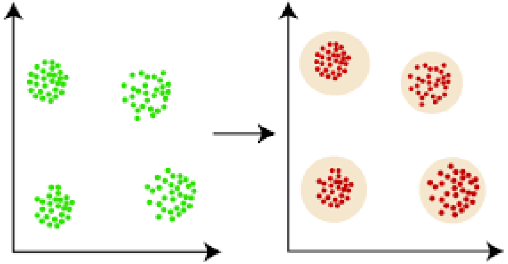




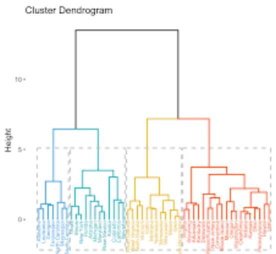


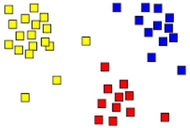
Data clustering

- Some algorithms can be used for cluster analysis. Search of common patterns by means of merging similar samples.
- Classification tasks.



Showing four clusters formed from the set of unlabeled data

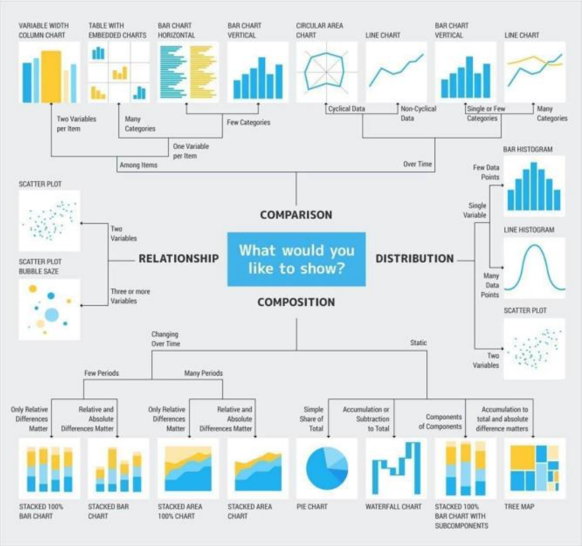




Optimisation of pickling process control and management by model-based simulation tools

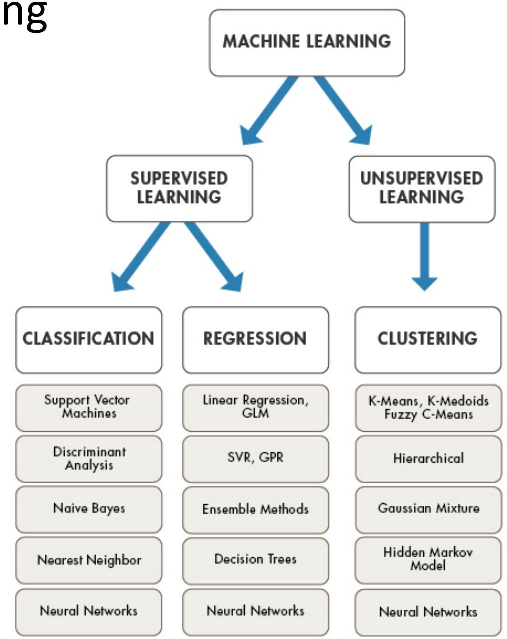
Data representation

- Data representation (e.g. plots, barcharts, etc.) of results for further discussion with experienced personnel.



Machine Learning algorithms

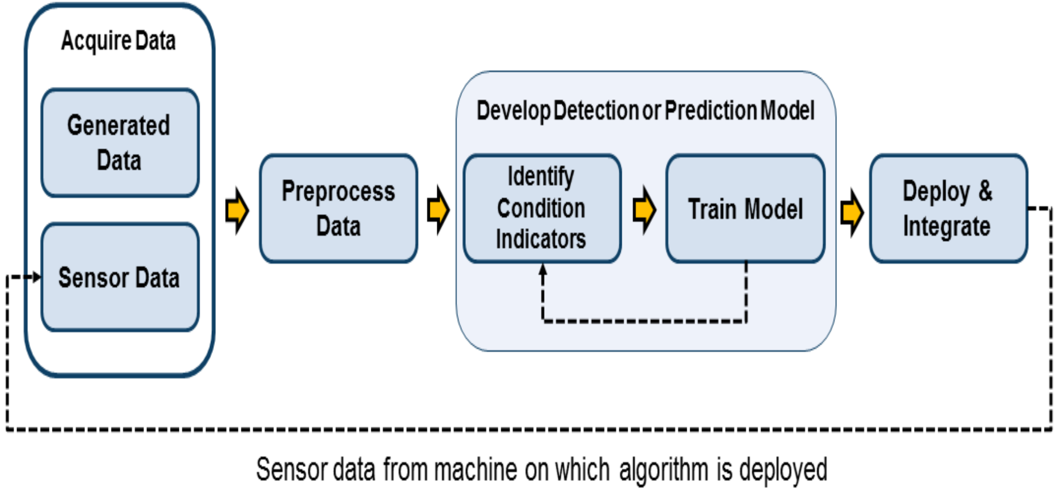
- Supervised versus unsupervised learning



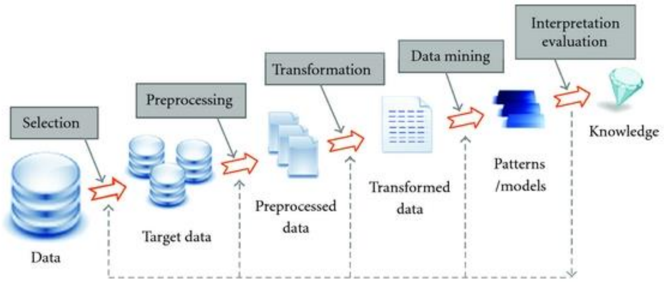
Optimisation of pickling process control and management by model-based simulation tools

Development of the process model

- Condition Monitoring and Predictive Maintenance



General procedure



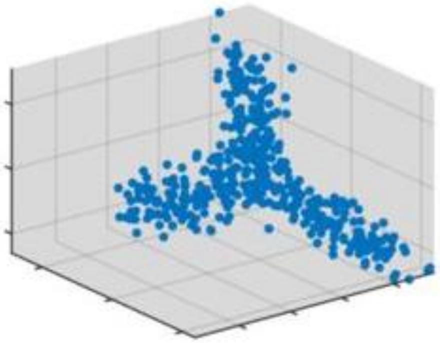
SensorControlPilot (I)

- Estimation the pickling strip speed by means of a model that indicates the mean values and standard deviation of the maximum speed for different conditions in the pickling line.
- Neural Gas network as model to establish a probabilistic distribution of the pickling line speed. The main idea is to calculate the optimum strip speed of the pickling line given the remaining process variables. Data from the hot rolling mill and the pickling line were used.
- Two different trained models were considered depending on the material destination: chromium or tin.
- The aim is to obtain a set of prototypes of coils by the application of this kind of algorithms. These prototypes are synthesizing all the information of the coils and they can be used to estimate the optimum strip speed of the pickling line.

