CONTROL OF BATH TEMPERATURE

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ABSTRACT

A constant bath temperature close to the liquidus temperature is needed for high current efficiency and long pot life. In daily pot operation the bath composition, the pot voltage and the metal height are used to control the bath temperature. At the TMS Annual Meetings of 1992 and 93 [1,2] a model was presented to control the AlF_3 concentration of the electrolyte. This model has been extended to control also the bath temperature. Conventional regression methods were used to determine a set of parameters, which describe the temperature behavior of the pot. Special account was taken of the time lag between actions on the pots and the reaction of the system. The paper shows, how the temperature model controls production pots, and it presents the corresponding operation results. A Graphic Pot Information System displays the predictions of the model which are compared visually with measured data. By changing pot parameters, such as the pot voltage on the screen, the reaction of the pots is studied interactively.

INTRODUCTION

Modern pot operation keeps the target value for excess aluminum fluoride concentration* $cAlF_3$ in the region of 10-15% (bath ratio R=1.17-1.04). Strong fluctuations of the bath acidity with time are observed together with similar changes of the bath temperature T_B (Fig. 1). In [1] the reason of these instabilities was discussed. The reactions of the pot e.g. $cAlF_3$ and T_B are delayed relative to actions of pot operation for instance adding AlF_3. Fig. 1 shows $cAlF_3$, T_B, the AlF_3 feed and the average pot voltage vs. time. The bath acidity stayed at $cAlF_3$ ~14% and the bath temperature at T_B~940°C for nearly 30 days during which virtually no AlF_3 was fed to the pot. The pot operators are then overreacting, leading to these fluctuations. Discussing further the reasons of the time lag between the AlF_3 feeding and changes in $cAlF_3$ it was hypothesized that AlF_3 is consumed or created in the electrolyte by the reaction of sodium fluoride or sodium from the bottom carbon blocks of the pots.

* The paper uses AlF_3 content, AlF_3 concentration, AlF_3 excess, acidity and $cAlF_3$ as synonyms. See also the chapter Explanation of Symbols at the end of the paper.

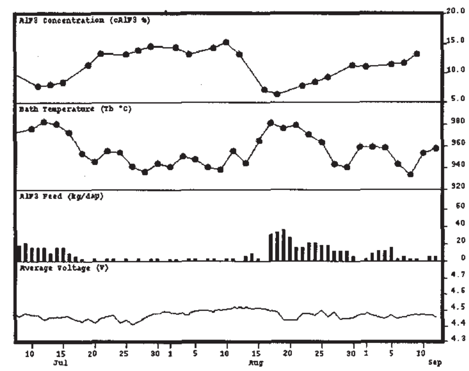

Figure 1: Fluctuation of bath temperature and aluminum fluoride concentration with time.

Using these ideas a mathematical model was developed to stabilize the AlF_3 concentration [1]. Experiences with this AlF_3-Model in several plants have shown that the model in fact reduces the fluctuations e.g. the monthly standard deviation of $cAlF_3$ but not the corresponding standard deviation of T_B in the expected amount. For a better control of the bath temperature the AlF_3-Model was extended to the so called Temperature-Model (T-Model). The model which is described in the following is a logical extension of the methods applied for the AlF_3-Model [1].

MODELING

Model Parameters

The time behavior of a pot is described by a set of linear equations. The parameters of these equations are determined in regular intervals by standard regression methods using the measured data of the past. In this way the model takes care of the individual pot states and adapts itself to slow changes for instance by pot aging (Fig. 2).

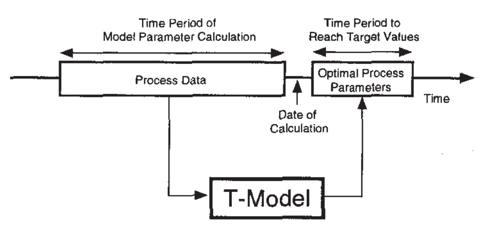

Figure 2: Principle of model calculation.

