Computer Aided Modeling and Pollution Control in Cement Plants

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Abstract

Pollution control in the cement industry pushes forward this industry to do something about the reduction of the pollutants produced by the manufacturing and handling of cement, lime and gypsum. We need to predict air quality because the public is worried about the sites and surroundings lands that are covered by gray dust.

This paper describes the software system called PoLogCem, a PC user-friendly software for pollution modeling and cement production optimization under environmental constraints. Nonlinear regression and optimization techniques are implemented and illustrated for a particular cement plant.

Key Words: pollution modeling, process modeling, constrained optimization

1. Introduction

The cement industry plays a vital role in the imbalances of the environment and produces air pollution and hazards. Cements production requires intensive use of natural raw materials and energy, which results both in emissions to the atmosphere and soil. Controlling both the cement production process and the pollution level is a difficult task.

This work presents a computer aided modeling and pollution control tool\(^1\) (called PoLogCem – Pollution Logistic Cement), with the following functionalities: (a) the achievement for representatives' mathematical models for the environmental pollution process; (b) the monitoring of the production process with pollution influence; (c) the searching for the optimal solutions for production planning, which minimize pollution effects.

Three principal modules (statistical modeling module, measurement management module and optimization module) are integrated in order to obtain a software architecture that is easy to manipulate and maintained. The module designed for modeling stage is able to assist the end user in experimentally determining the parameters of the environment pollution. Also a logistic module provides reports for monitoring the pollution level and the contribution of each specific item of equipment to

\(^1\) This project has been developed under the NATO-STI program within the framework of the collaborating linkage grant EST.CLG.979542.
the pollution level. Based on management principle of large system, the optimization module implements algorithms to minimize the production costs while fulfilling the production plan under conditions of process restrictions. A large collection of nonlinear models and constrained optimization techniques is implemented in an auxiliary software tool, called SISCON, and investigated in order to select the most suitable procedures for the cement industry case.

Practical experience in designing and implementing such a system for a cement plant are reported.

2. The cement technological process description

The cement production can be shortly described as follows: after the mining, grinding and homogenization of raw materials, the process of calcination is followed by burning the resulting calcium oxide together with silica, alumina and ferrous oxide at high temperatures to form clinker; the clinker is then ground or milled together with other constituents (as gypsum, slag etc.) to produce cement. The software under discussion is implemented for the Cement Plant “Moldocim” at Tasca - Romania, member of the Heidelberg group. The mentioned plant consists of two marl crushing, a raw materials drying-grinding department, a clinker burning-cooling department, two clinker grinding machines, a slag silos, a clinker silos, a cement silos, a homogeneous materials silos, a slag drying department and a cement expedition department. The configuration module shows this architecture, as in figure 1. The technological process flow, for the above mentioned cement plant, is illustrated in the figure 2.

![Figure 1. The Cement Plant Modules: Location, Points and Parameters](image)

From the point of view of the environmental protection, the clinker burning is the most important part of the process because the key environmental emissions are nitrogen oxides (NOx), sulphur dioxide (SO2) and gray dust. For further remarks, an important
The control of the pollution dynamics asks for taking into account the whole pollution chain. According to [5], the measurement was achieved by using special instruments and adequate procedures: TESTO 350, TESTO 400, TESTO 440, TESTO 450, TESTO 920, PS 003 LM, JIS K 103, etc.

Figure 2. The cement technological process flow

3. PoLogCem – a software for modeling and pollution control

The software system, called PoLogCem, is specially designed in order to scan the pollution activity specific for cement plants and to find logistical solutions with the purpose of pollution control in the cement industry. The main objectives and the usefulness of the PoLogCem software are illustrated in figure 3. As mentioned in [2], [3] and [4], the software is divided into three main parts: modeling, logistics and optimization. These components are integrated by using the “Configuration module”.

The data flow in the PoLogCem software is described in figure 4.

The modeling module provides the specific functions in order to establish a mathematical model for the pollution (the management of the pollution data, the model editing – including nonlinear functions, the syntactical analysis, nonlinear parameter estimation, the assessment of the adequacy of the designed models.)

The logistics module helps the user to manage the database containing the measurements (including the import of the data from other electronic sources). However, the recommended electronic sources are Paradox and Database (dbf) files. It can manipulate the following types: numeric, date/time and alphanumerics. Also, the following functionalities are provided: updating and viewing of the synoptic diagram, graphical views of the time series, etc. Multiple time series can be viewed.
Figure 3. The objectives materialized by PoLogCem Software

Figure 4. The data flow in the PoLogCem software
The aim of the optimization module is to provide the optimal parameters for the production unit so that the pollution level should be maintained in some limits according to the norms [1], [7], [8] to only mention some references.

In order to establish the most suited optimization techniques to be implemented in the PoLogCem software, an auxiliary tool was updated to the version 2.0 and used. This software, called SISCON, initially developed in [6] – as version 1.0, provides access to a large spectrum of optimization methods as shown in appendix 1.

Due to the particular case of the industrial system under study, a decomposition strategy is chosen and a hierarchical approach was established in order to optimize the activity of the cement plant under minimizing the environment pollution. The following methods are embedded into the PoLogCem software, the Gold section method, for the mono-variable case and the BOX method for the multivariate case. However the cement plant compartments are coupled and appropriate rules have to be established to describe this state. The PoLogCem software admits both standard and specific planning rules. The rules can be inserted/editing using an expression editor and the syntactic analyzer. We exemplify by using the following standard rule for the Clinker Burning-Cooling compartment:

\[
[\text{CLINKER BURNING} - \text{COOLING}] \text{[ESP Cooler-stack][Conc: Dust]} = (-49.8333) + ([\text{CLINKER BURNING} - \text{COOLING}] \text{[ESP Cooler-stack][Temp: Hot air]}/1000)*997.399 + ([\text{CLINKER BURNING} - \text{COOLING}] \text{[ESP Cooler-stack][Temp: Hot air]}/[\text{CLINKER BURNING} - \text{COOLING}] \text{[ESP Cooler-stack]})*(-103753.602)
\]

Internal labels are associated to the user-friendly format, explained above. As shown in figure 5, they are called X-variables.