SensorControlPilot (II)

- The following process variables were used to train the neural model:
  - for tinned material destination: hot rolling coiling temperature, initial strip temperature, iron concentration in bath 1, acid concentration in bath 1, steel type, destination, strip thickness, strip width and pickling line speed.
  - for chromed material destination: hot rolling coiling temperature, destination, steel type, iron concentration in bath 1, acid concentration in bath 1, pickling line speed and strip thickness.

- The euclidean distance within input data space for taking out the estimation of the strip speed setpoint.



MACOPilot

Development of an innovative pickling program management model based on online data of the wire rod pickling plant process.

- Specification of the pickling dwell time before the beginning of the pickling treatment by the management software tool.

- Selection of the dip tank by means of the management model based on the current process data for optimal pickling result.

- Simulated testing of the new pickling program management for wire rod pickling plant operation of DEW

Initial study of the variables affecting the effectiveness of the pickling process

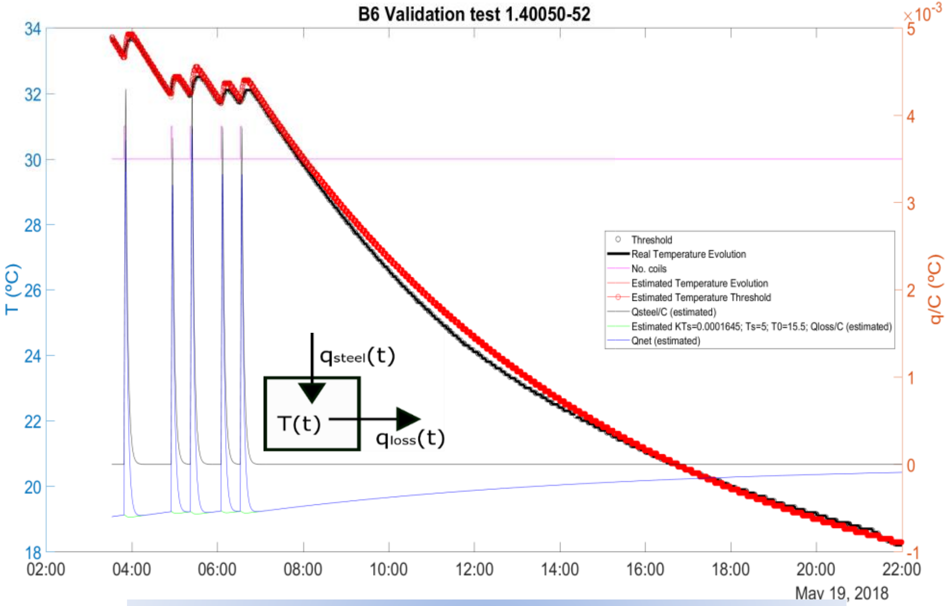
- Acid mixture composition and free Fe content. → stable due to acid bath regenerations.
- Steel type and allow composition.
- Previous heat treatment (austenization, annealing, tempering…).
- Dwell time and number of consecutive pickling operations.
- Hydraulic conditions in the acid baths.
- **Mixed acid bath temperature.**

} Fixed variables in the process datasets (dictated by steel code)

The temperature dynamics in the pickling baths are increased during the treatment due to the combination of the pickling exothermic reaction and the cooling system refrigeration.

The **control of the temperature** is essential for the development of the pickling:

- Too low temperatures decrease the efficiency of the pickling reaction (poor treatment results): recommended to pickle over 25 ºC.
- Too high temperatures affect the results of the pickling (more risk of overpickling and toxic steam emissions): higher temperature limit set at 40-45°C.

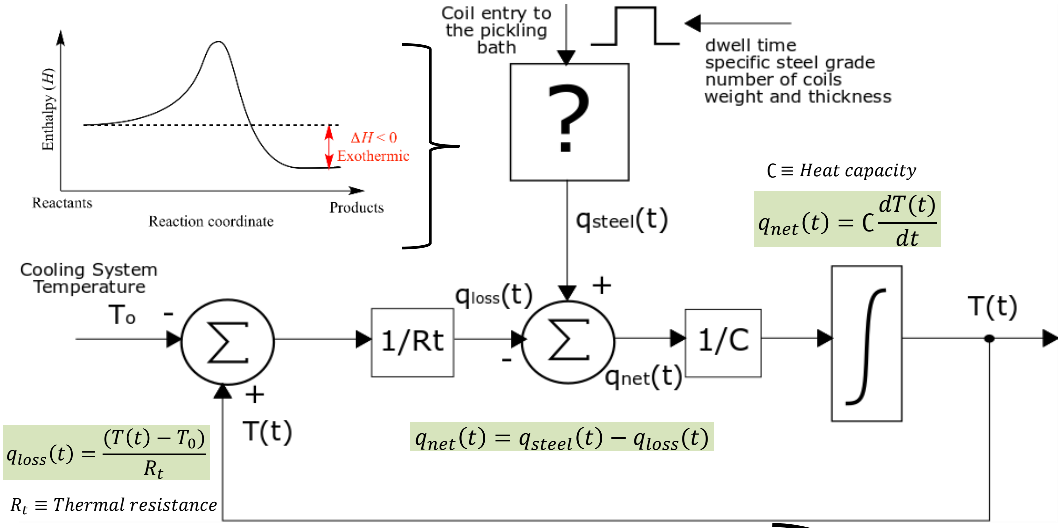


Necessary to develop a model of the temperature dynamics which can predict its evolution. →

Identification of the heat flux distribution due to:

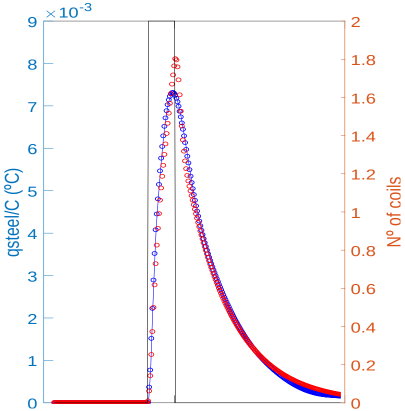
- Pickling exothermic reaction.
- Cooling system dynamics.

Development of the pickling programme management model



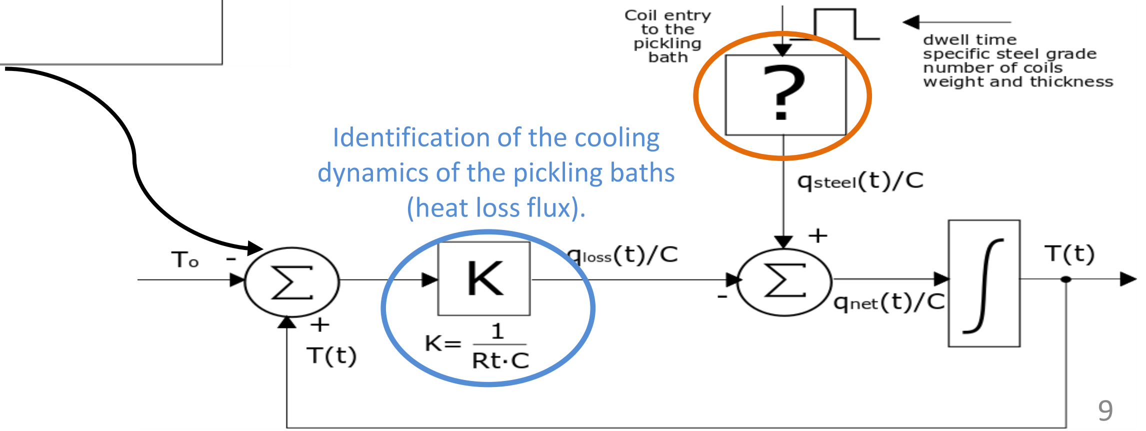
TF models for the behaviour of the steels in the acid exothermic reaction (pickling process): heat flux distribution identification and prediction for the pickling reaction.