One can write for the bath temperature

$$T_B = a_0 + \sum a_i \cdot P_i \qquad (1)$$

where a_0, a_i are the model parameters i.e. the coefficients of the linear equation, P_i are pot values like the AlF_3 concentration or the pot voltage. The values P_i are calculated from the pot data i.e. actually measured data by averaging the pot data over a time period pP_i and applying a time shift tP_i. In this way the model allows for the limited accuracy of the measured pot data and the time delay of pot reaction.
Some pot data like $cAlF_3$ and T_B are not measured continuously or at the same time. To facilitate the practical calculation procedure, values are created for a specific date by interpolating linearly between measured pot data. Since these values together with the other data are transferred from the hard disk to the working memory, the calculation is considerably faster.
Pot operators can influence the AlF_3 concentration, pot voltage or metal height only indirectly by changing the AlF_3 feed, the set value of pot voltage or the amount of tapped metal. Equations which relate data like T_B, $cAlF_3$ and U_B are called state equations, whereas equations which contain process parameters like the AlF_3 feed or the set point of pot voltage are called process equations.
Example: the bath temperature was correlated with the AlF_3 concentration and the pot voltage over a period of 40 days. The result of this calculation is the state equation Equ. 2.

$$\begin{aligned} T_B &= 498.08 - 5.02 \cdot cAlF_3 + 114.36 \cdot U_B \\ pc &= 2,\ tC=0,\ pU=3,\ tU=1,\ R^2=82.0 \end{aligned} \qquad (2)$$

pC, pU are the time period and tC, tU the time shift to calculate $cAlF_3$ and U_B respectively. To find Equ. 2 the T-Model has calculated 441 cases by changing simultaneously pC from 1 to 7, tC from 0 to 6, pU from 1 to 3 and tU from 0 to 2 days all in steps of 1. Equ. 2 was then selected by its highest square correlation coefficient $R^2 = 82$.
Using the same principle to correlate $cAlF_3$ with $FAlF_3$ and T_B the following process equation was found

$$\begin{aligned} cAlF_3 &= 117.05 - 0.113 \cdot FAlF_3 + 114.36 \cdot T_B \\ pF &= 3,\ tF=12,\ pT=3,\ tT=1,\ R^2=95.4 \end{aligned} \qquad (3)$$

where pF, tF, pT and tT are the time periods and time shifts for $cAlF_3$ and T_B respectively. For Equ. 3 the program calculated 567 cases by changing pF from 1 to 3, tF from 1 to 21, pT from 1 to 3 and tT from 0 to 2 days in steps of 1.
Fig. 3 compares the calculated $cAlF_3$ and T_B values (solid $cAlF_3$ and T_B lines) using Equ. 2 and 3 with measured data (filled $cAlF_3$ and T_B circles).

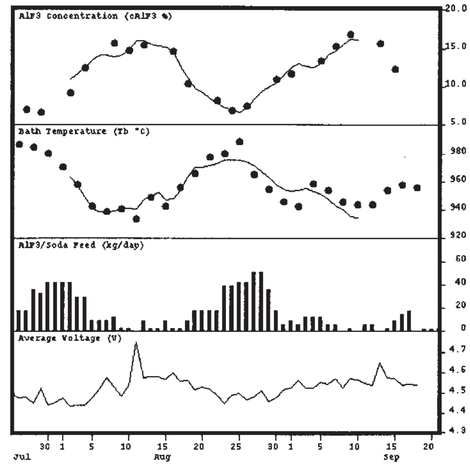

Figure 3: Comparison of model calculation ($cAlF_3$ and T_B lines) with measurements (filled $cAlF_3$ and T_B circles).

As to be expected by the high correlation coefficients the fit of calculation and measurement is quite good.

