

The development of a process charge expert system for a Basic Oxygen Steelmaking plant.

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Abstract

In an integrated steelworks the Basic Oxygen Steelmaking (BOS) process is required for the refining of molten iron from a blast furnace to produce steel. The development of an expert diagnostic system is considered in the context of the initial phase of BOS operation, the loading and operation of the BOS vessel. In this part of the steelmaking process the BOS vessel is charged with the molten iron, scrap metal and fluxes which are there to facilitate the capture of impurities by forming slag. The nature of the elements added requires knowledge of the steelmaking process, the actual state of the contents of the vessel and the available process management options. The expert system produced to oversee this process exhibits the capability of dealing with both continuous and batch data, combining the two together to aid effective decision making and management. Fuzzy inference is used in the main diagnostic system due to the large rule base required to diagnose faults and infer a process state. The operation of the system and its use by the process operators and the application of this approach into other areas of the steelworks is considered in this paper.

Keywords: Basic Oxygen Steelmaking; diagnostic expert system; fuzzy inference.

1. Introduction

In 2012 the World Steel Association reported that approximately 1.5 billion tonnes of crude steel was produced worldwide [1]. In an integrated steelworks this process consists of molten iron being supplied by a blast furnace to the Basic Oxygen Steelmaking (BOS) plant, where it is refined to produce steel. The BOS process, outlined in section two of this paper, accounted for around 70% of this crude steel output worldwide. The objective of this research is to integrate expert systems (ES) into the operation of the BOS integrated steelmaking plant in Tata Port Talbot. The BOS plant expert diagnostic system that needs to be developed for Tata Steel Port Talbot needs to cover a wide range of process areas: scrap, hot metal, blowing, temperature control, refractory, gas

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recovery and tapping. It also needs the capability of dealing with two different types of data, both continuous streams and batch data, ideally combining the two together. Due to the large rule base that will be required to diagnose faults and infer a process state, for all of the process areas, fuzzy inference was initially used and developed for the main diagnostic system. This was due to its ability to deal with large rule bases and the usefulness and transparency of the inference in making the system more beneficial to the operators. This aim is considered in this paper in the context of the initial phase of BOS operation, the loading and operation of the BOS vessel.

The application of ES within the steel industry has become a more widely used technique within the last few decades. They offer the potential for making the process as a whole less reliant of expert personnel as knowledge is made more accessible. These applications have been fairly diverse, and have covered the entire integrated steel making process for a wide variety of applications, from scheduling to diagnostics with varying degrees of success. Consideration here is given only to applications in the BOS plant which is the subject of this paper, which has seen developments of ES in the area of end point prediction over the last decade. The main application has been to calculate endpoint temperature and carbon content, to allow back calculation and the adjustment of oxygen volumes and scrap weights to better hit the target temperature and carbon content. End point prediction using neural networks was assessed for application in Tata Port Talbot [2]. It was found that the neural network was able to model the process well, provided that the data used for training was carefully selected, and that the process didn't change by a large degree during the period. The system however wasn't implemented on plant, as the issues of maintainability and reliability were too large to justify the implementation.

An approach using Least Squares Support Vector Machines (LVSM) was applied to modelling a top blown BOS vessel [3]. This was seen as a better approach to the end point prediction than a multi-layer perceptron, which the author had previously used. The large data bases used made this method impractical without pruning but a robust method is applied to the pruned LS-SVM to improve the system's ability to deal with outliers within the data set, which would detrimentally affect the accuracy of the prediction. An overall accuracy of 77% was obtained using the robust solution, showing that this application was feasible. The application of SVM is also applied for the prediction of endpoint carbon and temperature [4]. In this case mutual information variable selection was used and the input variables which were endpoint carbon and temperature were weighted. This proved to be very successful, with both carbon and temperature within the target range, of 88%. There is also the application of SVM with spectral analysis of the furnace flame for temperature prediction [5]. The spectral analysis of the flame was found to require too much data for the system to function online, but proved better for offline analysis. The system achieved state recognition at 98.6%, and an ability to control the errors of the end point time prediction within 4 seconds. The further work outlined for the paper was use of the spectral data to show the specific state of the BOS.