Obtained by ARMAX identification concerning bath temperature datasets for wire rod materials.



Obtaining the heat flux distribution corresponding to the temperature evolution as a result of the combination of the cooling system and pickling reactions.

Identification of the cooling dynamics of the pickling baths (heat loss flux).



Analysis of process variables influencing heat flux and temperature evolution

Important differences between each **type of steel**

- Martensitic: special care (reaction triggered, steam emission, short dwell times).
- Austenitic and duplex: hardest to pickle, not important for temperature troubleshooting or overpickling.
- Ferritic: easiest to pickle, medium size dwell times.

Noticeable differences between steels of each category → The more alloy, the more difficulty in pickling. → TF model for each steel code

The **amount of previous pickling stages** carried out affects the subsequent pickling operation. → **TF model for each steel code in each pickling stage**

Reducing the shooting of the temperature (since a large part of the scale has already been eliminated previously).

Analysis of process variables influencing heat flux and temperature evolution II

Fixed dwell times for each pickling programme
Exothermic reaction not finished before the coil is taken out → Martensitic steels

Speed of chemical reaction affects the heat flux produced by the exothermic reaction of each pickling operation.

Variable equivalent to reaction speed →

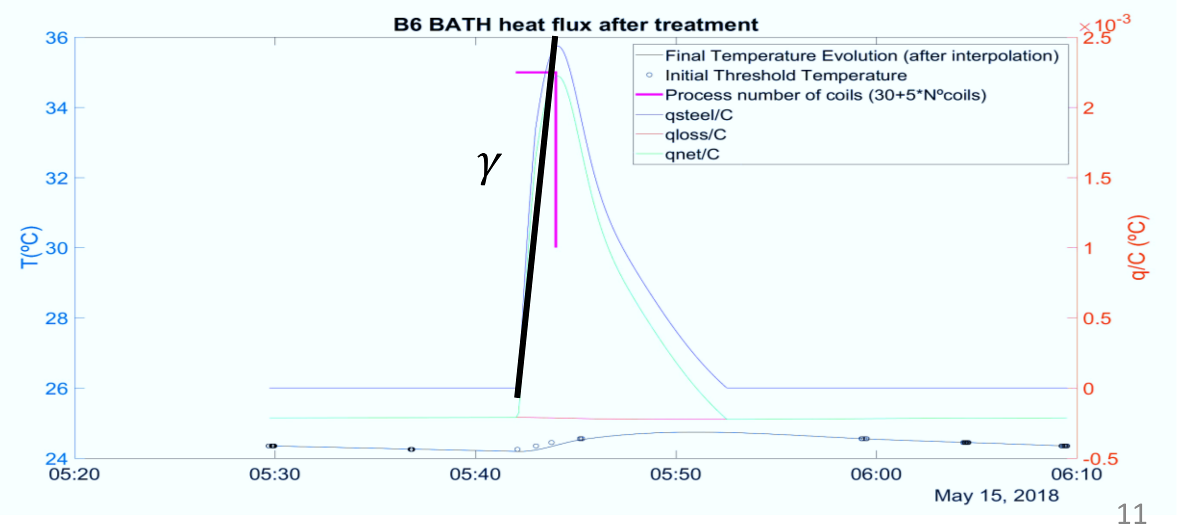
$$\gamma = \frac{\left(\frac{Qsteel_{max}}{C}\right)}{Dwell\ time}$$

Average speed of the heating

Temperature evolution affected by the speed of the reaction.

$\uparrow \gamma \longrightarrow \uparrow Qsteel_{max} \longrightarrow \uparrow$ Temperature triggering

(for a fixed dwell time)



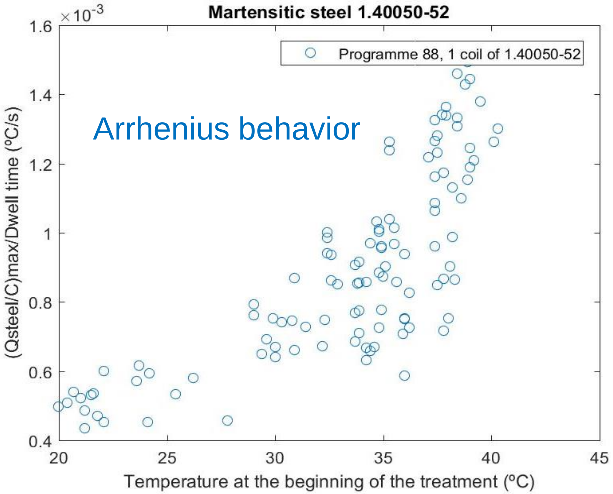
Analysis of process variables influencing heat flux and temperature evolution III

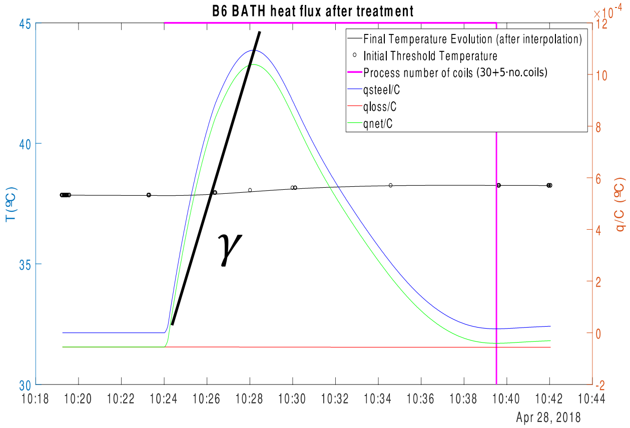
- Variables affecting the speed of the chemical reaction due to the pickling process

Temperature of the bath (ºC)

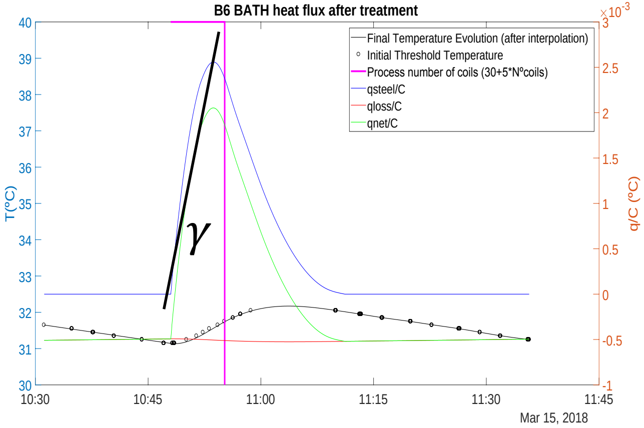
Affects the speed of temperature heating and cooling

- Higher dependence for martensitic steels
  - Lower dwell times (≈ 3 min).
  - Reaction not completed when the coil is taken out of the bath.
  - Greater temperature triggering for higher bath temperature.
- Medium dependence for ferritic steels
  - Medium dwell times (≈ 8 min).
  - Reaction almost completed before the coil is taken out of the bath ($Qsteel_{max}$ reached).
- Lower dependence for austenitic/duplex steels
  - Higher dwell times (≈ 15 min).
  - Reaction and temperature triggering completed before the coil is taken out of the bath.





