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Advanced Control Schemes for Cement Fabrication Processes

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1. Introduction

Taking into consideration that the cement market will record an increasing rate of 15 - 20%, related to the residential buildings development and to the initiation of large infrastructure projects the cement production is of great interest, both from the point of view of product's quality increase and raw material consumption and environmental impact diminishment. The demands on cement industry in relation with productivity, quality and price, mean an ever-increasing need to improve the quality products, the productivity increase improvement, modernization of the technological flow, improvement of environmental quality. Process automation is where the industrial area offers the biggest and most satisfying challenges in terms of combining traditional engineering skills with technological innovation.
The primarily goal of our work is to describe the state-of-the-art and future directions in update of the cement plant from Carpatcement Deva Branch (Casial).
The project aims the development of a series of patterns, more or less independent from each other, but all of them focused in the improvement of cement quality and diminishing of environmental impact, by means of models simulation and identification in this process. The main objective of this paper is to show through examples how process models can be inserted into advanced controllers to allow the successful control and optimization of the process when the controlled variables are not on line measured or they are measured infrequently.
The proper implementation of advanced control schemes for complex cement fabrication processes rely on the availability of the appropriate mathematical models. The control strategies are illustrated with actual data obtained for one typical process, the clinker fabrication process. We have done an analysis of rotary kiln from Casial-Deva Branch through finite elements approximation.
Three main stages in the cement production process exist:

- Raw limestone processing, raw material mixing and milling;
- Clinker production (as intermediary by-product) from raw limestone calcinations in a melting rotary kiln;
- Clinker mixing and milling with other products, to obtain the cement as final product.

In those three fabrication stages, due to multiple installations and technologies and the presence of a great number of parameters conditioning, is which are inter conditioning it is necessary that the process must by controlled a distributed expert system, based on the intelligent algorithms.

2. Overview and state of art

2.1 Process description

The cement related business in our country is divided between three big manufactures: Heidelberg Cement (Germany), Lafarge (France), Holcim (Switzerland), each one controlling about one third of the specific market.
Deva cement plant was established in 1972 and its operation started in 1976. It is located nearby Deva town, having an output of 1 million tons/year. Carpatcement Holding took over this plant in 2000.
This process is carried out employing the dry method, which generates the lowest emissions level and is the most efficient. The raw and auxiliary materials employed in cement and by-products processing are limestone, clay, pyrite, flying ash, slag, natural puzzolana, gypsum, sand wastes issued from other industries. The basic raw materials for cement production (limestone and clay) are mined out in open pits, from where after primary crushing is transported on the plant's site for storage and further preparation. Having high moisture, the clay requires a dehumidification and drying process. External suppliers supply other raw materials, such as iron ore (pyrite ash), granulated furnace cinder etc.
The cement production stages are involving the following activities, illustrated in Figure 1 **(**Procese de productie, 2008):

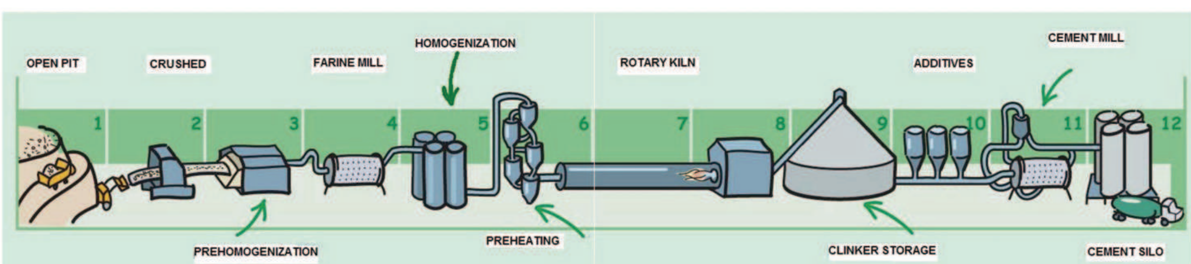


Fig. 1. The technological flow from cement fabrication

- **Extraction** in open pits of raw materials such as limestone and clay (1 and 2).
- **Limestone separation and overcrushing** (3), where the sizes comprised between 0 – 50 and 100 – 150 mm are transported to the crusher, where their diameter is reduced to the needed value for cement production, namely 0 – 25 mm, and then are stored in three limestone silos.
- **Obtaining the raw meal** for clinker (4 and 5) is using a laboratory assessed receipt, the limestone, clay and pyrite ash are closed and transported to the drying tower, and further to the raw mill.
- **Clinker production** (6, 7 and 8) based on raw meal contained in the storage silos is dosed and transported to the Humboldt four levels heat exchanger, where the raw meal is preheated from 60°C to about 800°C. The heat is taken over from the kiln's hot gasses passing through the heat exchanger, in counter- current with the supplied raw meal. Preheated and partially decarbonated rawmeal covers all the areas within the rotary kiln, in a special zone the clinker being obtained, at 1450°C temperatures. From the rotary kiln, the clinker is discharged in the grid cooler, where using the air forced into the system by 9 fans, it is cooled from 1350°C to about 100°C. The heat demands for obtaining the clinker is supplied by burning fuels as natural gasses, heavy oil, waste oil, SAF, eco-fuel on the hot end of the kiln, and the rubbers and waste tyres are supplied through the cold end to the ascendant

column kiln-heat exchanger. Three silos are in place for clinker storage. As mentioned before, the clinker kiln works on the dry procedure and meets the BAT requirements.

- **Cement production** (9, 10 and 11). The slag from the admixture hall is then stored in the cinder silos from the clinker mills. The cinder is dried with warm gasses from the grid cooler or, when the clinker kiln does not operate, by burning natural gasses in the drier's hotbed. Gypsum is transported from the admixture hall to the gypsum silos nearby the cement mills. The clinker, cinder and gypsum contained in silos, after a laboratory receipt, are extracted, dosed and supplied to the cement mills. The cement mills are tubular mills with balls, having two rooms and operating in a closed loop. From the mill, the material is brought to a high efficiency separator where it is separated, the fine fraction (cement) being taken over in a haulage relay and stored in 9 cement silos, the heavy fraction being recirculated into the mill.
- **Cement shipping** (12), from silos, the cement can be supplied both as bulk material and in bags, using rotary Mollers equipment. The cement delivery can be done by trucks or using the railway network.

The basic product is cement, 80% is clinker manufactured using a dry procedure which allows a production of 1,026,563 t/year clinker. The technological flow may be synthesized into a scheme presented in Figure 2. The Deva Branch, Casial has two technological lines to produce cement with 1.2 millions tons a year capacity. The flow sheet of material balance from Deva Branch, Casial is presented in Figure 3.

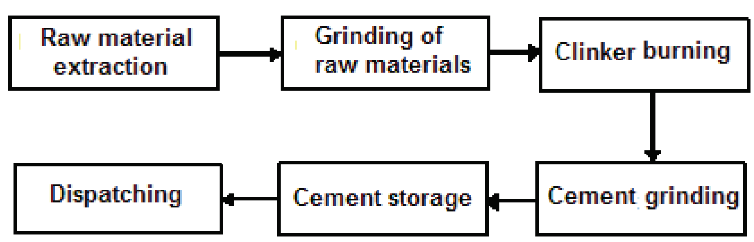


Fig. 2. Flow chart of process fabrication

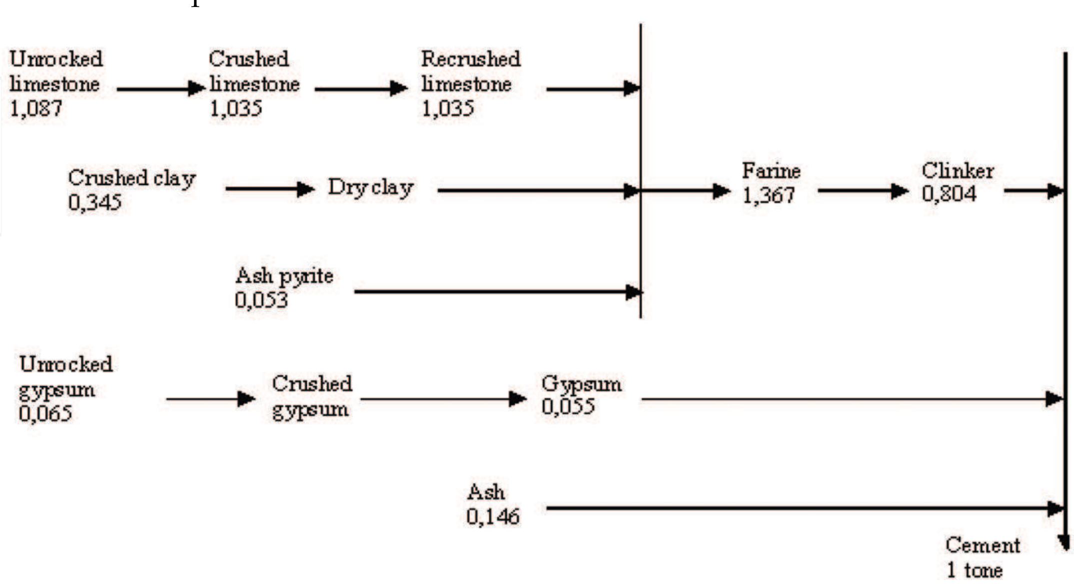


Fig. 3. The flow sheet of material balance

2.2 Kiln operating

Manufacturing cement by dry procedure is a huge energy consuming process. An important section of cement technological flow, with a great share in finite product (80%) is the making of the clinker which is presented in Figure 4, where are represented graphically the flow installations of clinker fabrications.