The application of an Adaptive Network based Fuzzy Inference System (ANFIS) combined with Robust Relevance Vector Machine has been used to predict oxygen and scrap coolant requirements based upon endpoint carbon and temperature estimations [6]. The ANFIS classifier is used to determine whether coolant is required or not, then an ANFIS regression model calculates coolant and oxygen amounts, based upon metallurgical standards and sub-lance measurements. The models achieve a hit rate for carbon content of 93%, and 76% for temperature, which proves the system to be effective.

The application of Fuzzy Inference techniques has been very broadly and successfully applied with expert diagnostic systems. This method has been used to produce a linguistic output easily understood by the operator. The technique has been very popular due to its transparency for the operators, as it allows them to see the logic behind the inference and allows flexibility on fault definition. Recent developments in this area have been in using genetic and evolutionary algorithms, which give the fuzzy inference system a learning capability, by allowing rule generation from data sets. The use of Fuzzy Inference would be very applicable to the BOS especially for the main fault identification system, as it is capable of dealing with very large rule bases for the

faults, and can be designed in such a way to advise the operators on current process state, as well as identify specific faults. To ensure the system developed is a robust and comprehensive solution, it was considered likely that the fuzzy inference system will be used as part of a hybrid system. The development of a Principle Component Analysis or Partial least Squares, PCA/PLS system was also to be pursued to assess the potential benefits of combining the two techniques into a single hybrid system. The operation of the BOS plant is considered in section 2 of this paper, followed in section 3 by an overview of the needs of a process management system. Section 4 then presents the development of the expert system to the scrap adherence control process.

2. The Basic Oxygen Steelmaking Process.

The principle of the BOS process is to form steel by the reduction of carbon and impurity content within the molten iron by oxidation. The general layout of the BOS vessel is shown in Figure 1. In the integrated steelmaking process molten iron is produced within the blast furnace from mainly iron ore, sinter and coke. Torpedo ladles then transport the hot metal to the BOS vessel which is normally charged with the molten iron, scrap metal and fluxes which are there to facilitate the capture of impurities by forming slag. The torpedo ladles empty into transfer ladles, which, depending on the grade of steel being made, are either charged directly into the BOS vessel, or are passed through a desulphurization treatment; the low oxygen and high silicon and carbon content of the hot metal mean that this is preferable to undertaking sulphur removal in the BOS.

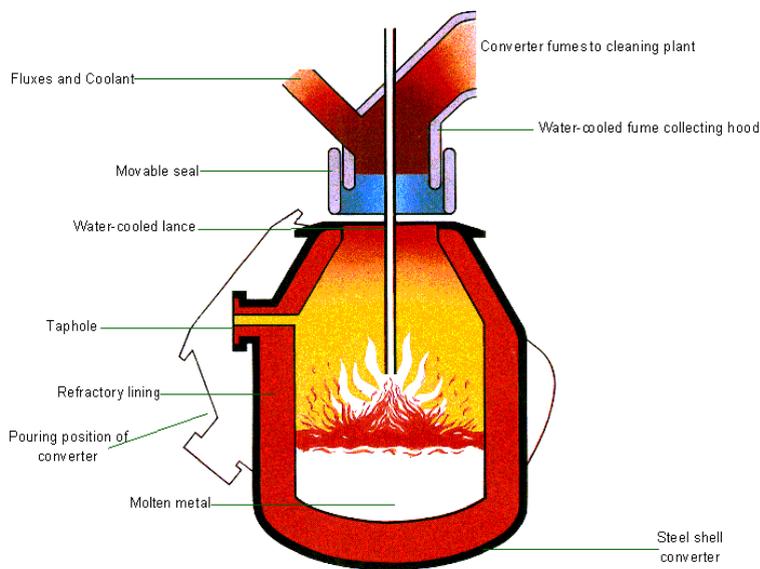


Figure1. Schematic of the BOS Vessel [7]

Within the desulphurizing unit, the transfer ladle that is already carrying the hot metal is charged through a nitrogen lance with pulverised lime and magnesium. The nitrogen is used as a carrier gas to effectively transfer the fluxes into the hot metal. It is used as it doesn't react with any of the materials in the hot metal, unlike air which would react with the silicon and generate large amounts of heat. The sulphur reacts with the lime and

magnesium to form calcium sulphide and magnesium oxide. The oxides formed have a melting point above the temperature of the molten iron, so they rise to the surface of the ladle as solids and settle in the slag. This slag is then skimmed off of the surface using a rabble, which is essentially a rake that is pulled across the top of ladle to remove the slag to a slag pot below. The removal of the sulphur rich slag is very important, as any slag left in the ladle will end up in the unfavourable sulphur removal environment of the BOS vessel, where the sulphur will most likely re-enter the steel.

