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TOPIC 9: FRUIT AND VEGETABLE CULTIVATION SYSTEMS

Use of the Control Chart to Monitor the Biomasses quality in Power Plants

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Summary
In the last years the biomass market for energy production grew quickly as a consequence of the European policy in this sector. In order to satisfy this growing demand, various kinds of raw materials can be used as biofuel. In this context, power plants need to develop new methodologies to check the biomass quality and reduce the risk of failures. The Biomass Lab of Polytechnic University of Marche has applied a method named "control chart" to perform the control of some characteristics of the biomass fuels (moisture content, ash content, gross calorific value, element analysis, sulphur, chlorine and mineral element content). The method and its application to a specific case are described. The obtained results show the possibility of improving the quality of the energetic materials used in the power plants. In the specific case of this application, there is the possibility of reducing the variability of all the parameters by over 50% and to limit up to 40% the average values of some chemical elements, in particular heavy metals, and up to 20% the ash content.

***Keywords:** Biomass Characterization, Monitoring, Control Charts*

Introduction

In Italy, about 257 MWe are generated by plants using solid biomass which would correspond to a biomass consumption of over 2.5 Mt/year. This estimation does not consider the biomass consumption of stoves and small boilers for which the estimation is more difficult. Considering the high level of consumption and the necessity to recover new supply sources, it is useful, in this context, to develop systems that control the fuel quality. The Technical Committee (CEN-TC 335 Solid biofuel) of the European Committee for Standardization (CEN) has been established for the standardization of solid biofuels, with reference to their specifications, quality and the method of sampling and analysis. Among the different developed standards, "CEN/TS 14961 Solid biofuels - Fuel specifications and classes" defines fuel quality classes and the relevant specifications. Nevertheless, the information provided by these methods is sometimes too broad, and the managers of the power plants need more sophisticated procedures. In order to implement a quality control system for solid biomass, biomass fuels used in two 10 MWe plants have been intensively monitored by the Biomass Lab of the Polytechnic University of Marche, over 500 sets of data have been used for a statistical survey, specifically aimed at the construction of "quality control charts". The control chart is useful to check that the values of different characteristics of individual samples are confined within pre-determined limits, when the sample values are distributed normally around the population average value. This tool, in general, is used to determine when a process is in a state of statistic control or not. In any production process, a certain amount of inherent or natural variability will always exist. This natural variability is the cumulative effect of many unavoidable causes and in the framework of statistical quality control is often called "stable system of chance causes". A process that is operating with only chance causes of present variation - is said to be in statistical control. Other kinds of variability may occasionally be present in the output of a process and depending from external sources. Such variability is generally large when compared to the background noise and it usually represents an unacceptable level of process performance. In this application it has been considered the concept of "process" as the complex of the operations and phenomena of biomass provisioning for a power plant. The aim of the application is to define a simple method to identify changes in the process that, in the case of this application, is defined on the base of the variation of the fuel quality. Considering power plants that has a system of analytical monitoring and biomass outlining, the method supports the power plant operators, to identify and remove the variation sources of the material quality on the base of control limits. An example could be the exclusion of biomass suppliers that deliver products with certain parameters out of the values limit.

Material and methods

During a period of two-years, 537 biomass samples were collected in two power plants (A and B) of 10 MWe, located in Italy. Each sample has been analysed according to the CEN standards, in order to determine the following parameters: moisture content, ash content, gross calorific value, carbon, hydrogen, nitrogen, sulphur, chlorine and minor elements (Cd, Ni, Pb, Mn, Cu, Cr, As). In detail, 279 and 258 sets of data were relevant to the plant A and B (database A and B). The biomass fuel was of lignin-cellulose type - wood chips, generally produced from waste of wood or forests. All the statistical analyses were carried out by the software MINITAB®, using control chart tool. In particular, individual charts (IC) of individual observations were used - they allow process level tracking and special causes detecting (unusual occurrence that is not normally part of the process). Using IC tool, the Minitab defines graphs drawing the center line at the statistical average by default, the upper control limit (UCL), 3 σ above the center line by default and lower control limit (LCL), 3 σ below the center line by default. A point that plots outside of the control limits is interpreted like a process out of control - investigation and corrective action are required to find and eliminate the assignable causes or responsible reasons for this behavior. In other words, special cause results in a variation can be detected and controlled. A descriptive statistic and an IC processing were applied for each database and each analyzed parameter. Data found out of the control limits were eliminated from each database, producing a smaller database where a new descriptive statistic were applied. A comparison of these two databases was done, highlighting the theoretical improving on general quality of biomasses, from the application of control charts.