Optimal Values

Pot operators want to run the pots so as to reach economic and technical target values. When the pot equations describe pot behavior with sufficient accuracy they can be used to determine in a rational way the optimal process parameters to reach these target values.
To determine $cALF3_x$ and UB_x the optimal AlF_3 concentration and pot voltage Equ. 1 is rewritten as follows:

$$T_B(Target) = a_0 + a_1 \cdot \frac{\sum cALF_3 + cAlF3_x}{pC} + a_2 \cdot \frac{\sum U_B + UB_x}{pU} \qquad (4)$$

The summation is extended over the time periods pC and pU days respectively while the time shift tC and tU has to be taken into account.
Knowing $cAlF3_x$ and UB_x one can calculate the optimal values of the AlF_3 feed ($FAlF3_x$) and the set value of the pot voltage (PSP_x) using the corresponding process equation. Since some equations may contain the same variables ($cAlF_3$ and T_B in Equ. 2 and 3) several iterations must be calculated until the results are constant.
Example: In Fig. 3 the results of a calculation of $cAlF3_x$, TB_x, $FAlF3_x$ and PSP_x are shown.

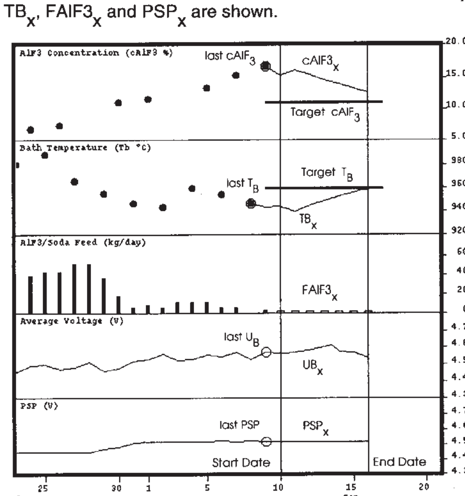

Figure 4: Plot of optimal values ($cAlF3_x$, TB_x, $FAlF3_x$ and PSP_x) calculated with the T-Model.

The calculation was done for the time period which is marked by the two vertical lines (Start Date and End Date). The last data which were available at the moment of calculation are marked with a big empty circle (last $cAlF_3$, T_B, U_B and PSP). Left of the last values the measured data (filled circles or filled rectangles) are plotted and on the right side there are the calculated optimal values ($cAlF3_x$, TB_x, $FAlF3_x$ and PSP_x). When new data are available they are overlaid on the plot over the measured values (Fig. 6 and 7). In this way the results of calculation can be compared with measurements.

Sudden Changes of the Pot State

Since the model parameters are calculated for regular time intervals the model, as already mentioned, adapts to slow changes of the pot state. After a change of alumina type for instance, the average AlF_3 consumption may however change abruptly because of the different content of sodium oxide of the alumina. In this case the prediction of the model would be wrong because the model parameters were calculated when the old type of alumina was used i.e. the model parameters referred to a different pot state (Fig. 5).

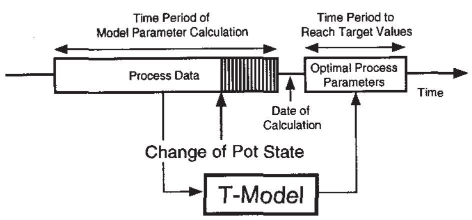

Figure 5: Schematic representation of a sudden change of pot state. The T-Model then uses virtual values which are derived from the actual pot data.

The T-Model takes care of this situation by using virtual values to determine the transition model parameters. The virtual AlF_3 feed for instance is increased for the time period of model parameter calculation according to the greater concentration of Na_2O in the new alumina type. These changes have to be predicted by experience with similar changes in the past.

POT INFORMATION SYSTEM

In [2] the Pot Information System was described which allows quick and easy access to graphic representation of measured data. It is an essential asset of the AlF_3-Model and the T-Model that the user can examine and verify the process data of a pot not only in form of numbers but also by visual inspection of graphic drawings.