Heat flux distribution, three coils of duplex steel 1.44620-54 (B6 tank)



Heat flux distribution, two coils of ferritic steel 1.47420-02 (B6 tank, BP 40).

Analysis of process variables influencing heat flux and temperature evolution IV

- Variables affecting the contact surface area for the reaction

Weight (Kg) and thickness (mm) of the coil

- Considering **approximately the same density** for every steel type, they can be considered as the variables to evaluate the influence of the pickled surface in the reaction.

Contact surface $A \approx \pi D L$

Volume $V = \dfrac{\pi D^2}{4} L$

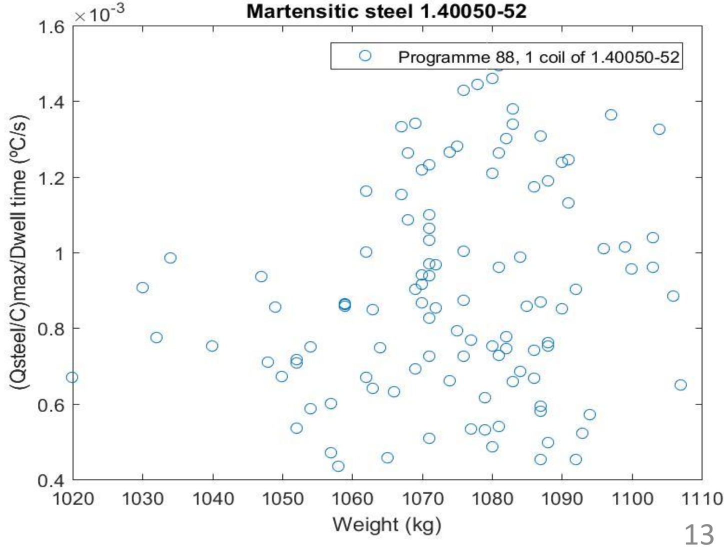
$$V \approx \frac{DA}{4}$$

For coils of the same weight, $V_1 \approx V_2$

$$A \approx k\frac{1}{D}$$

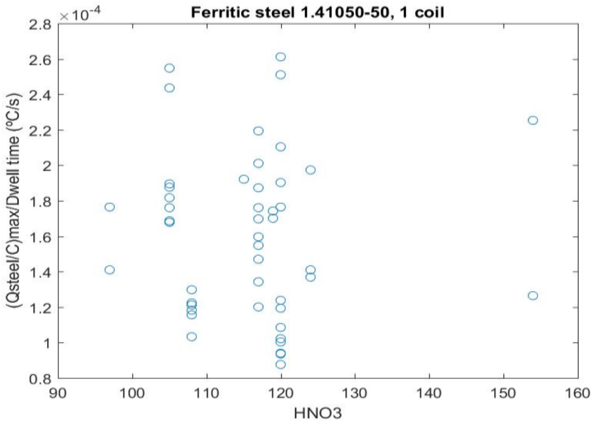
- The higher the weight, the higher the volume and the greater the contact surface.

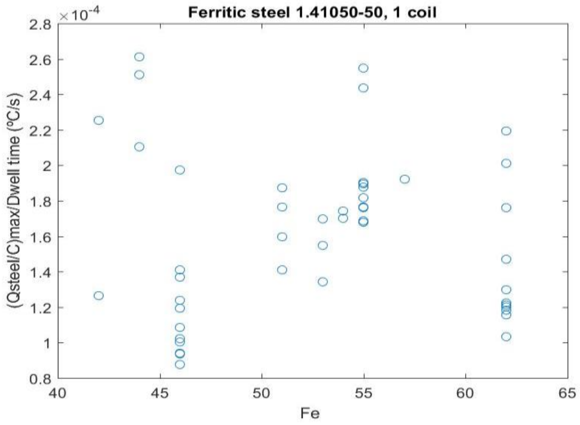
$$W \approx V \approx k'A$$

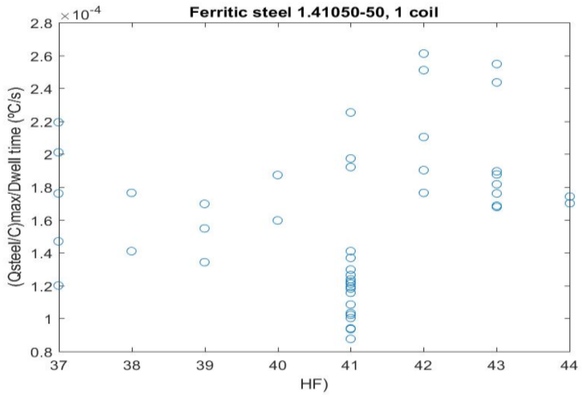


Analysis of process variables influencing heat flux and temperature evolution V

Influence of the % of acid and free Fe in the dynamics of the temperature and heat flux

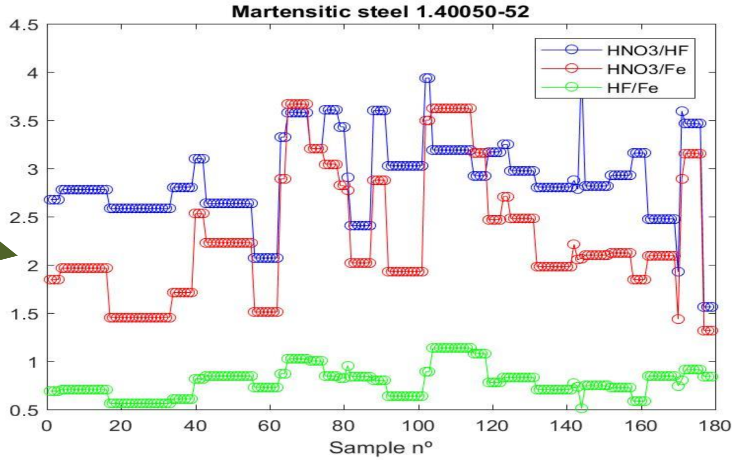






important for the efficiency of pickling process and avoiding overpickling or underpickling (relation free HF/Fe salt)

Relation between free HNO_3, free HF and Fe salt concentrations → Controlled due to pickling bath regenerations (open-loop concentration control system)



Obtaining the pickling TF models (Identification of the heat flux due to the pickling reaction)

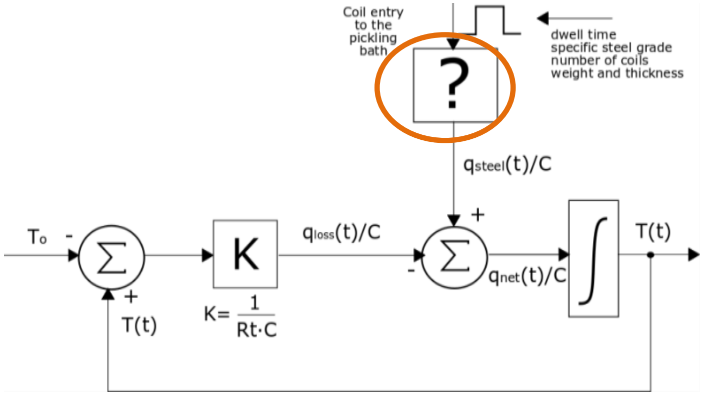
- Splitting the data to form a training dataset representative for the *qsteel*(t)/C heat flux triggered by the exothermic reaction of **each steel grade concerning the pickling stage**.