The calcinations process (transformation of raw material in clinker, the intermediate product from what the cement is produced) takes place in the rotary kiln. The existing temperature in the kiln for the process to take place is of 1450°C, while the flame's temperature is of about 2000°C.

The existing kiln systems at Carpatcement Holding are on the dry system with suspension pre-heating in 4 levels, Humbolt types. The material is supplied from the upper part of the cyclones and they are circulating in decreasing way in counter- current with the gases resulted from the burning processes which they are circulating through the separation cyclones from the lower level to the upper level. In this way, the gases are cooling down and the raw materials are preheating, Figure 1 (6) and it starts the decarbonated process. The raw material, which is in suspense it is separated from the gases inn each step of the changer and meets again the gases in the lower step. The repeating of this process (separation-blending) at each step of the changer until the discharge of the material into kiln it's ensures a good thermal transfer.

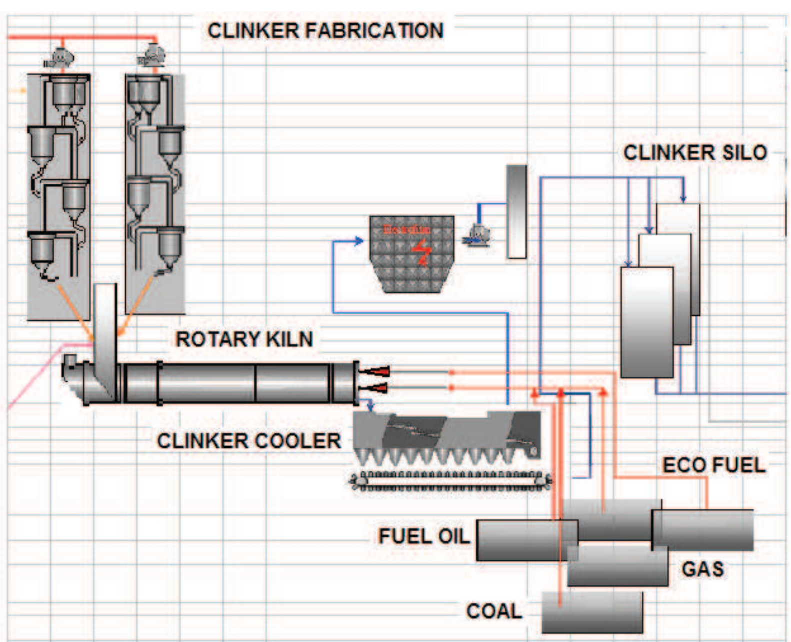


Fig. 4. Flow sheet of clinker fabrication

The raw meal charging station is equipped with control bins, gravimetric chargers type Schenk and pneumatic pumps type Fuller.

The control bunkers should maintain a constant raw meal height providing a prescribed constant material quantity in the supply. Raw meal is taken over from in supply control bunkers with rampart extractors, being charged according to the centralized commands given in the central command room, with Schenk gravimetric chargers.

The material charged in this manner is circulated in the screw pneumatic pump's bins that are transported it to the heat exchanger. For each technological line, three Fuller pumps are in place (2 operating and an auxiliary one) and a four-stage Humboldt suspension heat exchanger.
The charged material is pneumatically hauled to the exchanger's upper side, using the existing joint between stage I and stage II. The material receives heat from the hot gasses during its traject in the heat exchanger's cyclones, from upside down in the direction I-II-III-IV, after that entering the smoke chamber and then the furnace. Inside the exchanger, the material is heated up to 800°C - 810°C, also being partially decarbonatated. Gasses are then entering in exchanger at about 1000°C temperature, in his bottom side circulating along his cyclones in direction IV-III-II-I and finally are exhausted through VRA and VRB exhausters.
The partially decarbonated rawmix is fed into the rotary kiln, having 97 m length and a 5.8m in diameter. Here takes place the final stage of the clinkerization process, based on specific thermal and chemical processes.
For burning purposes, liquid fuel (heavy oil), gassy fuels (natural gasses), or both kinds of fuels are employed, the equipment being well designed to meet this demand. According to the reactions within the kiln and the resulting compounds, the rotary kiln comprises the following zones:

- Decarbonatation area (calcinations), where the alkaline carbonates are decomposed at temperatures comprised between 1000°C and 1100°C.
- Transition zone (solid phase reactions area), where the first mineralogical compounds are formed, through solid phase reactions, at temperatures 1000°C - 1350°C.
- Clinkerization zone (sinterization area) where, 1350°C - 1500°C temperature values , the liquid phase appears, in his presence the tri calcium, silicate (alit) develops, the cement's most valuable compound.
- Cooling zone, where, at temperatures ranging from 1450°C to 1250°C the mineralogical compounds occurs. Burned gasses are circulated in the kiln backwards related to material's advancing direction, than their dust, content is minimized employing a 560,000 m^3/h capacity electrostatic precipitator system (EPS).

EPS, works in optimum conditions when the gas temperature doesn't pass 180° C, because of this they are cooled down in a water tower. From the kiln, the clinker is discharged at the warm head of the cooling grate where it is taking place a suddenly cooling to 65° C.
A large volume of gases has to be moved through the kiln system. Particularly in suspension-preheated systems, a high degree of suction has to be developed at the exit of the system to drive this. Fans are also used to force air through the cooler bed, and to propel the fuel into the kiln. Fans account for most of the electric power consumed in the system, typically amounting to 10–15 kWh per tonne of clinker.
The grate cooler is composed from three grates of different sizes, on which are put high-melting steel plates with wholes. A bed of clinker up to 0.5 m deep moves along the grate. These coolers have two main advantages: they cool the clinker rapidly, which is desirable from a quality point of view, and, because they do not rotate, hot air can be ducted out of them for use in fuel drying, or for use as preheated combustion air. After cooling the clinker is crashed until, the granulation is max. 25 mm and then through a transport system made from two metallic chains with coupes and a relay of three belt conveyors, is transported at the tree clinker bunker. The dust collection from the cooling grates ensured with a multi - cyclones batteries with two frames.

3. The rotary kiln modelling

A rotary kiln, the world's largest manufacturing machine - is the major component of the cement line. Rotary kilns have wide use in industry from the calcinations of limestone to cement manufacturing to calcining of petroleum coke etc. The kiln is a large rotating furnace approximately 100 m long, and four to seven m in diameter that weighs over 300 tonnes, Figure 5. The rotary kiln consists of a tube made from steel plate, and lined with firebrick. The tube slopes slightly (3%) and slowly rotates on its axis at between 30 and 250 revolutions per hour. Raw meal is feed in at the upper end, and the rotation of the kiln causes it to gradually move downhill to the other end of the kiln. At the other end fuel, in the form of gas, oil, or pulverized solid fuel, is blown in through the "burner pipe", producing a large concentric flame in the lower part of the kiln tube. As material moves under the flame, it reaches its peak temperature, before dropping out of the kiln tube into the cooler. Air is drawn first through the cooler and then through the kiln for combustion of the fuel. In the cooler, the cooling clinker heats the air, so that it may be 400 to 800 °C before it enters the kiln, thus causing intense and rapid combustion of the fuel.
The dimensions and parameters of the oven are: dimensions ∅ 5.8 x 97 m, angle 3 %, backing points 4, production capacities Q = 3,125 t/ day, main driving P = 500 KW, n = 750 rot/ min, second driving P = 500 KW, n = 750 rot/ min.

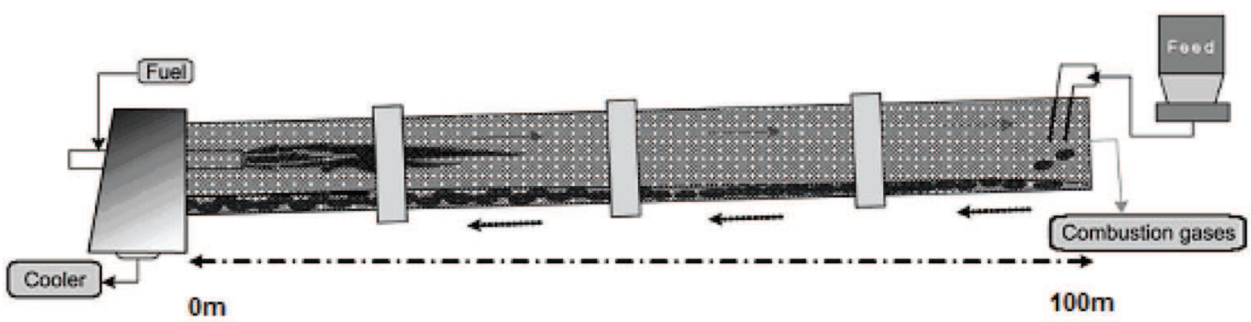


Fig. 5. Rotary kiln

Problems such as low thermal efficiency and low product quality have plagued rotary kiln operations yet these machines have survived and have been continuously improved (fuel efficiency, automation) for over a century.
With an ever-increasing focus on reducing greenhouse gas emissions, the continued or increased use of rotating kilns can only be achieved by reducing the thermal and electrical energy consumption used in these processes. A fluid bed calciner or dryer achieves rapid drying by the large heat transfer coefficient obtained through the high air volume being circulated. The penalty is the increase in electrical energy required to circulate this high air volume. Rotary kilns on the other hand have poor heat transfer coefficients, hence higher thermal energy demand, due to the need for larger devices and thus more opportunity for heat to be lost.
In most rotary kiln operations, the chemical reactions in the bed require high temperature, for example, cement kilns will require temperatures of approximately 1500°C. The energy to raise the temperature and drive endothermic reactions is from the combustion of a range of fuels such as natural gas, coal and more and alternative fuels. Heat transfer from the gas to the bed is complex and occurs from the gas to the bed surface and kiln wall to bed surface via conduction, convection and radiation.