After the hot metal, scrap is the second largest source of iron in the steel making process, accounting for 15-25% of the total metallic charge. Scrap is iron or steel that has been recycled; either from internal sources such as skulls, damaged strip or cuttings; or externally from end of life products, ranging from old industrial equipment, to incinerator scrap or even bales of used tin coated steel cans. Steel skulls are left over steel that solidifies within ladles within the steel plant, continuous casting and at the metal recovery site from the hot metal. There are two different sizes for this type of scrap; an “A” steel skull is over 300mm in size, and a “C” steel skull is between 22 and 300mm in size. Steel skulls are also formed in or around the desulphurisation process, and tend to be size “A”. The management of the use of this source of material by the expert system is considered in this paper.

The type of scrap that is charged is very dependent on the grade of steel being made. If it is a high quality grade which generally will be considered as very low in sulphur and residuals then extra clean scrap boxes are used to prevent the addition of any tramp elements or excessive sulphur to the steel. The chemical composition of the scrap is incredibly important in the manufacture of steel, as the introduction of tramp elements such as copper, molybdenum, tin and nickel cannot be oxidised and hence cannot be removed from the metal, only diluted [8]. The last section of the charge is the fluxes that are added to the vessel to form the slag. The purpose of these is to provide the environment within the vessel to allow the impurity oxides to be able to react out of the iron, and settle within the slag layer on top of the steel.

Once the vessel has been charged, a water cooled oxygen lance is lowered into the vessel and pure oxygen is blown through a converging diverging nozzle. During this process, argon is blown through the bottom of the vessel to cause a stirring effect increasing the efficiency of the vessel reactions. The pure oxygen then causes a large number of oxidation reactions, which refine the iron into steel. The first reaction to occur is the oxidation of silicon within the iron to form silica. This is a very important reaction within the BOS process, as the oxidation of silicon to silica is exothermic, which means the reaction generates significant amounts of heat. This heat increases the overall temperature of the charge, which causes the scrap to melt. The silica also then reacts with the fluxes, lime and dolomite, that are charged, to form the basic steel making slag. This slag is then used to help reduce the phosphorus content within the steel, as well as reduce other impurities.

The oxidation of carbon is the most extensive and important reaction within the process. It reduces carbon content from 4.5% to 0.05% via the formation of CO and CO₂ gas. The decarburization reaction is initially slow, as the silicon has a higher affinity to oxygen, and so oxidizes more readily than the carbon. The oxidation of the carbon speeds up once the silicon is significantly reduced within the hot metal. This reaction, like the silicon oxidation, is exothermic, and adds heat to the vessel, causing the vessel to heat up aiding scrap melting.

The oxidation of manganese from the hot metal is initially fairly constant, increasing as the silicon levels within the hot metal are decreasing. However towards the end of the blow the manganese content decreases, as more oxygen is available for its oxidation. Finally phosphorus removal is important within the BOS vessel, as the oxidizing environment within the vessel favors dephosphorisation, where phosphorus oxidizes to phosphorus pent oxide (P₂O₅). Here the slag basicity, essentially how basic (alkaline) the slag is, is very important for phosphorus removal. It's a ratio between the basic elements and the acidic elements within the slag, with phosphorus removal favouring a more basic (alkaline) slag.

The objective of this project is to design and development diagnostic systems for the BOS process, using new and novel techniques. To allow this to be easily managed and allow progressive deployment and testing of such systems, it was decided that there would be a number of separate systems developed looking at individual

aspects of the BOS process. The entire project uses Matlab, as it is widely and successfully used for other applications within other industries that share some similarity. The first area of development, due to its initial appearance of having a low level of complexity, was scrap adherence.

3. Process Management

There is a vast amount of data available made up of a continuous stream of data available through the process; other data is only available at certain stages on a heat-by-heat basis. The measurements available on a heat by heat basis that correspond to the BOS process can be split into five separate sections: Charge, In Blow, End Blow, Tapping and Slag Analysis & Procedures. Only Charge is considered here.