- *qsteel*(t)/C is standardized **per unit of weight and thickness**.

- Establish **zones of linear behavior regarding bath temperature ranges** for which the *qsteel*(t)/C heat flux is obtained.

- Input variables: number of coils introduced for a single pickling operation, dwell time, weight and thickness of the coil.

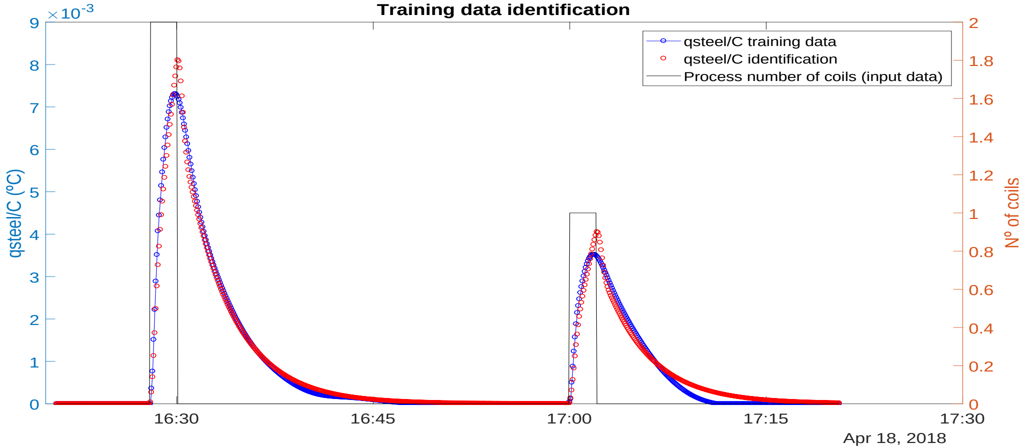
- Identification application: ARMAX model for the dynamics of the pickling process.



Model obtained for each steel and each pickling stage.

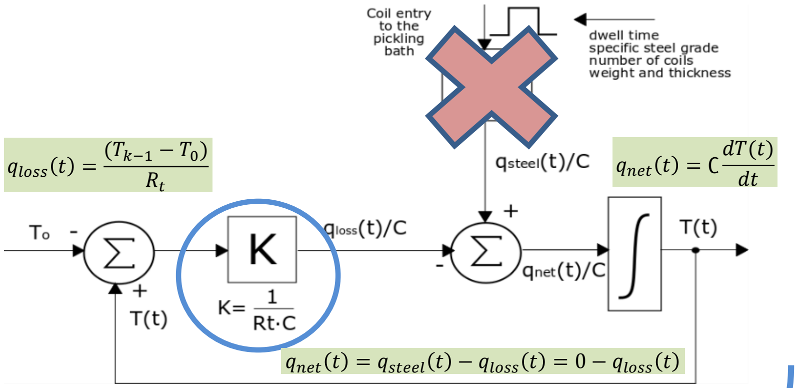
↓

Composed of a set of bath temperature ranges for which a transfer function is established.

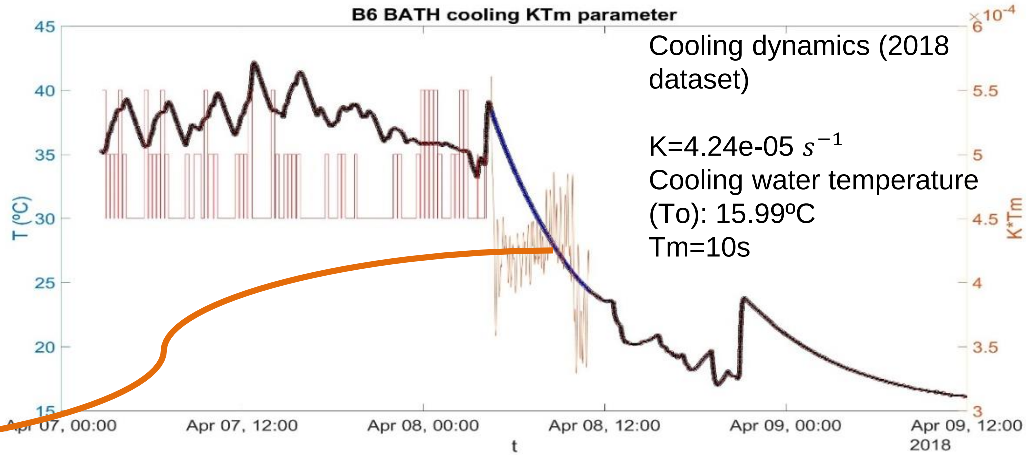


Martensitic steel 1.40052-52
Stage 1 of pickling programmes 88 and 89

Cooling system dynamics



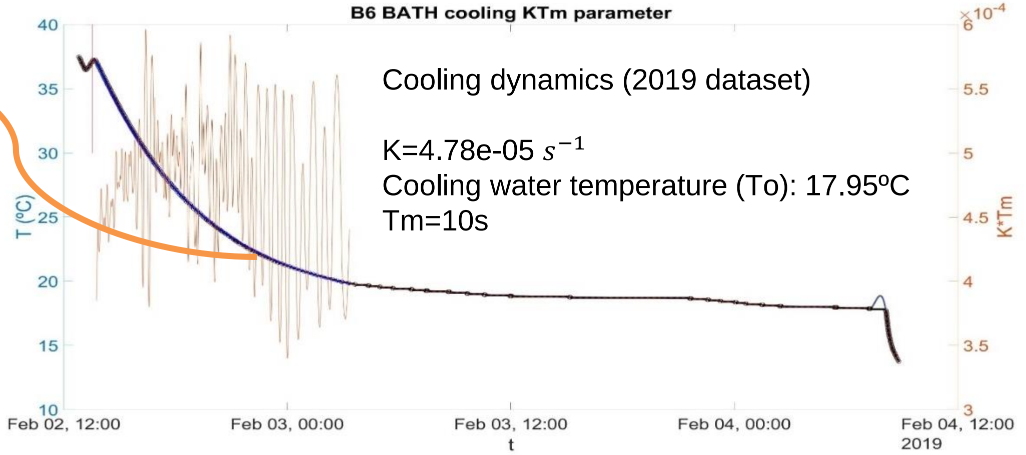
$$\frac{q_{loss}(t)}{C} = \frac{dT(t)}{dt} = K \cdot (T_0 - T_{k-1})$$



K parameter (constant) for the dynamics of the cooling system.