The Pot Information System contains plots of pot data vs. time namely

- **Short Term Data Plot**: data like beam position, alumina feeding rate, and pot voltage are plotted with a time scale of hours,
- ***Long Term Data Plot***: *bath temperature, AlF_3 concentration*, bath and metal height, for instance, are shown with a time scale of days,
- **Data View**: small thumbnail size plots of key data are shown for several pots to facilitate inspection and comparison of the data.

Fig. 1, 3 and 4 are examples of the conventional Long Term Data Plot. On the computer screen these plots are actually displayed in windows. For this paper those parts of the windows system which were not essential for discussion, like menus, scroll bars etc. were removed.

Dynamic Graphic User Interface

The plot of the Pot Information System, as described in [2], contained only measured data. These plots were completed with values of model calculations which were overlaid over the measured data (Fig. 3 and 4).

When inspecting the results of model calculation, the user may in addition want to modify some of these calculated values. In the windows of the Dynamic Graphic User Interface (Fig. 6) these interactive modifications of model calculations can be done with a simple mouse action on the screen.

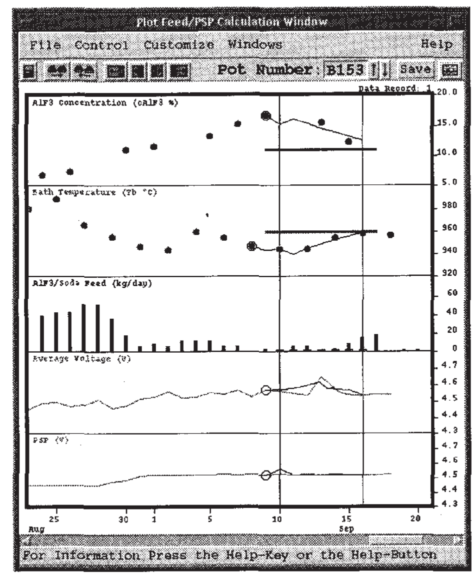

Figure 6: Dynamic Graphic User Interface

The T-Model values ($FAlF3_x$, UB_x and PSP_x) may be changed in the window of Fig. 6 by dragging a value ($FAlF3_x$ for instance) with the mouse. Dragging means pointing to the $FAlF3_x$ rectangle, holding down the mouse button and moving the mouse pointer to another place. A new $FAlF3_x$ rectangle is drawn and the model reacts immediately by calculating and plotting new $cAlF3_x$ and TB_x values. Fig. 7 shows the result of an extended interactive correction of model values. All the $FAlF3_x$ were set to 15 kg/day and UB_x to 4.50 V. Note the changed values of $cAlF3_x$ and TB_x in comparison to Fig. 6 . In this way the reaction of the pot, according to these changed values can be studied. The new values may be stored by clicking on Save, the save speed button (Fig. 6). They will be carried out on the pots the next day.

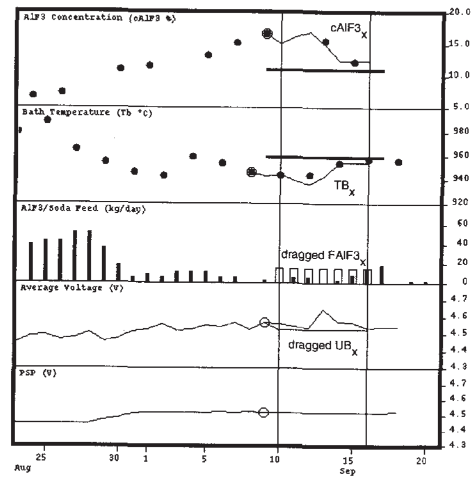

Figure 7: Result of dragging of AlF_3 feed and pot voltage. In comparison to Fig. 6 the courses of $cAlF3_x$ and TB_x are changed.