![Figure 5. Optimal parameters value for targeted parameters and internal labels](http://www.enbis.org)
The rules have to be converted into a mathematical model and, finally, an optimization algorithm is called to provide the optimal searched values. This is achieved along seven steps:

- The setting of the parameters and its required values;
- The assuming of all rules and replacement of the date and/or alphanumerical type parameters;
- The automating change of the names of the parameters from the notation [Module][Point][Characteristic] to the $X_i$ mathematical convention.
- The replacement of the technological coefficients from the base of rules;
- The replacement of the labels from the base of rules;
- The decomposition of the rules of type: “if ... then ... else ... “;
- The subsystem construction according to the hierarchy;
- The optimal computing and the validation of the obtained results.

**Figure 6.** The seven steps strategy

**Figure 7.** Processing “if … then … else …” rules
The layout of the first step is given in figure 6. The decomposition of the rules of type “if ... then ... else ...” is achieved using the scheme illustrated in figure 7, and the last step is illustrated in figure 8.

![Finding optimal values](image)

Figure 8. Finding optimal values

Based on the Configuration module, the software assists the user in the plant logistics to add or eliminate one or more marl crushing or cement grinding departments. The pollution level will increase or decrease depending on the currently configuration of the cement plant.

4. Case study

The software under discussion is currently under testing by the Cement Plant “Moldocim” at Tasca - Romania, member of the Heidelberg group.

The first step in the modeling of the pollution activity is to establish the polluting and meteorological parameters taken into consideration. The following set of variables was considered for all of the cement plant departments: [BarometricPressure], [Temperature], [RelativeHumidity], [DustConcentration]. For the Clinker-Burning & Cooling department was considered the variables like: Nox_Concentration and CO_Concentration. At 2400 m out of the plant was considered the powder concentration in suspension [mg/Nm³].

The methods used to estimate the parameters of the nonlinear models are based on nonlinear regression. Graphical representations are also provided as shown in figure 9. The PoLogCem software shows, also, the map of the pollution for the data set provided by the National Institute of the Cement in Bucharest – Romania, for the
“Moldocim” at Tasca cement plant. This image is captured in figure 10. The software provides, also, the value of the pollution parameter for every point of the map.

The hierarchical optimization calls the Box method, due to the large size of the optimization problem (44 variables). The list of variables is given in appendix 2.

Figure 9. Graphic representations from the modeling activity

Figure 10. The map showing the pollution level: the dust concentration variable
4. Conclusions

In order to obtain a reliable and robust software, a large collection of nonlinear models is investigated during the pollution modeling phase. The software was designed according to the Object Oriented Design methodology and was coded in the Borland C++ Builder. The development is based on software engineering common techniques and standards.

Due to the complexity of the analyzed industrial system, a hierarchical approach was considered. Managing such a hierarchy asked for the design of some rules and a finally validation procedure.

The PoLogCem software is under finally testing and will assist the cement plant management both from the production planning point of view and from the global environment production.

References


Appendix 1

The following tree structure describes the collection of optimization methods provided by the SISCON software.

```
IDOPT
  | Identification techniques for models management
  | Optimization techniques for decision's evaluation
  | Linear problems
  |   | SIMPLEX METHOD
  | Nonlinear problems
  | One-dimensional direct search methods
  |   | Interpolation method
  |   |   | COGGINS METHOD
  |   | Methods of interval's partitioning
  |   |   | GOLD SECTION METHOD
  | Multivariable direct search method
  |   | Linear
  |   |   | ROSENBRICK METHOD WITH RESTRICTIONS
  |   | Evolutionary
  |   |   | NELDER-MEADE METHOD WITHOUT RESTRICTIONS
  |   |   | BOX METHOD WITH RESTRICTIONS
  | Gradient methods
  |   | of 1st order
  |   |   | CAUCHY METHOD
  |   |   | FLETCHER-POWELL METHOD
  |   |   | FLETCHER-REEVES METHOD
  |   |   | ROSEN METHOD
  |   | of 2nd order
  |   |   | NEWTON-RAPHSON METHOD
  | Stochastic problems
  | Permanent admissible solutions case
  |   | PROBLEMS OF MINIMAL RISK
  |   | PROBLEMS OF ASSUMED RISK
  |   | GAMES THEORY, CRITERIA FOR OPTIMAL DECISIONS CHOSEN IN CASE OF INCERTAINTY

Equivalent transformations for large dimension problems

Decomposition problems

| Decomposition by partitioning and relaxing - Problems with diagonal block structure associated to weak coupled systems
| Linear
|   | ROSEN METHOD
| Nonlinear
|   | BENDERS METHOD
| Additive separable problems within criteria function and restrictions
|   | COORDINATION USING LAGRANGE MULTIPLICATORS

Penalty procedures

| PENALIZATION - MONOVARIBALE CASE
| PENALIZATION - MULTIVARIABLE CASE
| DUAL TRANSFORMATION PROBLEMS
```
### Appendix 2

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<th>Corresponding</th>
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<tr>
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<td>[CEMENT EXPEDITION][Bags filter-stack][Conc. Dust]</td>
</tr>
<tr>
<td>$x_3$</td>
<td>[CEMENT GRINDING no.1][Bags filter-stack][Conc. Dust]</td>
</tr>
<tr>
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<td>[CEMENT GRINDING no.1][ESP Mill-stack][Conc. Dust]</td>
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