- K do not depend on To.
- Evaluates the performance of the cooling system (resistance and constant of the coolant fluid).
- Better cooling performance → ↑ K

Affected by wear
↓K ↑Wear



Development of the pickling programme management model

- Functions programmed in .m archives to obtain both the training data and the validation data. Variables established in matrix format and data vector.
- Scripts in .m archives to obtain heat flux distributions and training variables in order to get the transfer function (TF) models.
- Transfer function models obtained with ARMAX identification for each steel treated in each pickling programme stage (stored in .mat archives).
- .m scripts to carry out simulations and offline testing of the heat flux distribution and the temperature evolution for each combination of:

  - Coil characteristics: steel code, thickness and weight.
  - Pickling programme and stage of the pickling sequence.
  - Dynamics of the cooling system (K parameter).

Training data (datasets from March to June of 2018)

Validation data (datasets from January to March of 2019)

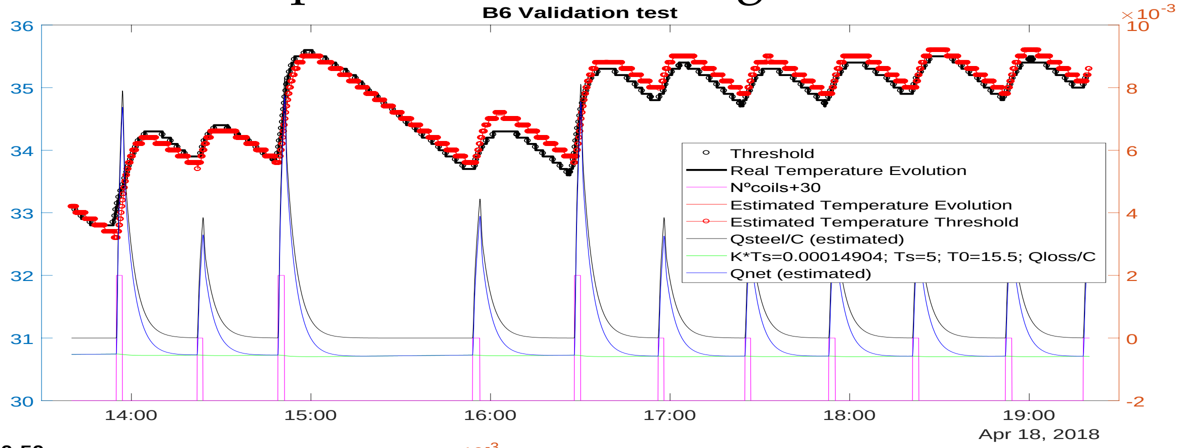
Offline-simulated tests and optimization investigations

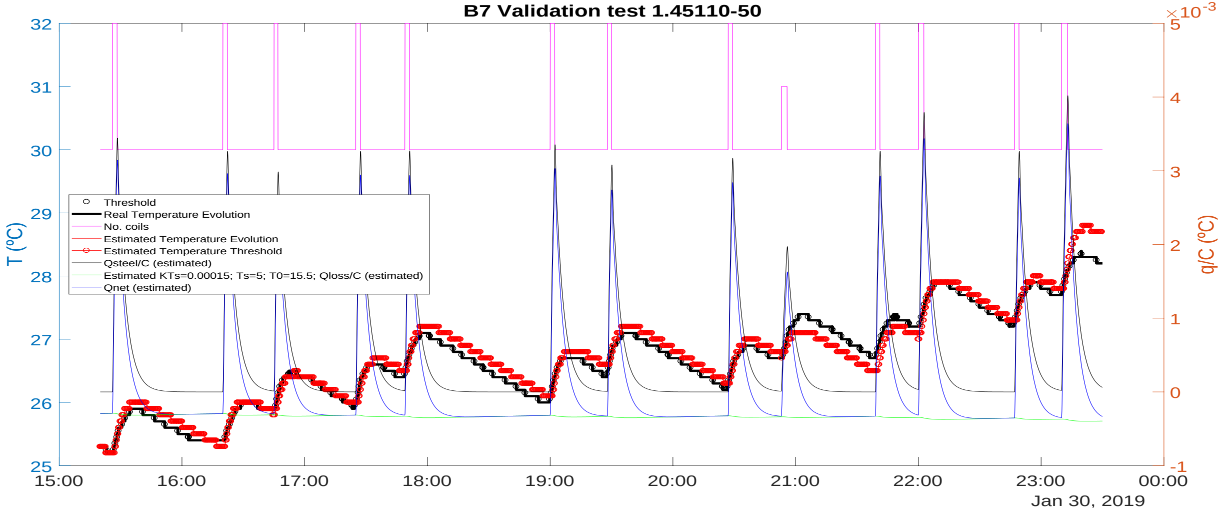
Martensitic steel 1.40052-52

Stage 1

TF in range between 30 and 35 ºC

Pickling programme 89





Martensitic steel 1.45110-50

Stage 1

TF in range between 25 and 30 ºC

Pickling programme 89

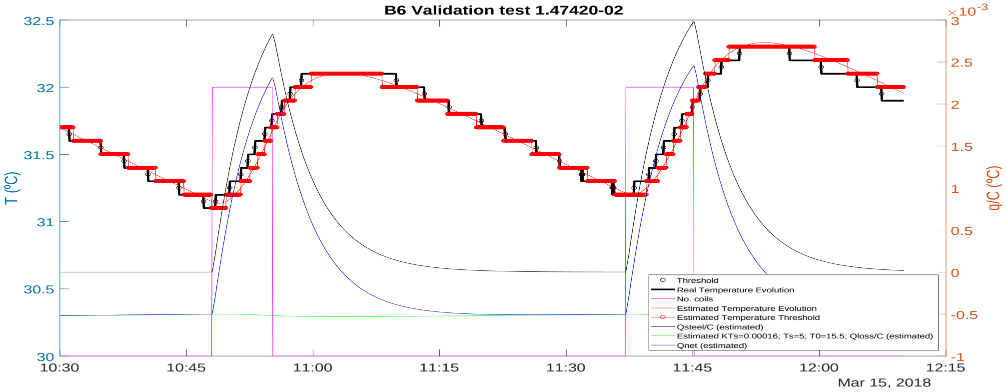
Offline-simulated tests and optimization investigations II