A number of rotary kiln models has been proposed over the years and recent computational fluid dynamic models can be developed but all have their limitations (Barr, 1989; Bui, et al., 1995). Most assume isothermal conditions through the bed at any axial position (Majumdar, & Ranade, 2006*)*. The bed motion regime, cascading, rolling or slumping depends on the rotational speed of the kiln, the percentage fill and the feed physical properties.

- They are models which have in the site the thermal processes, models that are following the thermal transfer between the material bed, gas, kiln walls and environment, where it appears conduction, convection and radiation phenomenon. The measures are the material temperatures from supply in those four steps, gas temperature, and walls temperature in the four steps.
- They are chemical models who analyze the endo -thermal phenomena that are taking place at the raw material calcinations. The kiln parameters are the gas emissions of O_2, CO_2, NOx, quantities and material compositions (Gorog, et al., 1981).
- They are models which have basis the energetically balance of the kilns where they are appearing energetic aspects in connection with the kiln's drive, rotation, motor moment and they are following the automation power adjustment.

A series of equations representing conservation of mass, energy and species averaged over the cross-section are solved using appropriate numerical methods (He, et al., 1996).
The bed for example is assumed to be well mixed and isothermal in any given transverse plane (Georgallis, et al. 2001). Although these models have been successfully used in industry, they are limited for information that can be extracted.
Due to the complex models character, nowadays many software packaging are allowing to employ numerical analysis of thermal phenomena (FLUX STUDIO, ANSYS, MULTIPHISICS, FLUENT, COMSOL MULTIPHISICS, QuickField, etc.). A 3D physical model of the kiln where it can be observed the physical components, walls, material bed and the burning pipe is given in Figure 6.
As a result a number of researchers have begun the quest for a more encompassing modelling effort. Boateng and Barr (Boateng, & Barr, 1996) have coupled a conventional one-dimensional plug flow model with a two-dimensional representation of the bed's transverse plane. This improves the ability to simulate conditions within the bed. Alyaser (Alyaser, 1998) has modelled for axisymmetric conditions. Fully coupled three-dimensional modeling is applied to the rotary lime kiln (Georgallis, et al., 2001). Three sub-models are coupled, namely the hot flow model, the bed model and the wall/refractories model. The model takes into account the major phenomena of interest including the gas flow, all modes of heat transfer and thermal effects of the refractory.

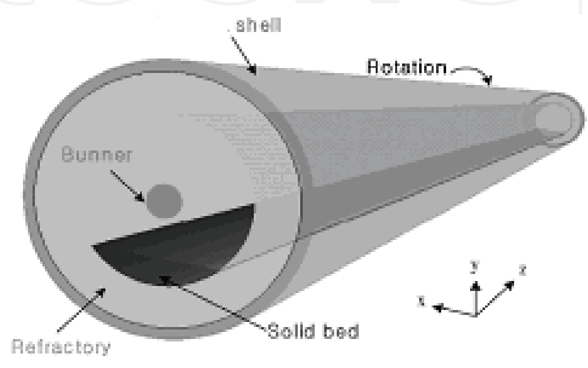


Fig. 6. 3D- rotary kiln model

A model of rotary kiln heat transfer, which accounts for the interaction of all the transport paths and processes to the rotary kiln from Casial, Deva Branch is presented in our paper. Information exchange and directions of transfer are shown in Figure 7 (Barr, et al., 1989).
Two dimensional modelling is applied using finite element method. Heat transfer within the kiln refractory wall was solved using a finite-element approximation for one-dimensional transient conduction. Interface temperature boundary conditions for the kiln are used in the model. Heat flux boundary conditions are used for both the inner and outer surfaces in the wall model.
The mathematical model of heat-transfer for linear problems is described by the differential mathematical model of the thermal conduction, Eq.(1) and (2):

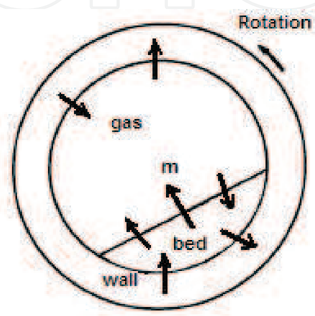


Fig. 7. Information exchange of heat transfer

$$div\left(\lambda gradT\right)+q-\rho c\frac{\partial T}{\partial t}=0 \tag{1}$$

$$\frac{\partial}{\partial x}\left(\lambda_x\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda_y\frac{\partial T}{\partial y}\right)=-q-c\rho\frac{\partial T}{\partial t} \tag{2}$$

Where: T is temperature, t- time, $\lambda_{x(y)}$-components of heat conductivity tensor; λ - heat conductivity, q - volume power of heat sources, burner - constant, $c(T)$ - specific heat, ρ - density of the substance.
In linear case all the parameters are constants within each block of the model. The oneness of the precedent equation solution of the thermal conduction proposes the knowledge:

a. The heat sources in the domain of calculus, q;
b. The material properties, ρ, c şi λ;
c. Initial conditions T;
d. Limit conditions.

The next limit conditions on surfaces S_1, S_2, S_3, on the frontier domain of calculus is possible. (Fireteanu, et al., 2004):

- Type Dirichlet,

$$T\left(x.z.y,t\right)=T_s,\ \ t>0, \text{ on } S_1 \tag{3}$$

- Type Neuman inhomogeneous

$$\lambda\frac{\partial T}{\partial n}=q_s,\ \ t>0, \text{ on } S_2 \tag{4}$$

- Type mix

$$\lambda \frac{\partial T}{\partial n} = \alpha\left(T - T_0\right) + \beta k_{SB}\left(T^4 - T_0^4\right), \text{ t>0, on } S_3 \quad (5)$$

Where, q_s is the superficial specific flow imposed, α is the thermal transfer coefficient by convection, k_{SB} is a Stephan-Boltzmann constant ($5.67032 \cdot 10^{-8}$ W/m²/K⁴), β is an emissive coefficient, and T_0 - ambient radiation temperature.
Convection boundary condition and radiation boundary condition can be specified at outward boundary of the region.

3.1 Formulate the problem

It will be accomplished the thermal analysis by numerical method with finite elements using as QuikField software, of the heat transfer problem at the rotary cement kiln.
It will be determined the temperature value in different points of the model, in each block, thermal gradients, heat flux densities, and temperature on the contour of shell.
The software is based on heat conduction equation with convection and radiation boundary conditions. The technical characteristics of the rotary kiln are shown in Table 1:

Geometrical parameters	Numerical value	Operational variables	Numerical Value
Lenght [m]	97	Temperature of clinkerization [°C]	1300
Internal kiln radius [m]	1.9	Velocity of kiln [rpm]	1.9
External kiln radius [m]	2.9	Limestone feed temperature[°C]	800
Inclination [%]	3.0	Thermal transfer coefficient α [W/Km² for (S1)	20
Refractory thickness [m]	0.9	Thermal transfer coefficient α [W/Km²] for (S3)	350
Kiln shell thickness [m]	0.1	Thermal transfer coefficient α [W/Km²] for (S2)	0.5
		Emissive coefficient β	1
		Thermal conductivity [W/K.m] in bad in gas in shell in refractory	 0.693 0.8 10 0.04

Table 1. Operational variables of the rotary kiln for calcining limestone

Defying the thermal transfer problem for this case it was made the geometrical model, the document describing the problem geometry, the labels of the blocks (bed, gas, refractory, shell) and it was made the mesh of our model. The model contains specific geometric objects and establishes the correspondence between the objects and material properties, field sources and boundary conditions. We gave the properties of each material from the named blocks (heat conductivity, emissive coefficient for convection and radiation (Table 1), the thermal field sources were defined and also the boundary conditions and limits.

It was defined three surfaces outlines S1, S2, S3, belonging the calculus frontier domain, with specified boundary condition like: S1 outer surface as interface between shell and environment, S2 surface interface between bed-gas and bad-refractory, S3 inner surface interface between refractory –gas.

3.2 Numerical solutions

The values of temperature T [K], heat flux F [W/m^2] and temperature gradient G [K/m] in some points at interface surfaces between gas and refractory and on the vertical axis of kiln through each isotherm, in gas, bad and in shell also were calculated and given in Table 2 and Figure 8. Also it was represented the temperature variation on the contour of the inner surface, Figure 9 and temperature distribution between shell and refractory, in Figure 10.