3.1. BOS Process Charge.

The charge as a whole consists of everything that is loaded into the BOS vessel. In general this will be the molten iron, also known as hot metal, scrap for cooling and the fluxes which are there to form the slags. The hot metal analysis from the sample and readings from the weighbridge gives a measurement of the parameters listed in Table 1. The hot metal can also go via the desulphurisation process and the measurements available from this process are also shown in Table 1.

Table 1 Available Charge measurements.

Available Measurements	Hot Metal and Weighbridge Analysis	Desulphurisation process	Scrap Box Type	Fluxes
	Carbon	Sulphur	Dirty	Lime
	Silicon	Treatment type	Normal	Dolomet
	Sulphur	Mg weight	High Residual	SiO ₂
	Phosphorus	Lime weight	Extra Clean	Gravel
	Manganese	Duration	Clean	FeSi
	Titanium	Skim Loss	Bales only	BOS Slag
	Nitrogen	Temperature drop		Ore
	Temperature	Flow rates		Limestone
		CaO purge		Doloflux

There are a large number of different types of scrap available during the BOS process for charging. The requirements of the grade of steel being made limits what scrap can be used. In general the different scrap types are combined into a large skip to form a scrap box. The scrap content is critical for the BOS, as the weights of the scrap are very important for cooling, as well as yield. If the scrap charged is lower than expected then there will be a drop in expected yield and over- heating within the vessel due to inadequate cooling. There is a large variety of different scrap types available providing flexibility if certain types of scrap increase in price when adopting more of other scrap types can keep costs down. There are six types of scrap box used for charging in Port Talbot, each having a different composition and sulphur content. This varies slightly depending on the total weight of scrap being charged, from 20 tonnes to 100 tonnes. There are variations in scrap boxes and usage to reduce costs where possible. The dirty scrap boxes have the highest sulphur content, and are the cheapest scrap box to use. The ultra-clean boxes have the lowest sulphur content, but also cost the most. If ultra clean scrap boxes were used for all grades, it would significantly affect the financial performance of the steel

plant, and so cheaper boxes are used on high sulphur grades, and more expensive low sulphur boxes used on the higher more valuable grades where low sulphur content is important. The last section of the charge is the fluxes that are added to the vessel to form the slag. The purpose of these is to provide the environment within the vessel to allow the impurity oxides to be able to react out of the iron, and settle within the slag layer on top of the steel. As with the scrap, the only measurement used for fluxes are the weights, which consists of two values; required and actual. The different fluxes used are shown in Table 1.

3.2. Scrap Adherence

When this area was reviewed it was discovered that the two main sections that needed to be considered were Scrap Box make up adherence and Quality Assurance adherence. An outside contracting company are responsible for all of the handling and processing of scrap on site. This ranges from externally sourced scrap being brought into site, to internally generated scrap, which is processed by a Metal Recovery Plant on site. The procedure from scrap mix selection to charging is as follows:

1. Charge Balance Model (CBM) coordinator selects scrap mix:
 - a. Based upon current Alumina (Al_2O_3) & Sulphur (S) levels
 - b. Taking account of available stock levels
2. Scrap Selection Passed Onto Contractor
 - a. Load scrap boxes 1-3 heats in advance
3. Scrap Box loaded with requested scrap mix
 - a. Weights and type of scrap loaded are recorded.
4. Scrap Box then charged when required

The main focus of the system for this section of the process is around point 3a. This data allows the system to assess whether or not the contractors have loaded the scrap weight that has been requested and that this is the correct mix of scrap. This has meant the system is able to cover scrap adherence by the contractor and highlight any issues with missing data, due to possible weighing issues. This involves looking at the differences between the weight and mix demanded by the CBM coordinator, and the weight and mix charged by the contractor. This is important for a number of reasons. It can highlight to the CBM coordinator that there is a potential stock issue; if there are low stocks of certain scrap types, then regardless how much is demanded, that scrap type will not be able to be loaded. Secondly there is an associated cost with each of the scrap types demanded with cleaner scrap such as mill products being inherently more costly. Clearly it is in the interests of TATA that performance is monitored and the BOS Plant gets the scrap mix that is demanded to reduce cost. The difference between the scrap demanded and the scrap charged is used to calculate the scrap adherence as a percentage, in equation 1.