Results

Tables 2 and 3 show the results of the descriptive statistic and IC processing of data relevant to the power plant A. In particular, the control limits for each parameter are shown in the table 2, used to identify the special causes data. Comparison between the values, contained in the two tables, highlights that removing the special causes has produced a general reduction of the averages values, variable between 8% and 35% for the metal element, and about 14% for the ash content (0,5% absolute). Moreover, it is possible to

notice the general reduction of the standard deviation of any parameter from 19% up to 81%, and the increasing of the GCV minimum value (8,7%). It is finally observed strong reduction of maximum values (in general over 50%), especially for metal element like Pb, Cu, As and also for ash content. As presented before, tables 4 and 5 show the results of the descriptive statistic and IC processing of data concerning the power plant B.

Table 2. Descriptive statistic and control limits of database from power plant A before IC processing.

PARAMETER	Unit	Mean	StDev	Minimum	Maximum	UCL	LCL
As	*(mg/kg)*	0.7	1.7	0.0	18.1	2.8	-1.4
C	*(%)*	49.22	2.01	41.80	62.40	53.57	44.86
Cd	*(mg/kg)*	0.4	0.3	0.0	3.7	0.8	-0.1
Cl	*(%)*	0.03	0.03	0.00	0.20	0.07	-0.01
Cr	*(mg/kg)*	2.6	4.2	0.0	31.8	10.2	-4.9
Cu	*(mg/kg)*	7.0	11.0	0.0	108.6	22.5	-8.4
H	*(%)*	6.18	0.31	4.83	7.48	6.84	5.52
Mn	*(mg/kg)*	56.9	38.8	0.0	294.6	150.1	-36.3
N	*(%)*	0.52	0.40	0.00	3.06	1.18	-0.15
Ni	*(mg/kg)*	2.42	2.14	0.00	16.45	6.90	-2.07
Pb	*(mg/kg)*	3.83	10.95	0.00	145.40	14.40	-6.70
S	*(%)*	0.03	0.03	0.00	0.24	0.08	-0.01
Moisture	*(%)*	43.7	7.0	16.3	62.2	58.0	29.5
Ash	*(%)*	3.6	4.5	0.2	57.1	10.0	-2.9
GCV	*(kJ/kg)*	19296	746	16494	24505	20699	17892

Table 3. Descriptive statistic of database from power plant A, after special causes removing.

PARAMETER	Unit	Mean	StDev	Minimum	Maximum
As	*(mg/kg)*	0.5	0.6	0.0	3.3
C	*(%)*	49.13	1.57	45.08	53.24
Cd	*(mg/kg)*	0.3	0.2	0.0	0.8
Cl	*(%)*	0.02	0.02	0.00	0.07
Cr	*(mg/kg)*	1.8	2.0	0.0	10.2
Cu	*(mg/kg)*	5.1	4.2	0.0	22.3
H	*(%)*	6.20	0.24	5.57	6.74
Mn	*(mg/kg)*	52.2	28.9	0.0	153.2
N	*(%)*	0.44	0.25	0.00	1.13
Ni	*(mg/kg)*	2.01	1.29	0.00	6.72
Pb	*(mg/kg)*	2.54	2.09	0.00	13.08
S	*(%)*	0.03	0.02	0.00	0.08
Moisture	*(%)*	44.4	5.7	30.0	57.9
Ash	*(%)*	3.1	1.7	0.2	9.2
GCV	*(kJ/kg)*	19318	466	17927	20459

The table 4 illustrated the control limits related to each parameter used to identify the special causes data. The comparison between the value of the two tables highlights that removing the special causes has produced a higher general averages reduction included from 12,5% up to 40% for the metal element, and about 19% for the ash content. It is also possible to notice the general reduction of the standard deviation for any parameters from

8% up to 70%. It is finally observed, an important reduction of maximum values (in general over 50%), especially for metal elements like Pb, Cu and Cd. Some observations can be made for the comparison of the control limits of the two powers plant. In general, excepting As, the control limits of the plant A are more restrictive in comparison to the plant B. In average differences are between 20% and 30%. Some metals, like Cr and Mn, show an important control limit differences (more than 40%), and particularly high is the case of the Pb, up to 74%. Moreover, important differences have been also found in the ash content (44%), unlike the parameters C and H, moisture content and gross calorific value - whose values are similar.