Inner surface points	Temperature value T [K]	Gradient Value G[K/m]	Flux heat F[W/m^2]
1	1295.6	298.97	239.17
2	1246.0	415.16	332.13
3	1192.2	584.58	467.67
4	1141.8	692.21	553.77
5	1184.8	1021.8	708.08
6	1032.7	1037.4	718.95
7	975.99	1016.9	704.68
8	914.44	991.89	687.38
9	778.01	18578	743.11
10	693.01	18367	734.69
11	636.96	18231	729.23
12	466.04	17808	712.33
13	318.27	70.556	705.56
14	316.21	66.78	667.8

Table 2. Thermal field values

The cross-section model is shown to simulate the measured thermal performance of the kiln for clinker. The interaction among the heat-transfer processes at cross-sections of the kiln was examined, and explanations were made for both the observed close coupling of the bed and inside wall temperatures and the high rates of heat input to the bed occurring near the kiln entrance and in the presence of an endothermic bed reaction.

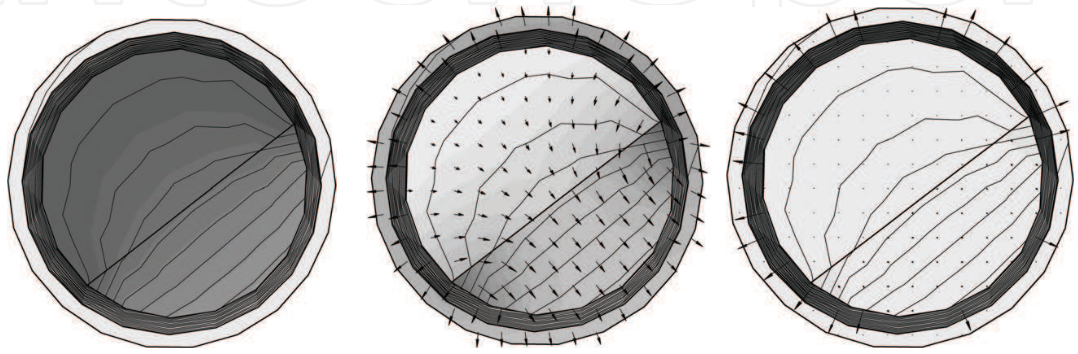


Fig. 8. Map of temperature, vectors of heat flux and thermal gradient in cross-section

The model was validated using thermal measurements from Casial's kiln. This effort demonstrates how a model may be used to capture flame phenomena for rotary kilns and to solve shell fault into the kiln.
A model accepts heat flux values from the hot flow side and temperatures on the wall interface. Evidence (such as a non-uniform product) has suggested that large temperature gradients exist near and within the bed.
The work carried out is aimed at understanding and improving the heat transfer in rotary kiln and to provide a systematic basis for the efficient operating of kilns. It can be noticed that temperature distribution nearby the kiln's shell is very close to the trend obtained by the pyrometer used for temperature monitoring.

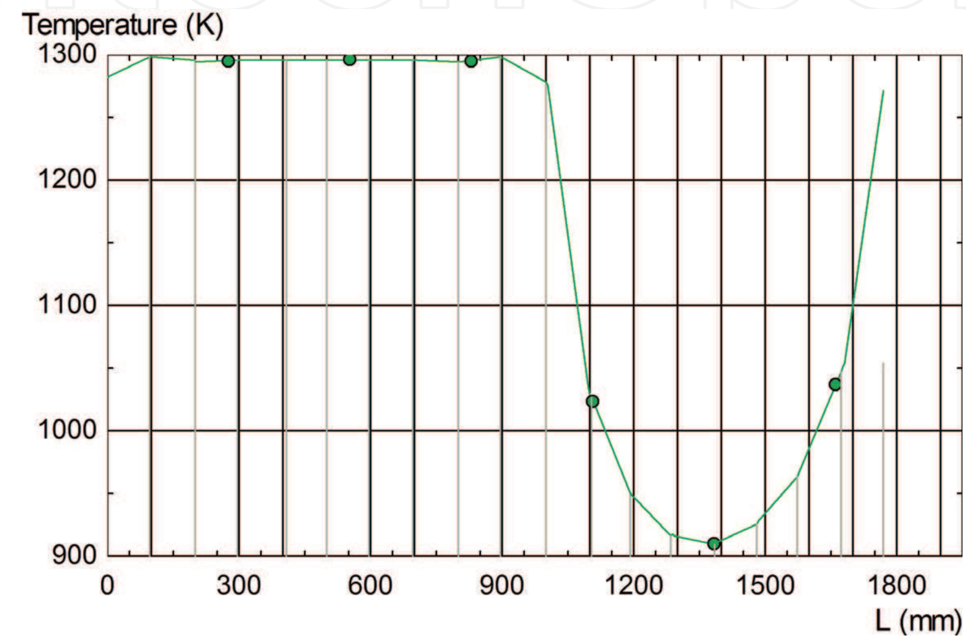


Figure 9. Variation of temperature on the contour of inner surface

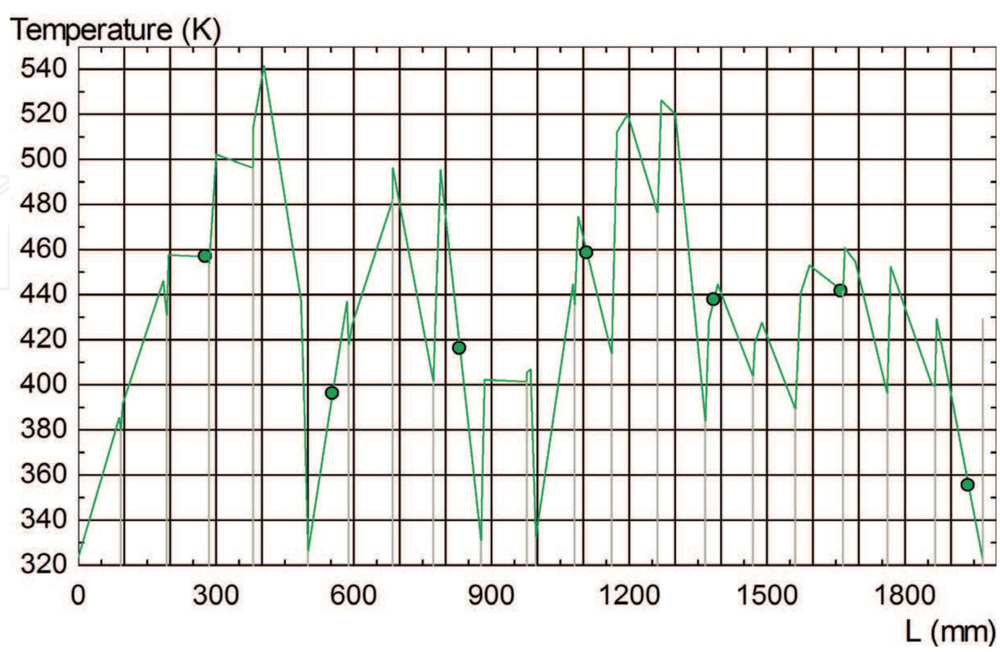


Fig. 10. Variation of temperature on the interface surface between shell and refractory

The data processed by statistic functions about clinker temperature and automate measured pyrometer temperature are shown in Figure 11 and Figure 12 and the values of the statistical parameters we have obtained. The result reflected on prediction performance plot with a correlation of 0.96 (Arad &Arad, 2003).

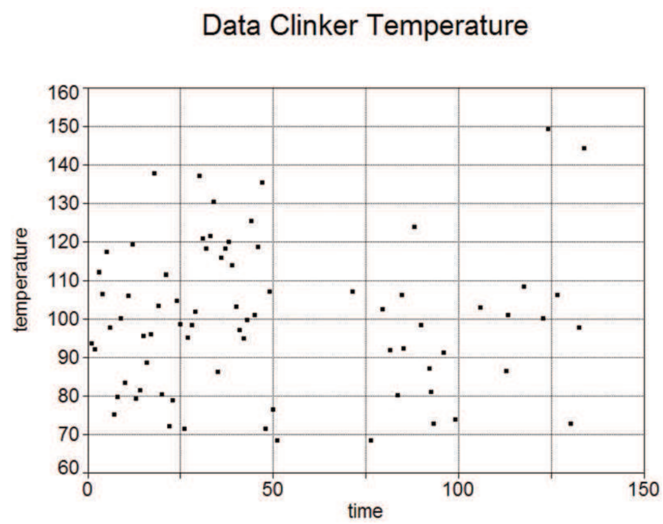


Fig. 11. Clinker temperature

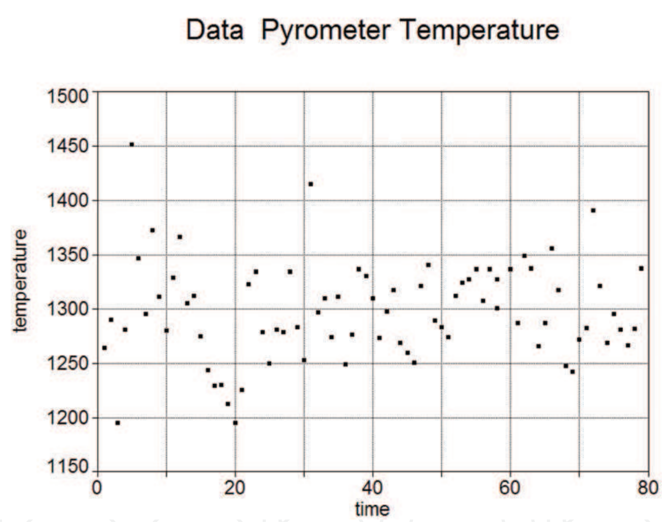


Fig. 12. Pyrometer temperature

4. Cement kiln emissions

The most important gas emissions from cement industry are CO_2. The carbon dioxide emissions which are generated represent about 5% from the world wide CO_2 emissions induced by human activities. These high level emissions are resulting basically from the specific technology for cement production. The main sources of CO_2 in cement industry are: raw material and fuel burning.
The N_2O emissions generated by the cement kilns as a consequence on combustion processes are relatively low, having no significance if related to CO_2 emissions. The last ones are issuing in the following stages:

- The calcinations stage:

- Kiln: direct CO_2 emissions having two main sources:
  - calcinations (decarbonification) of raw material (60%);
  - burning of fuel (40%), thermal energy consumption.
- The milling stage:
  - Cement milling: indirect CO_2 emissions, electric energy consumption.