Fig. 6 and 7 correspond to Fig. 4. They were however plotted at a later time, and contain data which were measured after the calculation. One can compare the measured $cAlF_3$ and T_B values (full $cAlF_3$ and T_B circles) with the prediction of the model. In the same way one can verify if the optimal AlF_3 was fed properly by the automatic feeding system of the pots. This is done by comparing the empty $FAlF3_x$ rectangles of calculation with the full $FAlF_3$ rectangles of pot operation.

In a similar way parameters of the simulation calculation as in Fig. 3 may be interactively changed. For instance the time period of simulation is extended to predict the pot behavior, or the model parameters are varied to investigate their influence on the model.

RESULTS AND CONCLUSIONS

In Fig. 8 the data of a well stabilized pot are shown. The corresponding mean values and their standard deviation for the time period of June 1 to Aug. 15 (76 days) are:

$$cAlF_3 = 11.1 \pm 1.1 \ (\%),$$
$$T_B = 962 \pm 5.5 \ (°C).$$

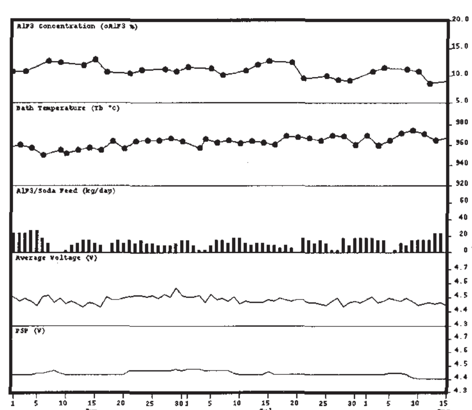

Figure 8: Example of a well stabilized pot.

These are typical values of pots which are controlled by the AlF_3- and T-Models.

Conclusions

The algorithm of the AlF_3-Model was extended to control the bath temperature, in addition to the AlF_3 concentration. The T-Model like the AlF_3-Model, takes into account a time delay for pot reaction after the corresponding action of pot operators. The models use state and process equations whose coefficients are calculated with regression methods from actual measured pot data. Optimal values of process parameters are determined to reach key target values of pot operation.

The Pot Information System was extended by the Dynamic Graphic User Interface. The user changes interactively the calculated values on the computer screen and can study the answers of the models which are plotted immediately.

EXPLANATION OF SYMBOLS

a0, ai:	coefficients of linear equations,
$cAlF_3$:	excess aluminum fluoride concentration (%). AlF_3 content, AlF_3 concentration and acidity are used as synonyms.
$cAlF3_x$:	optimal AlF_3 concentration (%) to reach the target bath temperature,
$FAlF_3$:	AlF_3 feed (kg/day),
FSoda:	Soda feed (kg(day),
P_i:	pot values calculated from pot data i.e. measured data by averaging over a time period and applying a time shift,
pC:	time period to average the AlF_3 concentration (days),
pF:	time period to average the AlF3 feed (days),
pU:	time period to average the pot voltage (days),
pP_i:	time period to average the pot value P_i,
PSP:	permanent set point of pot voltage (V),
PSP_x:	optimal permanent set point of pot voltage to reach the target bath temperature,
R^2:	square of the correlation coefficient,
T_B:	bath temperature (°C),
T_B(Target):	target bath temperature (°C),
tC:	time shift to calculate the AlF_3 concentration (days),
tF:	time shift to calculate $cAlF_3$ from the pot data (days),
tP_i:	time shift to calculate the pot value P_i,
tU:	time shift to calculate the pot voltage (days),
U_B:	pot voltage (V),
UB_x:	optimal pot voltage (V) to reach the target bath temperature.

REFERENCES

[1] P. M. Entner, "CONTROL OF ALF_3-CONCENTRATION", Light Metals 1992 ed. S. R. Cutshall (TMS, Warrendale, PA, 1991), 369-374.

[2] P. M. Entner, "FURTHER DEVELOPMENT OF THE ALF_3-MODEL", Light Metals 1993 ed. S. K. Das (TMS, Warrendale, PA, 1992), 265-268.