$$\text{Adherence (\%)} = (\text{Weight}_{\text{Scrap Charged}} / \text{Weight}_{\text{Scrap Demanded}}) \times 100 \quad (1)$$

Simply calculating the level of scrap adherence and displaying it to the operator isn't sufficient as the operator would still need to discern the useful information. In this work it was thus decided that this should be provided by an expert system. To facilitate this development data analysis was undertaken on the overall performance across 1000 heats, to firstly see what level of scrap adherence is typical, and secondly to ascertain what level should the adherence drop to before making the operator aware of an issue. Due to the nature of the process it was concluded that it would be most useful to alert the CBM coordinator if adherence below 90% occurred for two or more consecutive heats for each individual scrap type, as this would highlight an ongoing issues such as crane faults or low stocks. The requirements thus placed on the ES by scrap adherence and the manner in which these were met will now be considered.

4. Outputs for Scrap Adherence

The outputs for this type of system need to be designed to be concise and easily understandable to enable the CBM coordinator to identify the issue quickly. There are two consecutive types of output that are identified within individual scrap adherence, the first termed “poor adherence” highlights if the adherence for a given scrap type has been below 90% for 2-4 heats. The second “low stock” output signifies poor scrap adherence arising due to low stocks and is indicated if there has been poor adherence of a certain scrap type for 5 or more consecutive heats. The loading of scrap is monitored through the logging of data provided on loading by the contractor regarding scrap type and weight. This data is uploaded throughout this process. However currently there are a number of occasions when certain parts of the process, such as the weighbridge, are not fully functioning and don’t record. This section of the system has been designed to highlight when this occurs, both on a heat by heat basis and also looking back across the last ten heats to see if this is a recurring issue. When this does occur, to ensure records are kept complete, the contractor is required to manually input the data, typically later on in the shift. It should be noted that there are a rare number of cases when a special process is being requested with no scrap demanded. This may appear in the record as being missing data. This happens when there is a recycle, which is a ladle of steel being brought back to be re-blown. Due to the potential for misinterpretation of missing data it was necessary to create a decision tree for the process, to allow the logic to then be programmed into the system to allow it to discern between missing or manually inputted data and a recycle. The logic is shown in Figure 2 indicates how outputs from the system differ.

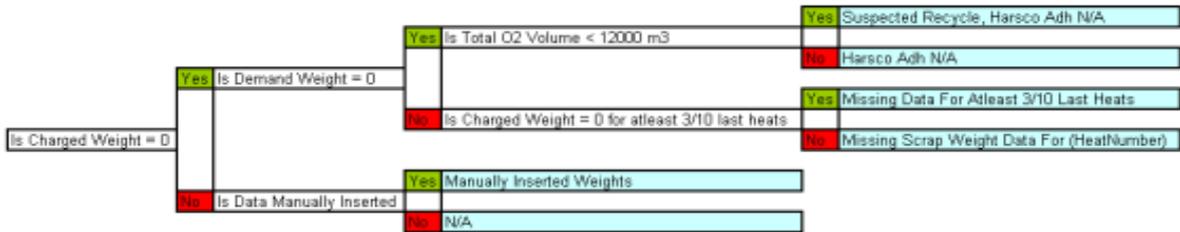


Figure 1. Decision Tree For Scrap Weight Data

As Figure 2 shows, when a recycle occurs, there is firstly no scrap demanded by the operator, and the blow is shorter, resulting in a reduced volume of O₂ being used. The outputs for this section shown in Figure 2 cover a number of different areas. The first is for missing data for a single heat, which is displayed to the operator in the following way: *No Scrap Weight Data Available*. If there was no data available originally, but contractor entered the data before the end of the heat, then the system displays the following message: *Scrap Data Input Manually*. If there is a recurring issue with the scrap weighing, to the point that at least three out of the last ten heats have had missing data the system displays the following message: *No Scrap Weight Data For at least 3 Out Of the Last 10 Heats*. Finally if there is missing data because no scrap was required, due to a recycle, then the system displays the following message: *Not Applicable, Suspected Recycle*.