The direct CO_2 emissions in the process are mainly occurring by employed fuel and raw materials (calcium carbonate), being released during the stage of clinker production in kiln (the so called calcination). Thermal energy is also used during this stage. So, if natural gas is used instead of coal, the CO_2 emission is decreased with 25%. The thermal consumption and CO_2 emissions also related to the kiln type employed for calcinations and clinkerization. Apart from this, the emissions are different according the kind of the raw materials employed. About 60% of total amount of CO_2 emissions are depending on the employed raw materials (during calcination), and the rest of 40% is related to the fuel consumption.

Indirect emission of CO_2 from the process are having as main source the use of electric power for milling purposes, from primary calcinations or from clinker milling (when it is mixed with additives for the final cement production process).

Three important environmental issues can be outlined as major problems confronting the European cement industry, two being local and one global, by their nature:

- emissions from factories, other than CO_2 (SO_2, NOx, dust, etc.) and local transportation of raw materials and products;
- raw materials extraction and transportation and their environmental impact (rural areas, natural resources and biodiversity) and their effect on human life environment (dust and emissions related to transportation, noise, vibration);
- CO_2 emissions from plants (emissions from factories and vehicles) and energy consumption (use of fossil fuels).

A major role in emissions generation is related to the employed fuels. In fuel selection, the major factor is represented by the cost involved at burner's level, comprising all the expenses with acquiring, processing and feeding. The presently employed fuel at Carpatcement Holding, Deva Branch, is methane, but for economical reasons it was replaced from 2007 with pet coke and heavy oil.

CO_2 emissions reduction measures in the calcinations process (direct emissions) aim the followings:

- Raw material composition
- Fuel replacement
- More efficient technological process
- Cement's final composition (clinker content)

4.1 The diminution of environmental impact

Producing cement has significant positive and negative impacts at a local level. On the positive side, the cement industry may create employment and business opportunities for local people, particularly in remote locations in developing countries where there are few other opportunities for economic development. Negative impacts include disturbance to the landscape, dust and noise, and disruption to local biodiversity from quarrying limestone and fabrication process. The cement industry make real efforts to diminish the CO_2 emissions by implementing actions derived from Kyoto protocol, such as:

- improving the production processes through more efficient technologies;

- final cement composition (clinker content);
- raw material composition;
- use of wastes in production processes (European-Union countries have different policies and legal requirements from this point of view);
- replacing high level CO_2 emission fuels with fuels generating lower CO_2 emissions;
- carbon dioxide extraction from emitted gasses;
- CO_2 emission level reduction at vehicles;

Emissions from cement works are determined both by continuous and discontinuous measuring methods, which are described in corresponding national guidelines and standards. Continuous measurement is primarily used for dust, NO_x and SO_2, while the remaining parameters relevant pursuant to ambient pollution legislation are usually determined discontinuously by individual measurements.

Taking into account the significant environmental impact of the cement fabrication, the major environmental polluting factors by using the mathematical simulation procedures was done.

The environmental impact analyses regarding the activities developed at the Casial cement factory were realized by simulating the pollutants' dispersion into the atmosphere from 1995 to 1998 (Arad, 2001)**.**

Referring to air quality in the area we distinguish two categories of pollutants:

- Pollutants resulting from cement fabrication processes, represented by dust,
- Pollutants resulting from fuel burning processes with SO_2, NO_2, CO and other emissions.

The air quality was assessed at the outset of the technology up dating activity.

The analysed area was monitored in 1998 by means of 12 monitoring points by the Agency of Environmental Protection Deva and also by 5 monitoring points by Casial factory and at a point (107) situated 450 m away from the pollution source the gaseous pollutants were assessed. The experimental data obtained regarding the air quality were used to represent the monthly average concentrations at 10 monitoring locations, depending on the distance between each assessed location and the cement factory.

The monitored data provided by the beneficiary have pointed out the following:

- By analysing the degree of pollution with airborne powder, we find but that the monthly average values in 1998 did not often exceed the values specified in regulation - STAS 12574/87, namely the maximum allowable concentration is 0.150 mg/daily. The maximum annual values exceeded Maximum Admitted Concentration (MAC) with the frequency of 5.1 %.
- Regarding gaseous pollutants we can notice that the average daily values as well as the maximum values for NO_2 do not exceed MAC. The same holds true for SO_2, where neither the daily average values nor the maximum ones were exceeded.
- The pollution degree with dust is high. The average monthly values of ten exceed the 17 m^2/monthly limit.

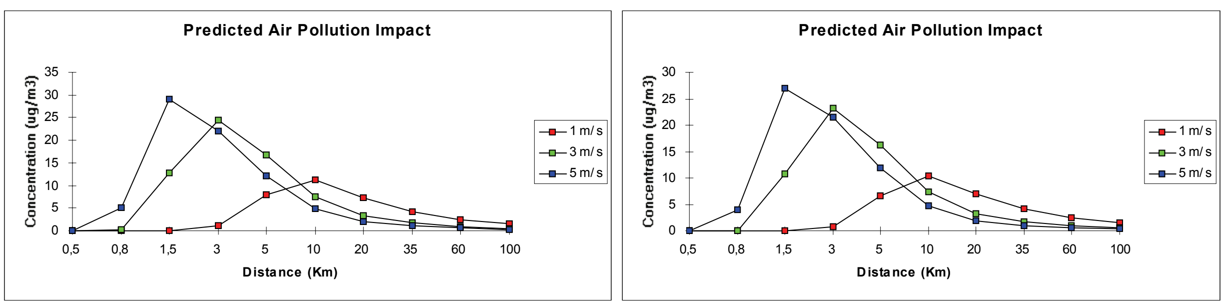
In order to assess the pollution sources contribution we resort to mathematic modelling and also to the results obtained from monitoring, thus having enough information available to make a study on the pollution impact.

4.2 Predicted air pollutant impact

We have used a software Spreadsheet type, Excel for analyses and pollutant dispersion prediction in the air. The model assumes that the concentrations spatial distributions of the pollutant produced are of Gaussian shape. The model is therefore a Gaussian model combined with a procedure of averaging concentrations on long time intervals. It is a Gaussian model because the vertical and horizontal concentrations distributions are the normal ones.

From the measurements available at Deva Branch, Casial we have simulated the dispersion model of the pollutants resulting both from the processes of burning fuels and from burning in clinker kiln and in the lime kiln (Arad & Arad, 2002). The nitrogen dioxide (NO_2) and the sulphur dioxide (SO_2) were taken into consideration, the other pollutants being insignificant. The flow rates are much higher when fuel oil is used. The concentrations are appraised at ground level, at various distances from the source.

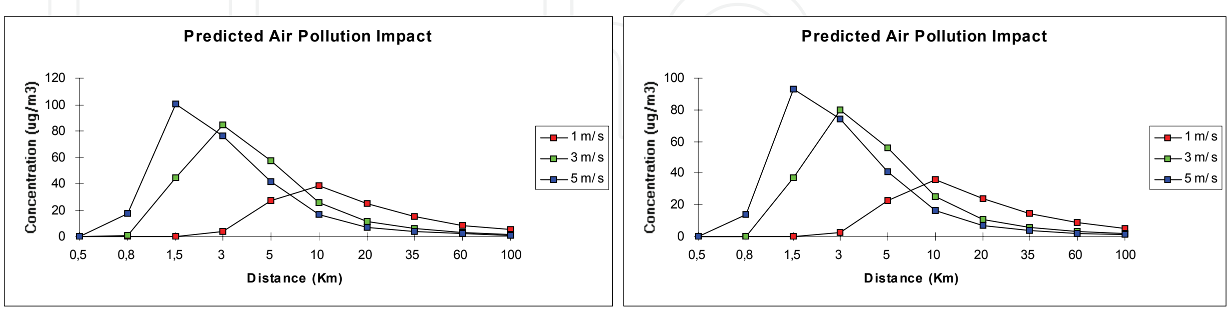
The atmospheric concentrations are appraised by the stability grade from 1 to 6, representing situations from unstable to stable. With our data, a grade of stability 3 has been estimated, slightly unstable. In the Figure 11 and Figure 12 are rendered the concentrations at ground level, at various distances from the source for NO_2 and SO_2 for the clinker kiln whose smokestack is 68 m high while the ambient temperature is 10^{o} C in Figures 13,a and 14,a respectively 0^{o}C in Figures 13,b and 14,b.



a. b.

