TRACEABILITY OF RAW MATERIALS IN SILOS IN AN ANODE PLANT

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Abstract

Carbon anodes, regularly consumed in primary aluminum production, are made of calcined petroleum coke, coal tar pitch, and recycled materials. The properties of calcined coke depend on the source of crude oil and the calcination conditions. Similarly, pitch properties depend on the coal tar source and the manufacturing process. Different calcined coke and pitch mixtures are commonly used in anode manufacturing to meet various regulations and/or due to economics and availability. This makes it hard to maintain the anode quality. Calcined coke and pitch are placed in silos and used when required for production. It is hard for the industries to track the source of raw materials used in their daily recipes. This article presents an approach to trace back the details of the use of particulate raw materials with a custom-made software, which takes into account the type (mass flow or funnel flow) of silos. Such tracking can help identify the causes of problems and maintain/improve anode quality.

Introduction

The carbon anode is one of the key components required for the production of primary aluminum. It is made of calcined petroleum coke, coal tar pitch, and recycled materials such as butts and rejected anodes [1]. The raw materials are usually the by-products of different industries. Coke used in anodes is a by-product of oil refineries and constitutes about 2% of their overall production [2]. Also depending on the starting raw materials, the quality of the coke [1] or pitch can vary.

In an anode plant, coke is purchased from different suppliers. Also, the quality of coke from the same supplier can vary depending on the petroleum crude and calcination conditions used [1]. They are then stored in silos and used when required. Thus, different consignments of coke may rest in a silo at a certain point in time.

Measured quantities of raw materials are taken out of the silos, and anodes are made using these raw materials in a manufacturing process that involves a series of stages: sizing, mixing, forming, cooling, and baking [3].

Due to variations in the quality of raw materials, the quality of anodes changes from time to time [3]. In the plant, the parameters related to the production are usually recorded and maintained for future analysis [3]. The granulometry and the coke/pitch composition are recorded, but the consignment numbers corresponding to the raw materials are not usually kept. The properties of the raw materials for each consignment are usually documented in the records which can provide an insight into the quality of an anode provided that the consignment numbers corresponding to the raw materials used are known. However, in the plants, as the consignment numbers corresponding to the raw materials used are not usually tracked, it is difficult to analyze the quality of an anode as a function of the raw material properties.

In this article, a method is described and presented which can be used to track the consignment numbers corresponding to the raw materials used.

Methodology

<u>Types of silos</u>

About 60% of solid state industrial products, at some stage of production, appear as powders or grains. They are stored in containers, mostly in silos [4].

A hopper is the conical or converging section of a powder storage container, and the bin is the parallel sided section, usually cylindrical or rectangular, and the word silo is often used to cover the entire container. There are two main silo types; namely, mass flow and funnel flow, which describe the discharges of particles from a silo [5-7]. In a mass-flow type, the flow pattern is often described as first-in-first-out (FIFO) whereas for the funnel-flow type, the flow pattern is last-in-first-out (LIFO).

In the case of mass-flow type, all the material is in motion during the discharge [8]. The flow is uniform and the feed density is independent of the head of solids in the bin. There are no stagnant regions in the silo. Usually small and free flowing particles or those prone to caking behave according to mass-flow type. In the case of mass flow, the hopper walls are usually steep and low in friction [8].

In the case of funnel-flow type, some of the material moves while the rest remains stationary. The stagnant zone can reach the top level of filling [8]. Funnel flow discharge usually takes place if the bulk solid is coarse, free-flowing, and not prone to caking. In this type of silo, flow segregation may occur. In the case of funnel flow, either the hopper wall is too flat or has high friction [8].

When the particles are coarse, free-flowing, do not degrade with time and segregation is not important, a funnel-flow type silo is the most economical option. On the other hand if the particles are free-flowing but not coarse mass-flow type of silo is desirable.

Before the 1960s storage bins were designed usually by guessing. The approach changed by the research of A. W. Jenike in the 1960s. He developed the criteria that can affect material flow in storage vessels along with the theory and methods to implement them. His primary works were published in "Gravity Flow of Bulk Solids" [9]. He developed the translational shear tester, known as Jenike Shear Tester, to determine the internal friction angle, wall friction angle, bulk density, flow function and rate, and to define the flow pattern in mass and funnel silos [10]. Carr [11] developed a classification system to help in the design and selection of type of silo. He identified a set of test indices such as, angle of repose, angle of fall, angle of difference, loose bulk density, packed bulk density, compressibility, cohesion, uniformity, angle of spatula, and dispersibility which control the type of flow of material in silos.