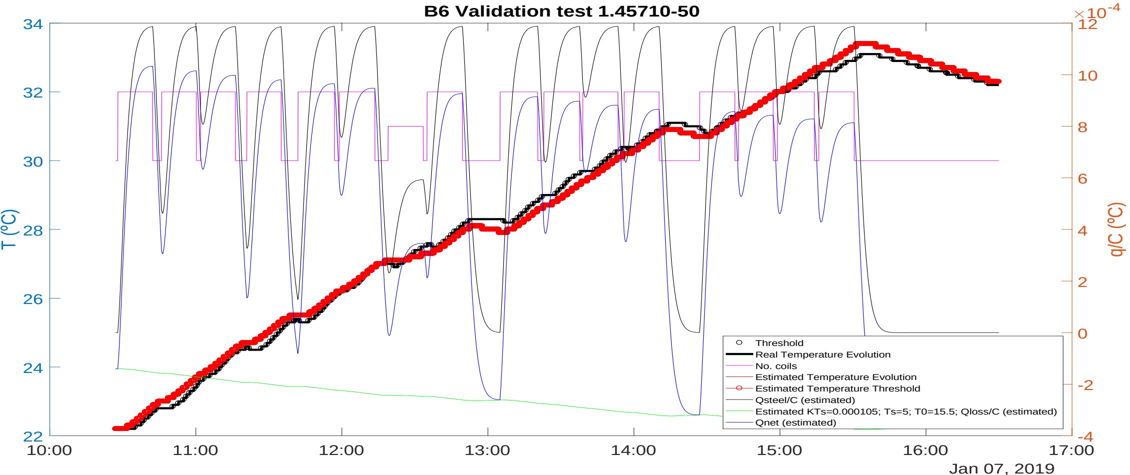
Ferritic steel 1.47420-02

Stage 1

TF in range between 30ºC and 35ºC

Pickling programme 40





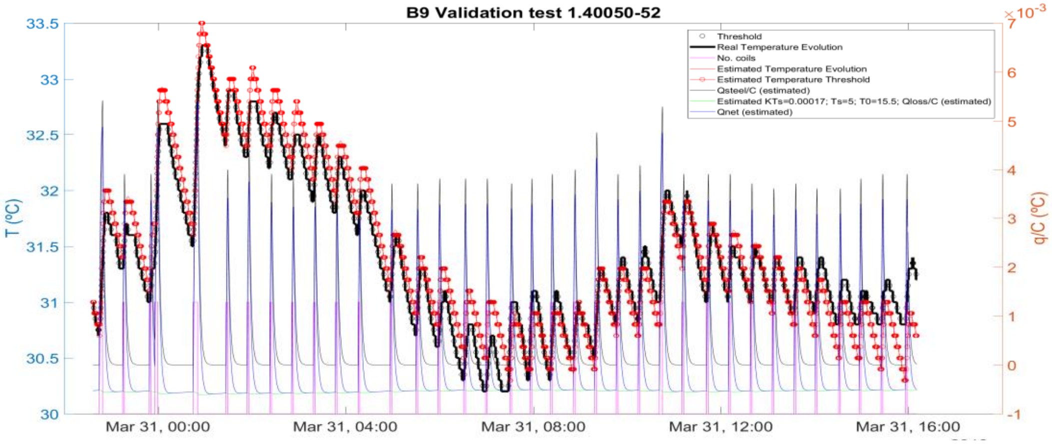
Austenitic steel 1.45710-50

Stage 1

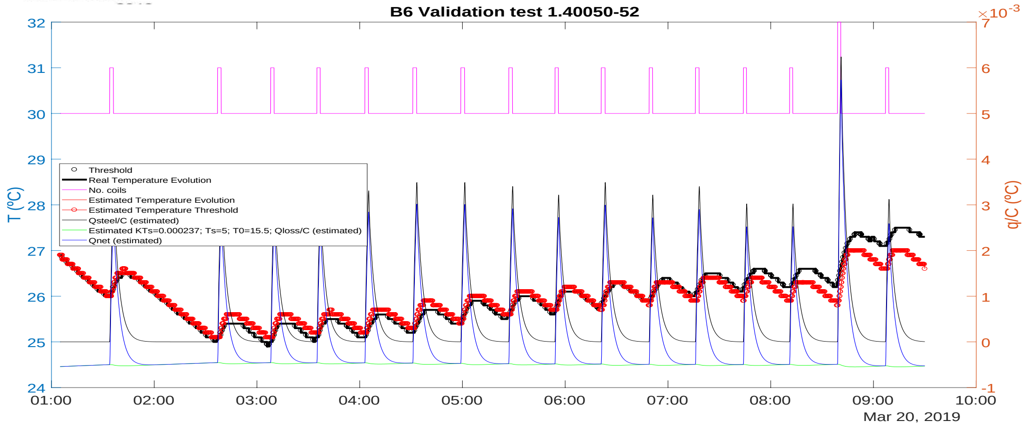
TF in range between 20ºC and 30ºC

Pickling programme 23

Offline-simulated tests and optimization investigations III



- Martensitic steel 1.40050-52
- Stage 2
- TF in range higher than 30ºC
- Pickling programme 88



- Martensitic steel 1.40050-52
- Stage 1
- TF in range between 25 and 30 ºC
- Pickling programme 88

Establishment of the platform for the online model

The online model (GUI application) is programmed under Matlab environment and can be run as a script (.m file).

- Functions and complementary scripts programmed in .m files (modifications must be carried out in Matlab environment).
- Transfer function models obtained with ARMAX identification for each steel established as .mat archives.
- Editable .xlsx file including the pickling programme characterization (BEIZPROGRAMM.xlsx).

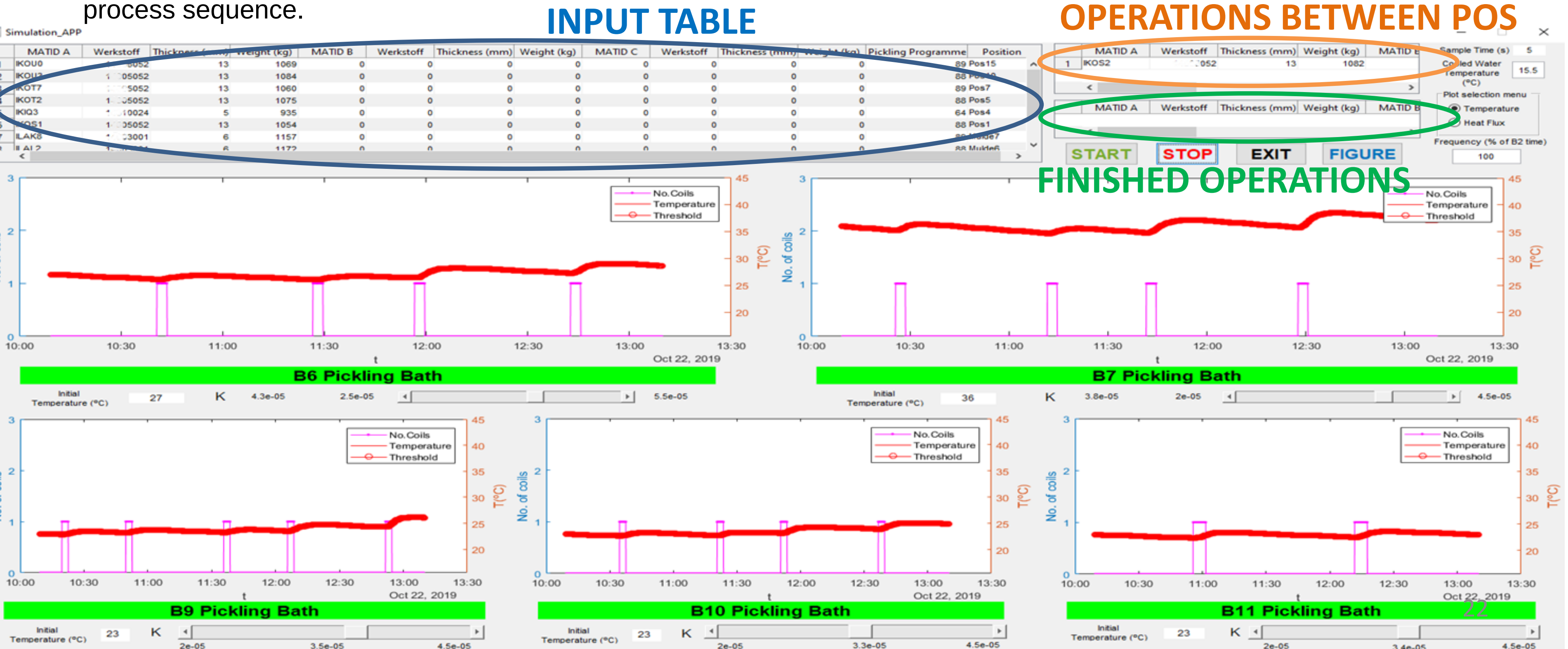
The GUI application can be run outside Matlab environment (standalone application).