Fig. 13. Concentrations at ground level from the source for NO_2 at 10 and 0 degree

It can be noticed that the concentration values are higher at temperatures of 10° C. The situation of the concentrations is far below the allowable values for NO_2 sometimes above them for SO_2 at wind velocities of 3.5 m/s and at higher temperatures.



a. b.

Fig. 14. Concentrations at ground level from the source for SO_2 at 10 and 0 degree

The dispersion conditions improve for the pollutants given off by a polluting source 68 m high (H= 68m) due to horizontal transport conditions, through an increase of wind velocity over 2 m/s, the atmospheric calm decrease under 25% and because of vertical dispersion.

4.3 The simulation of the dust dispersion using MATLAB

The dust pollutant (settling suspensions) represents the main environmental negative factor generated during the cement fabrication at the cement factory Casial, Deva Branch.

The simulation's results enable the comparison with the data obtained by classical analyses and a high prognosis of the pollutants evolution was done.

The environmental impact analyses regarding the activities developed at the Casial cement factory were realized by simulating the pollutant's dispersion into the atmosphere, by using a computing sequence of the MATLAB space, (Arad & Arad, 2002). We have represented the concentration fields on a surface area of 100 - 150 km^2 for the data collected of 1995 years, Figure 15 and 1998 year, Figure 16 and 17.

The data measured by Casial factory and Agency of Environmental Protection Deva are represented by average monthly concentrations in 10 monitoring points depending on the distance of that point to Casial factory. The results of the simulation for the year 1998 show that dust pollutant has come down compared with the first period analysed. The representation of the data obtained in a longer period (1995-1999) is the surface with level peaks of concentrations on a surface of 10 km^2 from the sources .

The model predictions were verified by comparing them with the experimental data.

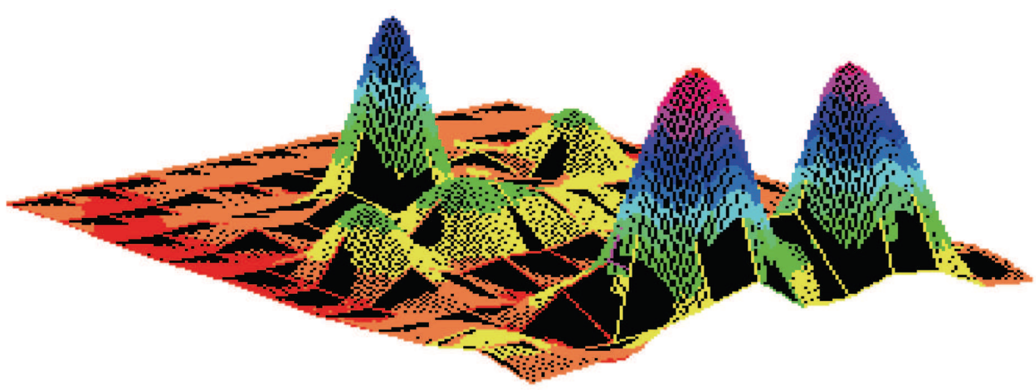


Fig. 15. Dust Pollutant dispersion for 1995 year

The integration in the environment legislation of the activities in the analysed site has been made based on the synthetic assessment of the quality indicators and based on the obtained prognosis by simulation where have been take actions.

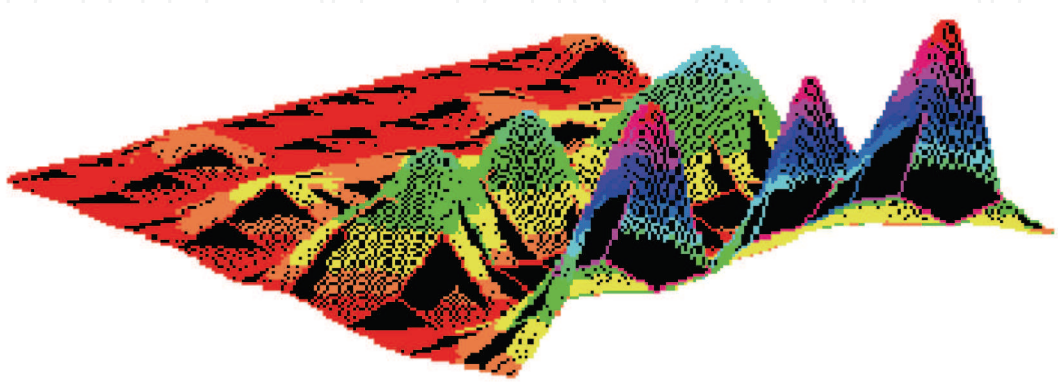


Fig. 16. Dust Pollutant dispersion for 1998 year

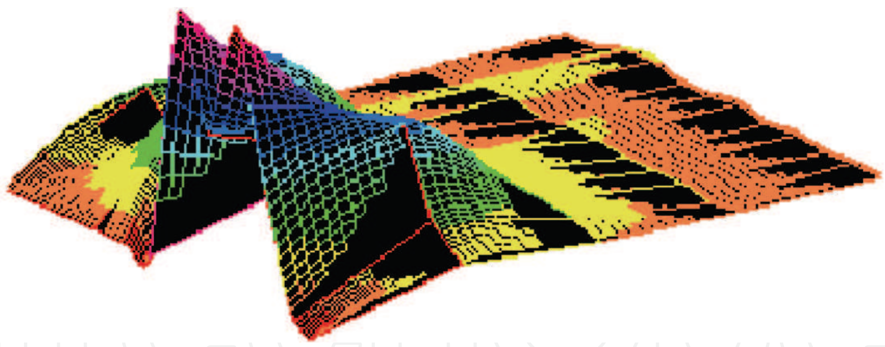


Fig. 17. Dust Pollutant dispersion with data measuring by Casial for 1998 year

As far as the monitoring of the outlets in 1999 there was no system of monitoring them on the platforms of Casial Plant.

Now, the technologies were up to date and an automatic monitoring system was achieved. The care for the environment protection was materialized by the modernization of the mill's EPS (electrostatic precipitators) and the introduction of the bags filters for the auxiliary de-dusting. Carpatcement Holding, Deva Branch have already implemented and certified an integrated management system of quality, occupational health and safety, and environment, in accordance of the international standard requirements: Quality management system-requirements-ISO 9001, Environmental Management System, specification and using guide ISO 14001 and Occupational Health and Safety Management System, after OMSAS 18001 standard. Obtaining the certification of the system after OMSAS 18001 (occupational health and safety), generates confidence that the society respects: the legal and statutory requirements, provides a high standard of occupational health safety management as a part of the firm's general management system.

The total amount of environmental investments is of 8.6 billion Euros, consisting in:

- dust suppression equipments updating;
- purchase an automated equipments of alternative fuel valorisation.

5. Kiln control and advanced control schemes

Effective control of the kiln is complicated by several factors, including nonlinearities in the dynamics and the large dimensionality of the problem. A linear control scheme has been already implemented and tested with success. In order to improve the performance of the control scheme, linear controllers must be replaced by fuzzy controllers.

Fuzzy control is a practical alternative for a variety of challenging control applications since it provides a convenient method for constructing nonlinear controllers via the use of heuristic information. Such heuristic information may come from an operator who has acted as a "human-in-the-loop" controller for a process. In the fuzzy control design methodology, we ask this operator to write down a set of rules on how to control the process and then we incorporate these into a fuzzy controller that emulates the decision-making process of the human. In other cases, the heuristic information may come from a control engineer who has performed extensive mathematical modelling, analysis, and development of control algorithms for a particular process. Again, such expertise is loaded into the fuzzy controller to automate the reasoning processes and actions of the expert. Regardless of where the heuristic control knowledge comes from, fuzzy control provides a user-friendly formalism for representing and implementing the ideas we have about how to achieve high-performance control (Passino & Yurkovich, 1998).

Formation of the desired clinker minerals involves heating the raw meal through the temperature stages mentioned above. To meet the clinker quality objective, the most obvious control is that the clinker should reach a peak temperature such that the finishing reaction takes place to the required degree.

However, for efficient operation, steady conditions need to be maintained throughout the whole kiln system. The feed at each stage must be at a temperature such that it is "ready" for processing in the next stage. To ensure this, the temperature of both feed and gas must be optimized and maintained at every point.

The independent use of fan speed and fuel rate is constrained by the fact that there must always be sufficient oxygen available to burn the fuel, and in particular, to burn carbon to carbon dioxide. If carbon monoxide is formed, this represents a waste of fuel, and also indicates reducing conditions within the kiln which must be avoided at all costs since it causes destruction of the clinker mineral structure. For this reason, the exhaust gas is continually analyzed for O_2, CO, NO and SO_2.

The assessment of the clinker peak temperature has always been problematic. Contact temperature measurement is impossible because of the chemically aggressive and abrasive nature of the hot clinker, and optical methods such as infrared pyrometer are difficult because of the dust and fume-laden atmosphere in the burning zone. The traditional method of assessment was to view the bed of clinker and deduce the amount of liquid formation by experience. As more liquid forms, the clinker becomes stickier, and the bed of material climbs higher up the rising side of the kiln. It is usually also possible to assess the length of the zone of liquid formation, beyond which powdery "fresh" feed can be seen.

The two-colour pyrometer MPZ 4x is used at Casial factory for the intensity measuring of infrared radiation at two different wavelength. The series MPZ1x to MPZ5x provide five efficient, microprocessor-controlled pyrometers for noncontact temperature measurements. The temperature range covers 700 °C - 3000 °C.