For the same material the cone angle of the silo can dictate the type of flow. Mass flow can be ensured by providing a steep enough cone angle (greater than 45^o with the horizontal) and ensuring that the discharge opening is wide enough [12]. The flow patterns in silos and accumulations can be calculated based on three approaches namely, granular dynamic algorithms, kinetic theories, and cellular automata approaches. However, all those methods can only qualitatively describe experimental results [13].

Assumptions used in the development of the software

The mass-flow and funnel-flow silos follow algorithms for queue (FIFO) and stack (LIFO), respectively. In both cases, it has been assumed that no two consignments mix with each other while transferring the materials into the silos. However, standard algorithms for queues and stacks cannot be directly applied for the silos because part of the material corresponding to different consignments is consumed during use.

Description of the Software

In this work, the algorithms to describe the flow in different types of silos were developed based on the basic flow types. Granular dynamic algorithms, kinetic theories, and cellular automata approaches have been avoided to keep the approach simple.

The software consists of two parts: the user interface and a database. The user interface is used to accept data from the user and to show the results to the user. The software processes the data, stores in the database, and then retrieves necessary data from the database based on the requirement of the user. The database consists of three tables based on specific functionalities. In a plant, the raw materials are purchased and consumed to make anodes. The purchase records for different silos are maintained in the purchase_table. On the other hand, the information on the daily consumption of raw materials from different silos is stored in the consumption_table. Another table named temporary_table has been included to process the data required by the user. For each query by the user, the data in the temporary_table is refreshed. That is why the table is so named. The algorithms for mass-flow and funnel-flow types of silos are given in Figures 2 and 3, respectively. The software allows the generation of as many silos as needed for any type of silo (LIFO or FIFO).

Results and discussion

The algorithm was implemented using Visual Basic 6.0 as the front end and Microsoft Access as the back end. An application software was developed and validated with plant data. Figure 4 shows the user interface of the software developed. This software can predict the availability of raw material in any silo at any given date for both types of silos. An example with imaginary data is given below to show the utility of the software.

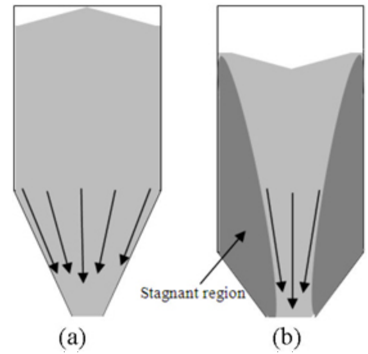

Figure 1. Two types of silos: (a) Mass flow (b) Funnel flow

Tables I and II show the lists of purchases made and consumptions occurred in the month of November 2012, respectively. The data used in the tables are imaginary and intended just to show how the algorithm works. To simplify the demonstration, it was assumed that the silo was empty on 31 October 2012. Table I shows that the total purchase before November 16 was 5900 tonnes whereas the total consumption for the same period was 4300 tonnes. Thus, the balance of raw material in the silo on the night of November 15 was (5900-4300) or 1600 tonnes. On November 16, 600 tonnes of material was consumed, thus the balance after November 16 should be (1600-600) or 1000 tonnes. Without the traceability software, only the total quantity is known. On the other hand, the software allows the determination of the quantity of different types of materials in the same silo. The purchase index shows the order of purchase. The higher the index is, the more recent the purchase is.

Table I. List of purchases

Supplier	Purchase date	Quantity, tonne	Purchase Index
X1	01-Nov-12	1500	1
X2	03-Nov-12	2200	2
X3	06-Nov-12	1000	3
X4	07-Nov-12	1200	4

Table II. List of consumptions

Consumption date	Quantity, tonne
02-Nov-12	700
03-Nov-12	700
04-Nov-12	600
05-Nov-12	700
08-Nov-12	800
13-Nov-12	800
16-Nov-12	600

Table III lists the details of material present for a mass-flow type silo at the end of November 15. This table shows that in the mass-flow type silo, at the end of November 15, 400 tonnes of raw material of purchase index 3 stays at the bottom, and 1200 tonnes of raw material of purchase index 4 stays on top. The dates corresponding to the two purchase indices show that the raw material corresponding to purchase index 3 was purchased before the one with purchase index 4. As for the mass-flow type silo, the material that enters first leaves the silo first (FIFO); thus on November 16, material corresponding to purchase index 3 will be consumed first. When all the material of purchase index 3 is consumed, material corresponding to purchase index 4 will be consumed. On November 16, 600 tonnes of raw material were consumed. Thus, 400 tonnes of purchase index 3 material was consumed followed by 200 tonnes of purchase index 4 material. The consignments corresponding to the raw material (600 tonnes) used for the mass-flow type silo are shown in Table IV on November 16. After the consumption, 1000 tonnes of purchase index 4 material will remain in the silo.