4.1. Quality Assurance (QA) Procedures

QA procedures are implemented if either the Al₂O₃ or S limits are exceeded for a number of consecutive heats. The cheaper scrap types used, such as internally generated skulls are amongst the highest sources of S and Al₂O₃ entering the vessel, so the procedures instruct the operators to remove these scrap types incrementally to isolate the cause. For high Al₂O₃, it is often the case of excess fines (residues) within the scrap bays, so if there is an improvement in these levels when a certain scrap type is reduced or removed from the scrap mix, the respective scrap bays will get cleaned before reinstating the scrap completely.

4.2. An example of the ES development; Alumina QA

This element is used when there is an alumina issue. To fully understand why high alumina levels are an issue, it is worth explaining what effect alumina actually has on the slag, and more importantly on the process. The alumina within the slag affects the viscosity. Lower alumina slags are very viscous creating a poor emulsion and reduce the refining capability within the vessel. Alternatively, if the slag is too viscous, with high alumina content, then the slag will potentially mix too well into the steel, which will cause a large slag carry over at tapping, as the slag and steel will be difficult to separate. The actual implementation of the logic that was planned out for the alumina procedure required a lot of data, both directly from the plant databases, and data derived from calculations.

The implementation itself used a combination of simple programmable logic, as well as the application of Mamdani type Fuzzy Logic, to produce Fuzzy Inference Systems all of which was done within Matlab. The most important data for this is the slag alumina content, which is always given as a percentage. The procedure used within the system is best considered by setting out the steps:

- Step 1. 3 out of last 5 heats Al₂O₃ above 2.8%
 - a. Lag value set to 1
 - b. Data input into FIS 1
 - i. System advises reduction in scrap levels
- Step 2. Used scrap mix monitored by system
 - a. Whilst scrap mix not what system is advising
 - i. Lag value stays at 1
 - ii. FIS: Still advises correct mix
 - b. Once scrap mix set to what system is advising
 - i. Target heat number set to current heat number + 2
 - ii. Lag value stays at 1
 - iii. FIS: Advises to keep current mix
- Step 3. Once Alumina sample available for target heat number
 - a. Lag value set to 10
 - b. Al₂O₃ from last 3 heats evaluated by FIS 2
 - c. Data including evaluation of alumina levels input into FIS 1
 - i. If improvement
 - FIS1. Advises increase in scrap levels**
 - FIS2. Advises cleaning of relevant scrap bays**
 - ii. If no improvement
 - FIS1. Advises further reduction of other scrap types**
- Step 4. Previous lag value checked
 - a. Lag value set to 2
 - b. Stages 2, 3 repeated accordingly but with lag values 2 & 20

The first step of the alumina QA section of the system checks the last available alumina sample and the samples from four heats prior to this. If three or more of these have alumina content at or above 2.8% then the system begins the QA procedure for alumina control. When there is no alumina issue there is a variable set within the system called “Lag” which is set to 0. When this value is not 0, there is an issue with alumina, and depending on the value a course of action is required. If the lag value is a factor of 10, it is considered a decision point. It is these points within the system where the alumina content for previous heats gets evaluated and a new mix is advised by the system. However if the lag value is less than 10, the system simply advises the use of the mix calculated at the previous decision point.

The operation of the FIS1 can be defined in terms of its inputs and outputs:

- | | |
|--|--|
| There are a total of 6 different inputs into the FIS1: | There are a total of 3 outputs from the FIS: |
| 1. C Skull adherence (%) – shown in Figure 3 | 1. C Skull Output |
| 2. Incinerator adherence (%) | 2. Incinerator Output |
| 3. Alumina evaluation value from FIS2 | 3. QA Output |
| 4. Lag value | |
| 5. Prior C Skull output | |
| 6. Prior Incinerator output | |