Correct measurement of the temperature on a kiln shell is essential for efficient operation of the kiln. ECS/CemScanner represents the state-of-the-art in kiln shell infrared scanning. It combines a robust design with advanced software features, making it an indispensable aid to the operation and optimisation of kilns.

The CemScaner system controls the kiln (shield) temperatures and it was specially developed for supervisory control, monitoring and reporting functions from central control room (CCR) at Casial factory. The adjustment of temperature is done in real time and in the same time the safe operation of the equipment is assured.

As an exercise in process control, kiln control is extremely challenging, because of multiple inter-related variables, non-linear responses, and variable process lags.

Since 2000, the technological flow from Cement Plant is controlled automatically by ECS system (Expert Control and Supervision) from the CCR using the ECS/NTech platform, complex high level supervisory control system. The ECS environment offers a set of basic programmed interlocking sequence in process-control. From this point of view, the installation was equipped with measuring and control devices.

The operator user interface with full SCADA functionality for technological flow control, interactive display of results has also been developed and for example the kiln operating is presented in Figure 18.
Local process automation and monitoring were accomplished. The Casial factory is divided in areas of automation:

1. Raw Mill
2. Rotary Kiln and Cooler
3. Cement Mills
4. Packing Product.

Automation in Area (2) is based on 2xMain PLC 5/80E Allan Bradley, with 4 and 3 RIO racks, the communication is DH+. Main PLC-5 communicates also on Modbus with dosage system Schenck, with the burner furnace based on Allan Bradley SLC 500/4 processor and with the PLC of Electrostatic precipitator Kiln being the same type as Cooler Main PLC. Also, a channel of the processor is used to connect the PLC drive system with the PLC of the kiln. So the PLC Kiln system controls each of the four units.

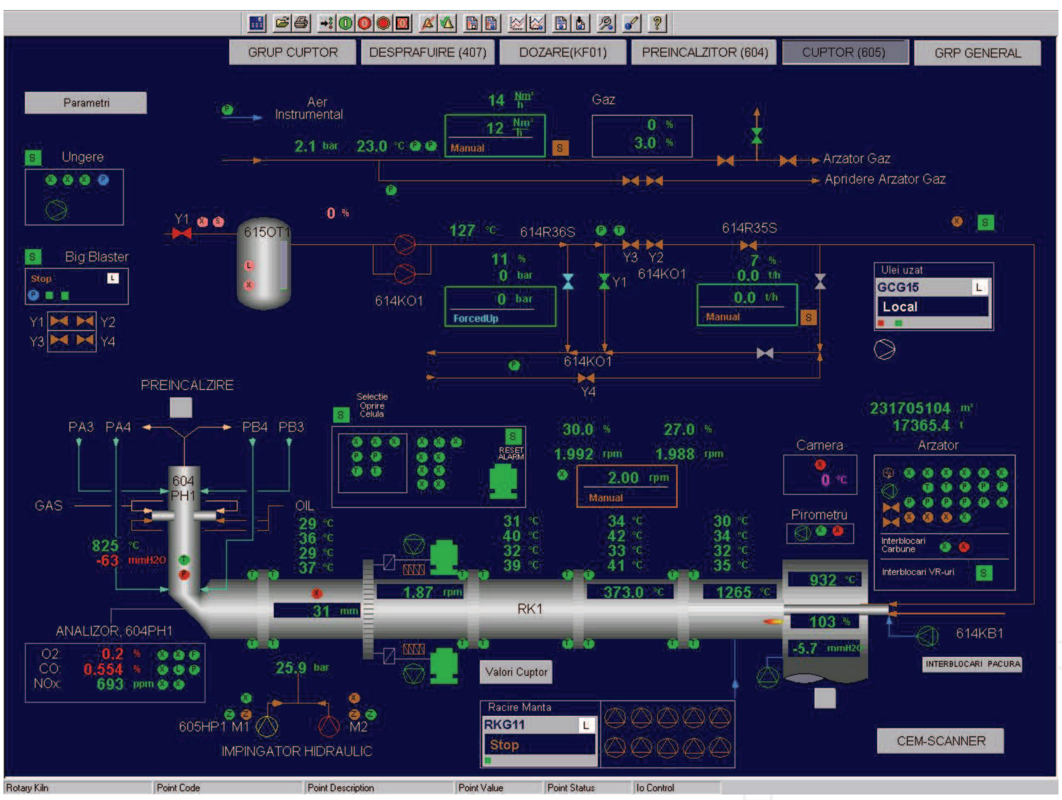


Fig. 18. Monitoring system and control kiln

Programming for the PLC-5 and SLC 500 used software RSLogix 5. The rest is developed on the PLC Siemens S7-400 structure with profibus communication. For these PLC's it is used Simatic V5.4, Chart 6.1 Programming.
Further information can be obtained from the exhaust gas analyzers.
In our work, an intelligent kiln control system was proposed, with advanced simulation; Figure 19 shows a schematic of the simulation system. In the system, neural network models are used in conjunction with advanced high-level controllers based on fuzzy logic

principles. These operate using expert system strategies that maintain a "just sufficient" burning zone temperature, below which the kiln's operating condition will deteriorate catastrophically, thus requiring rapid-response, "knife-edge" control.
A local control in each particular operation and an optimum control of entire plant are enforced. The Expert system is built on a true real-time process control platform that can be easily linked to the process, through communication with an existing control system. Simplified structure of a fuzzy control system is presented in Figure 20. Rule-based expert systems are used to improve production and optimize fuel efficiency.

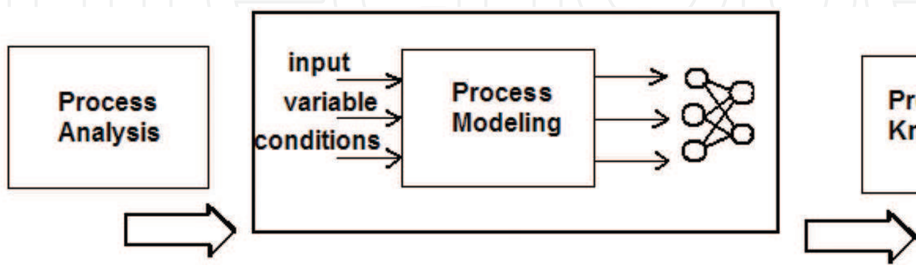


Fig. 19. Advanced simulation system

The system is not based solely on fuzzy logic but on a hybrid system that utilizes a number of techniques such us Statistical Process Control (SPC) and Model –based Predictive control (MPC).
The proposed control scheme of the kiln considers a fuzzy control system in which we have as rules the chemical model variables of the process as well as the thermal and energetically ones, look like in Figure 21.

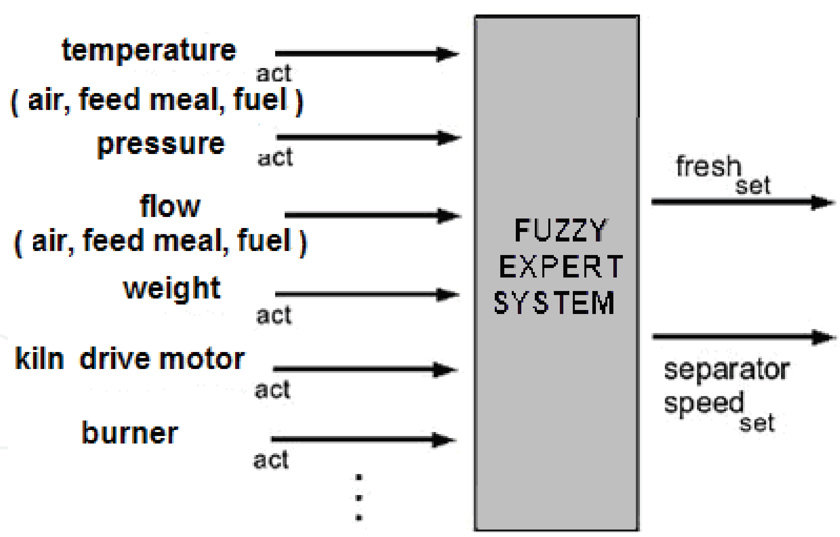


Fig. 20. Fuzzy-Expert system

Control strategies are following:
- Fully automatic start-up and shut down
- Automatic change of kiln parameters
- Control strategies can be completely customised
- Self optimising control schemes
- Intelligent management of external disturbance,

The temperature in the clinkerization area is an output variable y(t) needing to be regulated. The external controls available to achieve this are few:

- Feed rate: this defines the kiln output
- Rotary kiln speed: this controls the rate at which the feed moves through the kiln tube
- Fuel injection rate: this controls the rate at which the "hot end" of the system is heated
- Exhaust fan speed or power: this controls gas flow, and the rate at which heat is drawn from the "hot end" of the system to the "cold end".

The input variables are:

- Primary air flow rate
- Secondary air flow rate
- Natural gas consumption
- System total pressure.

Kiln Control System is based on a database, which inherits Fuzzy-technologies for process optimisation. Based on an ongoing rating of the process, the current state of the facility is evaluated.

Sophisticated algorithms, which inherit Kiln Control System's and the customers experience it will be implemented then calculate new parameters for subordinate control systems (pre heater system, burner, kiln cooler, gases analyzer, charger Schenk, clinker silo).