Table III. List of available raw material at the end of November 15 for the mass-flow type silo

Supplier	Purchase date	Quantity, tonne	Purchase index
X4	07-Nov-12	1200	4
X3	06-Nov-12	400	3
Total		**1600**	

Table IV. Composition of raw material used on November 16, 2012 for the mass-flow type silo

Supplier	Purchase date	Quantity, tonne	Purchase index
X3	06-Nov-12	400	3
X4	07-Nov-12	200	4
Total		**600**	

Similarly, Table V lists the details of material present for the funnel-flow type silo on the night of November 15. Table 5 shows that at the end of November 15, 800 tonnes of raw material of purchase index 1, 200 tonnes of material of purchase index 2, and 600 tonnes of material of purchase index 3 stay in the funnel-flow type silo. In a funnel-flow type silo, the material that enters last leaves the silo first (LIFO); thus, on November 16, material corresponding to purchase index 3 will be consumed followed by the material of purchase index 2 and 1. On November 16, 600 tonnes of raw material were consumed. Thus, 600 tonnes of purchase index 3 material was consumed and no material of purchase index 2 or 1 was consumed. The consignments corresponding to the raw material (600 tonnes) used for the funnel-flow type silo are shown in Table 6 on November16. Thus, the material remaining in the silo will be 800 tonnes of purchase index 1 and 200 tonnes of purchase index 2 (total 1000 tonnes of material).

It may be noted that, in both silos, the raw material remaining after the consumption on 16 November was 1000 tonnes. However, in the case of mass-flow type silo, the material remained had purchase index 4 whereas for funnel-flow type silo, it had purchase index 1 and purchase index 2. Here lies the advantage of the software on traceability from the industrial viewpoint. For example, for any type of silo used, if there is any problem in anode quality due to raw material on November 17, it will be easy for the plant to identify the property of the raw material that caused the problem since the type of raw material used in anode production can be determined from the predictions of this software. This will help plant personnel take preventive measures to maintain anode quality and reduce loss due to rejections.

Table V. List of available raw materials at the end of November 15 for the funnel-flow type silo

Supplier	Purchase date	Quantity, tonne	Purchase index
X1	01-Nov-12	800	1
X2	03-Nov-12	200	2
X3	03-Nov-12	600	3
Total		**1600**	

Table VI. Composition of raw material used on November 16, 2012 for the funnel-flow type silo

Supplier	Purchase date	Quantity, tonne	Purchase index
X3	03-Nov-12	600	3
X2	03-Nov-12	0	2
X1	01-Nov-12	0	1
Total		**600**	

Tables IV and VI clearly show that the composition of raw materials used on November 16, 2012 for the two types of silos are completely different. This also helps correlate the properties of the raw materials with the baked anode properties.

It is difficult to validate the data using the silos in the anode plant. Thus, during the maintenance and cleaning of the silos in the anode plant of Aluminerie Alouette Inc., the types of flow of the silos were determined using a consignment of high sulfur coke and it was observed that some of the silos were of mass-flow type and the others were of funnel-flow type.

The following example shows an industrial application of the traceability software. In the month of November 2010, the baked anodes produced on 5 and 30 November under similar conditions differed a lot in terms of reactivity, though the electrical resistivities were nearly the same. Using the software, it was found that the suppliers were different on those two days, and the cokes were different in terms of physical and chemical properties. Apparent density data (density excluding bed porosity measured using the helium pycnometer) provided by the suppliers showed that coke of supplier A had lower porosity compared to that of supplier B. Also, the contact angles measured for a pitch drop on the coke surfaces by the sessile-drop test showed that pitch wetted the surface of the coke supplied by supplier A less than that of the coke supplied by supplier B.

Table VII shows the differences in the properties of anodes produced on those two dates. The results are presented in the form of ratios of the properties of anodes produced on 5 November to those on 30 November, 2010. The ratio for the electrical resistivities was 0.99, which shows that the electrical resistivities of the two anodes were nearly the same. In spite of similar electrical resistivities, the ratios for the air and CO_2 reactivities were greater than 1. This shows that the anode produced on 5 November was more reactive compared to the one produced on 30 November, 2010. With a similar amount of pitch and other forming conditions, more pitch can enter into the pores of the coke particles if the porosity of the coke is higher and the coke surface is wetted more by pitch. If the porosity of the coke is less, then most of the pitch will stay in the space between the coke particles. The pitch that remains in the space between the particles influences the air and CO_2 reactivities; if its amount is greater, the reactivity is higher. It was found from the plant data that the same quantity of pitch was used in both anodes; however, less pitch could enter into the pores of the coke of supplier A, and more pitch stayed in the space between the particles. This resulted in higher reactivities. Thus, the traceability software helped identify the cause of high reactivity of the anode produced on 5 November 2010 compared to that produced on 30 November 2010.