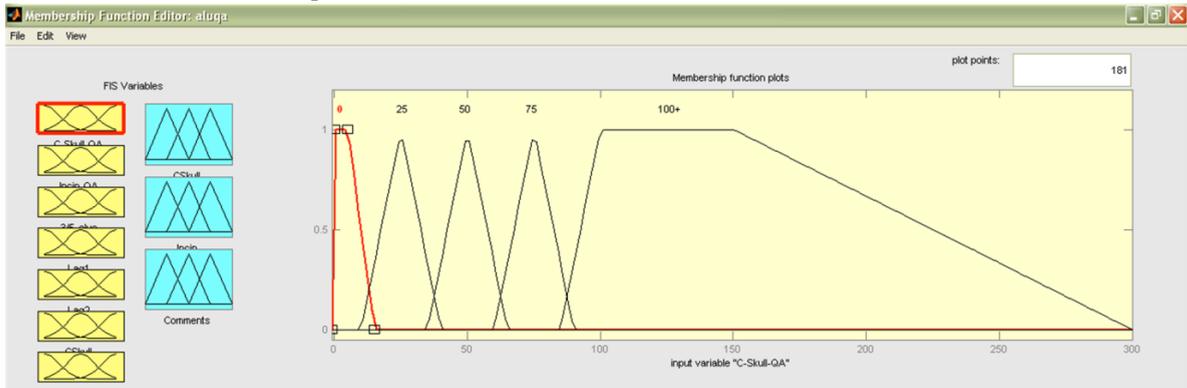


Figure 3. Membership Function For Input C Skull Adherence

There are membership functions for each of the inputs, as well as all of the outputs, an example of one of these is shown in Figure 3, which is used to assess and output suggested scrap levels for C Skull and Incinerator scrap based on alumina performance. The first two inputs are the current level of adherence against the calculated QA mix. This is entered as a percentage into the system and is evaluated to be a member of 1 of the 5 membership functions. The output from FIS 2 evaluates the alumina content of the last three available samples to assess if there has been an improvement in the alumina levels. The outputs from this have been structured so that the system deems there to have been an improvement if the output is below 3, and no improvement if above or equal to 3. FIS2 does however increase its output above 3, dependent on whether there has been no improvement or a worsening of the alumina levels, which is useful for monitoring of the system, and checking system outputs. This is only taken into account when lag values are greater than or equal to 10, as these are the decision points within the system.

Step 2 in the process is monitoring of the used scrap mix against the mix that the system advised. When the lag value is below 10, but not 0, the system takes account of the current scrap mix, and compares this with the previous outputs and simply advises whether these scrap types need to be reduced, kept at or increased to the values previously advised.

Step 3 uses the result from FIS2 where the alumina performance is evaluated. The output from this along with all of the other required inputs are put into FIS1 where the system calculates new scrap levels. If there has been an improvement in alumina levels, the system will advise increasing certain scrap types, and cleaning the scrap bays of the scrap type deemed to be the cause. If there has been no improvement in the alumina performance, then the system will advise further reductions in one or both of the scrap types to try and improve the alumina levels.

Step 4 updates the lag value to the current value divided by 10 plus 1. So if the current lag value was 10, then it will be made to equal 2. Then the procedure simply repeats until the end of the decision tree is reached. So the system will advise the adjustment of the scrap levels until they match what's being advised. Once this happens a target heat number will be made, and the system will monitor the process until the alumina sample is available for the target heat number, at which point the new scrap levels will be calculated and the process repeated. The outputs for this section have been kept very simple, to ensure they can be quickly understood.

There are a wide range of different outputs from this section that are built using the same structure:

Alumina QA – [x] [y] [z] Where:

[x] Is either: Reduce To, Keep At or Increase To

[y] Is either: C Skull or Incinerator

[z] Is either: 0%, 50%, 75% or 100%

An example of an output from the system would be:

Alumina QA – Reduce C Skull To 50%

Alumina QA – Increase Incinerator To 100%

These and the outputs from other deployed systems are being integrated to provide a robust, accurate and usable ES. The calculations for QA adherence have been implemented in Matlab and the current outputs of the system provide the adherence for the last heat and the total QA adherence from the sum of all of the adherence values for each heat within the data set used.

5. Conclusions

The alumina QA system presented here is a small but important part of the BOS plant ES. The many elements required are being brought together. The most efficient way to do this was to create a database that the system writes all of the messages relevant to each heat to, which can then be extracted and displayed up on a web page. This is the main method of deployment for future systems for different aspects of the BOS process. This is a very challenging ongoing research activity. The long-term aim of the project is to develop an advisory process diagnostic system for the BOS plant, covering all areas from scrap adherence to end blow carbon and temperature control. The system will make the process more cost effective, as it should help to reduce down grades, by reducing operator error, speeding up the identification of operational issues and improving the process control.

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