Table 4. Descriptive statistic and control limits of database from power plant B before IC processing.

PARAMETER	Unit	Mean	StDev	Minimum	Maximum	UCL	LCL
As	*(mg/kg)*	0.5	0.9	0.0	9.5	2.0	-1.0
C	*(%)*	48.22	3.46	31.92	68.87	56.06	40.39
Cd	*(mg/kg)*	0.4	0.5	0.0	4.0	1.2	-0.4
Cl	*(%)*	0.0	0.0	0.0	0.3	0.1	0.0
Cr	*(mg/kg)*	4.3	6.8	0.1	49.1	17.4	-8.8
Cu	*(mg/kg)*	10.3	18.2	1.6	226.0	35.4	-14.9
H	*(%)*	6.14	0.46	4.22	9.01	7.26	5.02
Mn	*(mg/kg)*	77.1	103.2	6.8	1252.5	250.0	-1.0
N	*(%)*	0.6	0.4	0.0	2.7	1.6	-0.4
Ni	*(mg/kg)*	2.7	3.4	0.0	32.0	8.4	-3.1
Pb	*(mg/kg)*	13.3	25.7	0.0	293.7	56.0	-29.4
S	*(%)*	0.0	0.0	0.0	0.5	0.1	0.0
Moisture	*(%)*	37.5	10.6	7.7	56.0	65.9	-9.1
Ash	*(%)*	5.9	5.3	1.0	37.1	18.0	-6.3
GCV	*(kJ/kg)*	18883	1183	10301	23200	21456	16311

Table 5. Descriptive statistic of database from power plant B, after special causes removing.

PARAMETER	Unit	Mean	StDev	Minimum	Maximum
As	*(mg/kg)*	0.3	0.5	0.0	3.3
C	*(%)*	48.73	2.30	31.92	55.96
Cd	*(mg/kg)*	0.3	0.2	0.0	1.1
Cl	*(%)*	0.0	0.0	0.0	0.1
Cr	*(mg/kg)*	2.7	3.5	0.1	23.3
Cu	*(mg/kg)*	6.6	4.2	1.6	25.7
H	*(%)*	6.19	0.30	4.37	6.92
Mn	*(mg/kg)*	57.2	34.1	8.7	206.0
N	*(%)*	0.5	0.3	0.0	1.4
Ni	*(mg/kg)*	1.9	1.2	0.2	11.0
Pb	*(mg/kg)*	7.9	8.6	0.2	54.8
S	*(%)*	0.0	0.0	0.0	0.1
Moisture	*(%)*	39.1	9.8	12.6	56.0
Ash	*(%)*	4.8	3.7	1.0	32.9
GCV	*(kJ/kg)*	19069	998	10301	23200

Discussion

The application of control chart on physical-chemical biomasses data has permitted to determine reference values for every power plant, defining when the physical-chemical characteristics of biofuel are considered as having a good performance. Through UCL and LCL values, it may be possible to classify the biomass acquired on the owner biomasses market and to make management decisions. It could be also the possibility of thinking of monitoring the general information of the samples that do not respect the control limits established, and to investigate on the origin, on the type of supplier and on other aspects of the acquisition and material delivery chain. The power plants, managing information on the biomasses received, can verify, for instance, whether there are suppliers that have the tendency to not respect the values of the control limits and, thus, eliminate the provisioning of the biomasses, improving the quality of the material. The definition of the control limits can depend on the type of biomasses market, from where the power plant acquires the product. It is possible to observe a lower UCL values for power plant A compared to power plant B. The differences are bigger for parameters linked to impurities, such as ash content and chemical element like Cu and Pb, but lower in the case of gross calorific value and moisture content. In the specific case of the two power plants, the consequential potential benefit from the application of the control charts has been underlined by the comparison of the descriptive statistics of the databases with and without the considered values "anomalous" (special causes). It is highlighted an important improvement of the materials quality, especially in terms of ash and metal contents and a reduction of the parameters variability. However, it is evident how the parameters considered as materials control can be diversified and selected from the operators on the base of specific peculiarities and demands of the operational context.

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