Table VII. Comparison of variation in property with variation in raw material

Date	Supplier and purchase date	Ratio of Property on 5 Nov to Property on 30 Nov		
		Air reactivity	CO_2 reactivity	Electrical resistivity
5 Nov 2010	Supplier A, 20 Oct 2010	2.6	1.2	0.99
30 Nov 2010	Supplier B, 20 Nov 2010			

Conclusions

This article presents an approach to trace back the details of raw materials used with a custom-made software. The software takes into account the type (mass flow or funnel flow) of silos. Such tracking can help identify the causes of problems and maintain/improve anode quality. An example demonstrating the utility of the software is presented and discussed.

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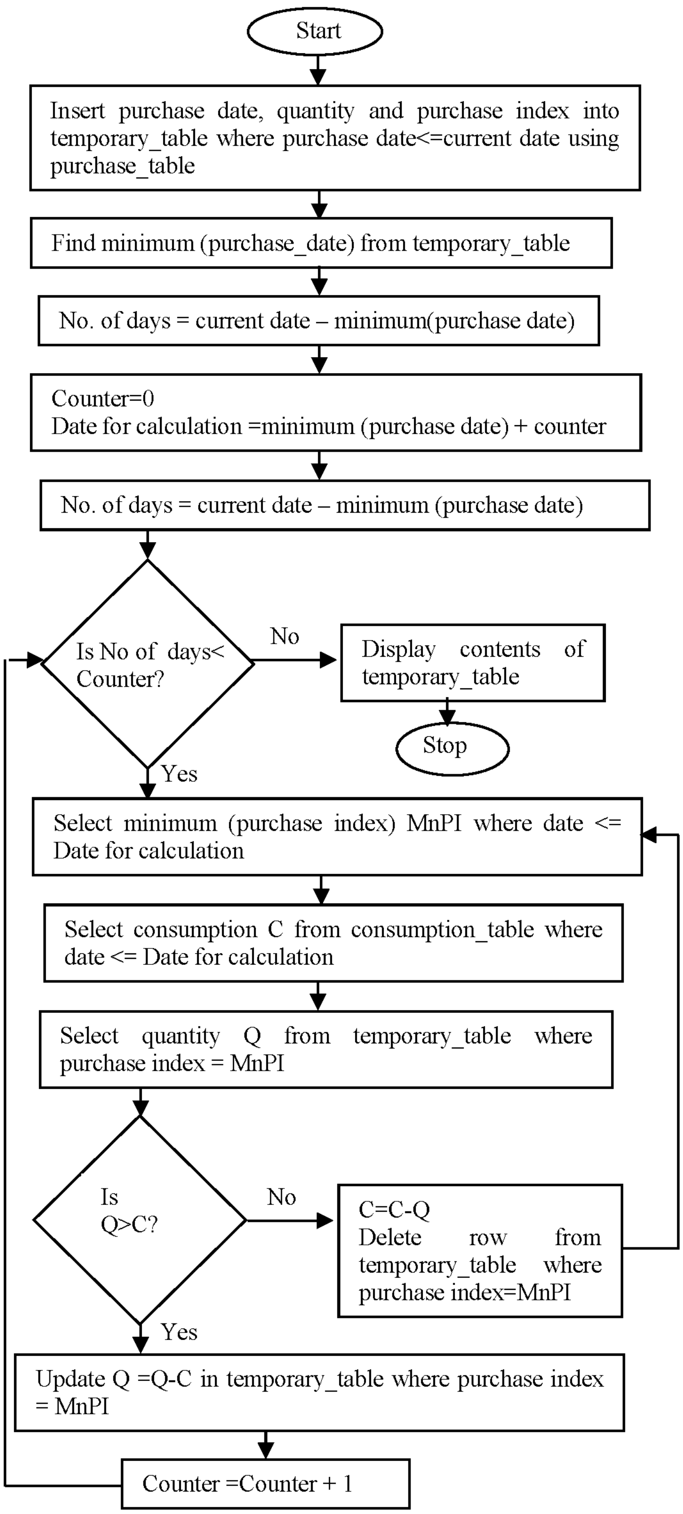