- Executable file .exe included in the same folder as the model files (.mat) for the stainless steels and the BEIZPROGRAMM.xlsx.
- User-friendly graphical interface with multiple options to simulate and evaluate the evolution of the temperature due to a pickling sequence.

GUI versions for the pickling management tool

Supervision version

- Graphical User Interface for the continuous supervision of the pickling process concerning data from the database system (refreshes every minute to synchronize the database system).
- Predictions for the evolution of the temperature of the pickling baths and the heat flux distribution generated by the pickling process sequence.



GUI versions for the pickling management tool

Supervision version

- The frequency between single operations can be increased or reduced percentage-wise.

- The figures plotted in the user interface can be changed between Temperature (temperature evolution) and Heat Flux (heat flux distribution).

- The water temperature of the cooling system can be modified regarding the current necessities.

- The temperature of the pickling baths is captured and actualized from the database system every minute, and it is established as the initial temperature for the simulations.

- The efficiency of the cooling system (K parameter) can be increased or decreased regarding the current necessities for each pickling bath.

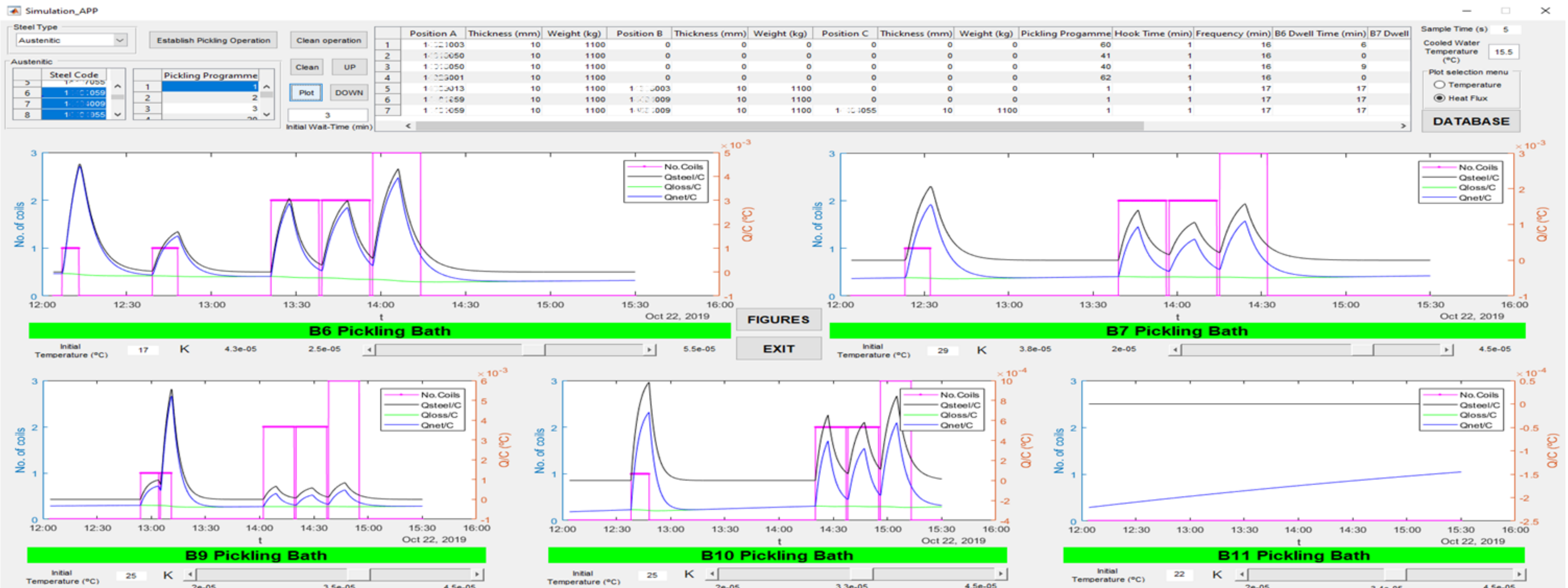
- The pickling process sequence is established avoiding overlaps between processes.

- The simulation avoids operations which are already in positions after pickling baths and does not consider stages of the pickling already carried out.

GUI versions for the pickling management tool

Logistic version

- Graphical User Interface to manage the logistics of an integral pickling sequence.
- Predictions for the temperature of the pickling baths and the heat flux distribution generated by a pickling sequence.
- The pickling sequence is obtained from the database system and can be modified (all variables in the input table are editable, and processes can be also included from the user interface selection menu).



GUI versions for the pickling management tool

Logistic version

- The figures plotted in the user interface can be changed between Temperature (temperature evolution) and Heat Flux (heat flux distribution).

- The cooled water temperature of the cooling system can be modified regarding the current necessities.

- The temperature of the pickling baths is captured from the database system when the PLOT button is pressed, and it is established as the initial temperature for the simulation.

- The efficiency of the cooling system (K parameter) can be increased or decreased regarding the current necessities for each pickling bath.

- The pickling process sequence is established avoiding overlaps between processes. The simulations are done considering the whole information contained in the input table and maintaining the operation order established.

- Press PLOT button to carry out the simulation of temperature evolution and heat flux distribution regarding the sequence and the information established in the input table.

GUI versions for the pickling management tool

Additional characteristics

- New steel models can be added and recognized by just including them in the application folder (.mat archives).
- Pickling programmes can be modified or created by editing the file "BEIZPROGRAMM.xlsx" (respecting the format and proportions of the document).
- When opening both applications, the connection to the database system is evaluated, delivering error messages when the connection fails.
- After the connection to the database system is successful, the file "BEIZPROGRAMM.xlsx" must be selected and charged to the application (a window will pop up for its selection, delivering error messages if the file selected is not "BEIZPROGRAMM.xlsx").

Thank you for your attention!

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