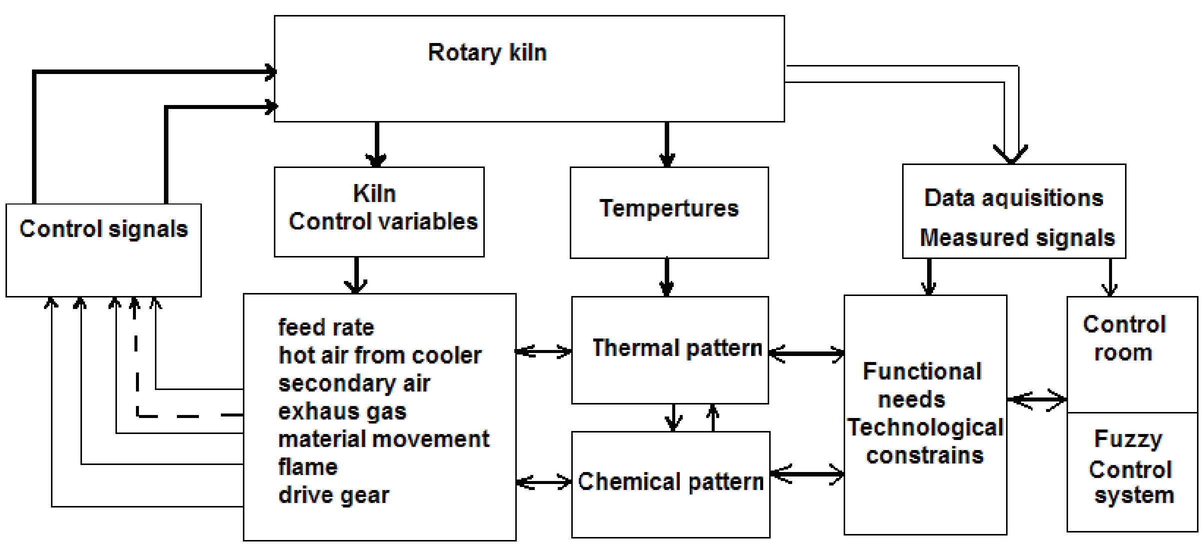


Fig. 21. Kiln Control

For the acquisition and long term storage of process data, the database is used also. A flexible and very easy to use software system for the management of process data, display of trends analysis and reporting is available. The software is running on a standard PC, which can very easy be connected to all automation systems, which are used in plant. Due to the fact that Kiln Control is designed as a configurable Fuzzy Expert system, new possibilities to control cement plant arise.

Simple PID-controller can only use a single input to calculate a single output only to be used for the loop control. Kiln Control's Fuzzy-technology processes a multitude of inputs. The system can be tuned to follow different targets.

This flexibility facilitates new innovative solutions for plant controllers, which render much better results, than classical PID-controllers.

Of course, modern versions of the „classical" strategies: feed = constant; temperature = constant, can be chosen.
Our computer control systems make a "calculated" temperature, using contributions from all information sources, and then set about controlling it.
The new hybrid control system uses predictive-adaptive controllers to keep the main variables close to the set points and reject disturbances are available (Barreto G., A., 1997). When doing so, the advantages of the Fuzzy-Expert system are preserved, namely the consideration of several inputs, which might be contradictory.
The system architecture, as depicted in Figure 22, which is composed of six units components which are interconnected with Kiln Control System. Greater process knowledge in the hands of operators, engineers, and managers will lead toward optimized equipment design and operation, and will have significant impact on cement fabrication economics.
The models must be completed by new software tools that provide the process information in an interactive user-friendly environment which maximize the benefits of process modelling. A 3D model of the heat transfer for numerical analyses should be used to obtain valid results along the entire length of the kiln (Martin, et al., 2003; He, et al., 1996).

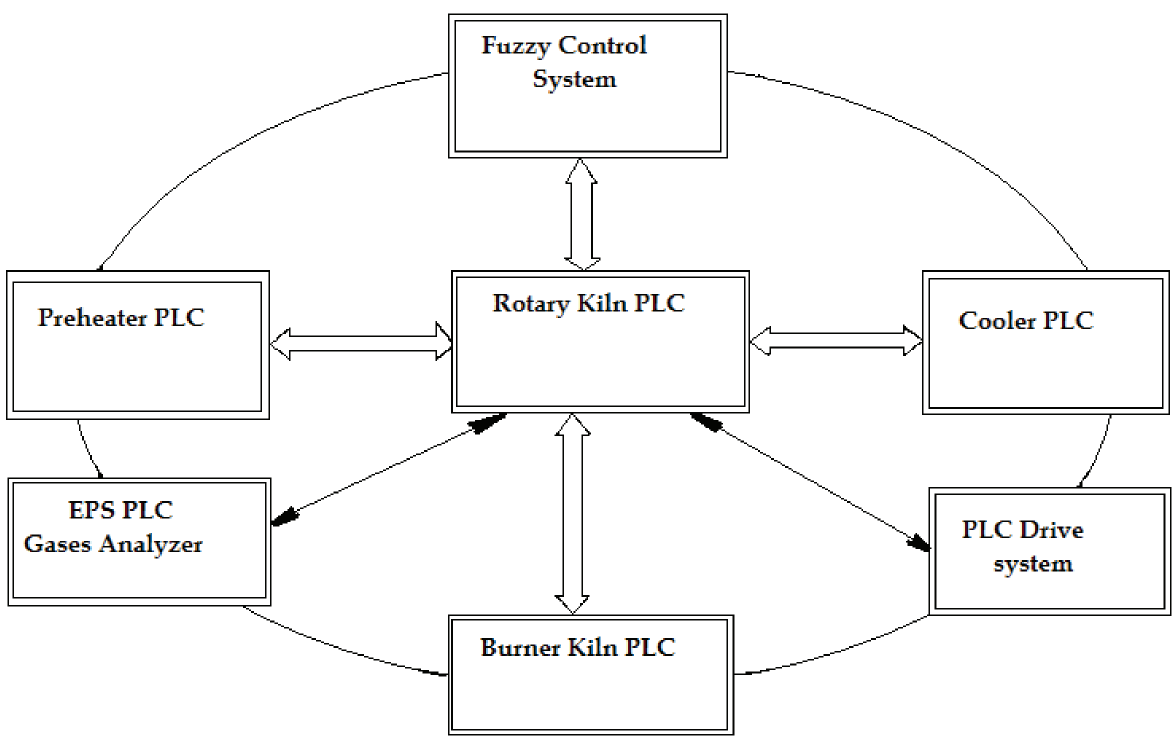


Fig. 22. System architecture

6. Conclusions

Process modelling is an effective and economical method of analyzing and diagnosing process operations. The highly informative and detailed information provided by modelling cannot be achieved by any other means.
Computer aided finite element modelling was used to predict temperature profiles and heat fluxes involving linear properties of the exterior insulation materials and internal radiation

effects. Process modelling provides effective, safe, and economical ways of creating a detailed database of information about the process. Data includes detailed fields of temperature, heat transfer and a host of other important information.
The solution indicates that such a model may be used to identify problems of kiln operation. Our numerical kiln model which uses existing heat transfer correlations for rotating kiln and incorporates in-kiln combustion provides a tool for modelling temperature, calcining, drying, in a rotating kiln. We use modelling to improve the clinker kiln operation.
Graphical representations of the results have been developed to facilitate the determination of the gas temperature and the total heat flux to the wall and to the solids. We have also achieved the emissions prediction and the simulation of the pollutants dispersion in the air.

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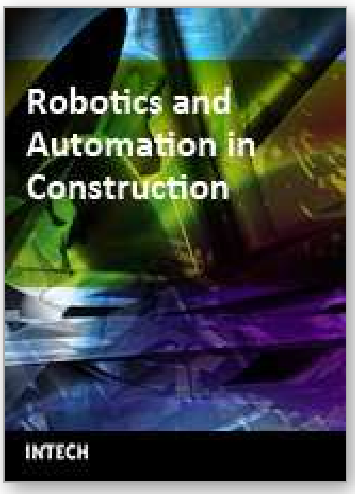

Robotics and Automation in Construction

Edited by Carlos Balaguer and Mohamed Abderrahim

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This book addresses several issues related to the introduction of automaton and robotics in the construction industry in a collection of 23 chapters. The chapters are grouped in 3 main sections according to the theme or the type of technology they treat. Section I is dedicated to describe and analyse the main research challenges of Robotics and Automation in Construction (RAC). The second section consists of 12 chapters and is dedicated to the technologies and new developments employed to automate processes in the construction industry. Among these we have examples of ICT technologies used for purposes such as construction visualisation systems, added value management systems, construction materials and elements tracking using multiple IDs devices. This section also deals with Sensorial Systems and software used in the construction to improve the performances of machines such as cranes, and in improving Human-Machine Interfaces (MMI). Authors adopted Mixed and Augmented Reality in the MMI to ease the construction operations. Section III is dedicated to describe case studies of RAC and comprises 8 chapters. Among the eight chapters the section presents a robotic excavator and a semi-automated façade cleaning system. The section also presents work dedicated to enhancing the force of the workers in construction through the use of Robotic-powered exoskeletons and body joint-adapted assistive units, which allow the handling of greater loads.

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