Figure 2. Algorithm for the mass-flow type silo

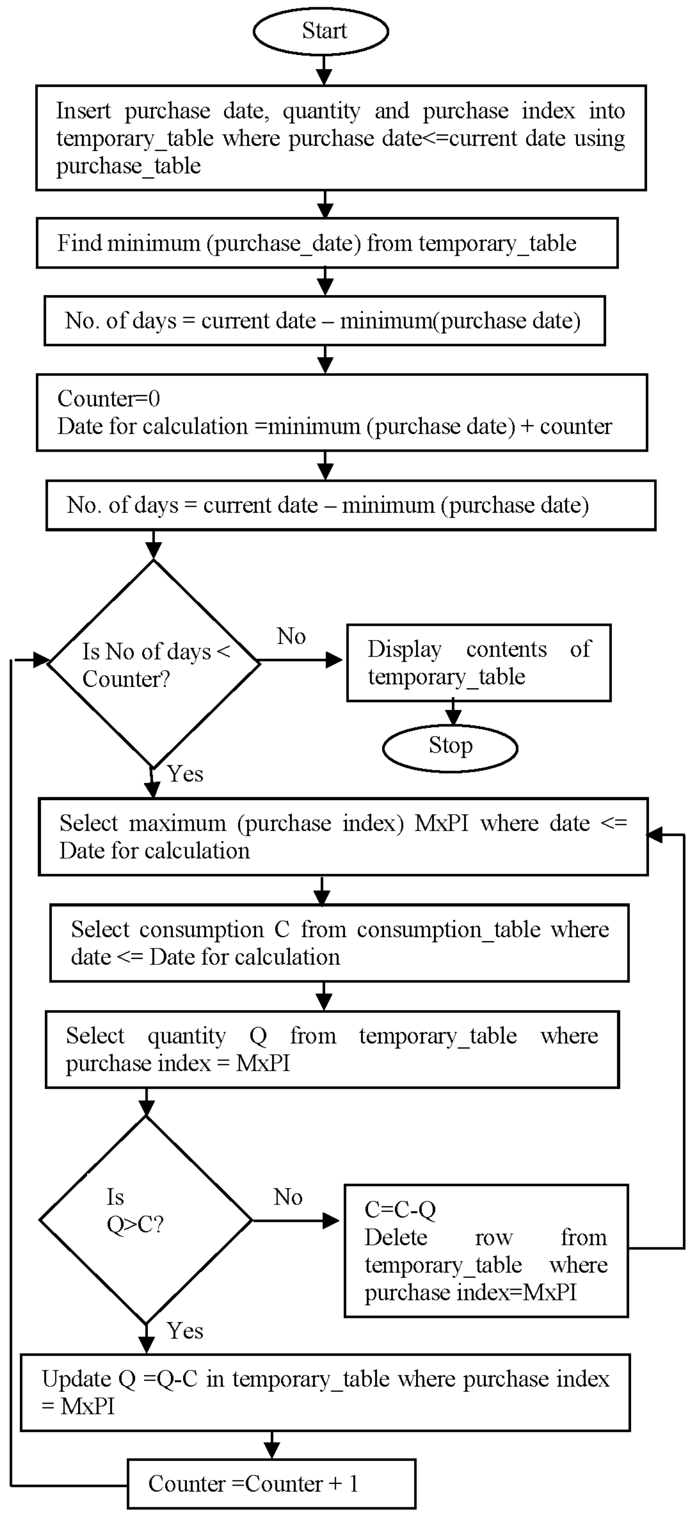
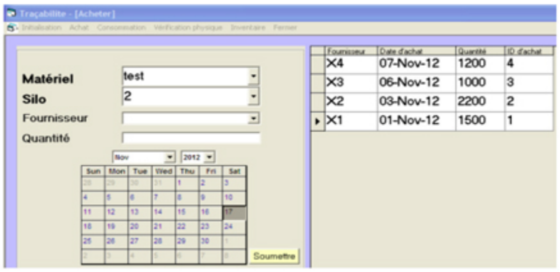
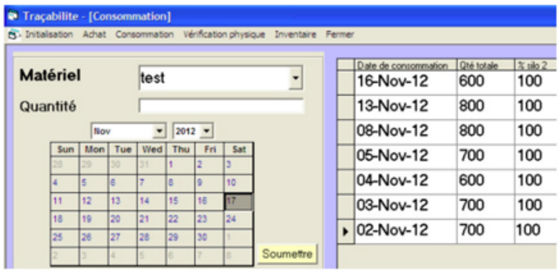


Figure 3. Algorithm for the funnel-flow type silo



(a)



(b)

(c)

(d)

Figure 4. The interface of the software for the traceability study (a) Purchase details, (b) Consumption details, (c) Inventory for funnel-flow type silo, and (d) Inventory for mass-flow type silo.