ENERGY SAVING TECHNOLOGY OF CEMENT MANUFACTORING

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SUMMARY

The new and different mathematical modelling concerning mass balances of parallel flowing preheater cyclone system is based on four different components, which are $CaCO_3$, CaO, $MgCO_3$ (or MgO) and other oxides. Calcination proportion and amounts that take place within bottom cyclone groups and rotary kiln as well as the carbonation proportion and amount that take place in the cyclone group right over the bottom cyclone are included in this mathematical model. Besides, modifications that occur in solid and gas masses as a result of these reactions happening in the rotary kiln and preheater cyclone are expressed.

Keywords: Cement, mass, balance, mathematical modelling

1. INTRODUCTION

Raw material and gas flows in parallel flowing preheater cyclone are as follows. Preheater gases are equally distributed into two parallel cyclone groups at the exit of the rotary kiln. While preheater gases keep going equally up in the parallel cyclone groups, 100% of the raw material is fed by Number 1 cyclone. All the raw material passes rapidly all the way through each cyclone and reaches from one side of the preheater to the other side of it and after being calcined in the bottom cyclone, it is fed to the kiln. The basic property of this system is the rapid flow of raw material all through both of the parallel gas flows. Therefore, only half of the existing gas has contact with the entire raw material (Figure 1).

Since raw material and hot gas are completely mixed in parallel flowing preheater cyclones, gas exit temperature remains lower than other recognized systems. Kiln exit gases enter in the preheater cyclone with a temperature of 1000-1200ºC. The temperature of chimney gases flown out of the preheater cyclone is under 300ºC. The control of allocation of kiln gases through preheater cyclones is managed by dampers. The position of the damper system managed by two analysers showing CO and O_2 amounts. This gas analyser is placed after bottom cyclones and normally displays 1% O_2 for kiln gases and 2% O_2 for bottom cyclone gases. Practically CO quantity is accepted as zero [1,2].

2. MATHEMATICAL MODELLING OF MASS BALANCES

There are separate mass equation calculation methods for different cement production systems (wet, semi-wet, dry etc.). Since wet and semi-wet cement production systems are out of use anymore, here we will basically focus on the dry system. Valuable studies in this field are carried out by [3].

When cement production system are taken as a whole and mass equation clinker production taken as the basis, calculation can be made through six different oxide equations of the calcium oxide, iron oxide, magnesium oxide and non-volatile oxides (nvo) as well as oxygen balances [4-11]. In the mathematical model to be explained here the raw material is assumed to be composed of four components such as; $CaCO_3$(X), CaO(Y), $MgCO_3$(V) or MgO(w) and other oxides as (Z) [12,13,14].

Figure 1. Gas and solid flow scheme in a cement factory with parallel preheater cyclone

Therefore, in the preheater cyclone stages of solid and gas masses, it is possible to calculate the quantities and composition at the entry and the exit. In the cement factory there are three basic units to be taken into account in the calculation of mass equality. In the cooling unit of these units no modification is observed in the solid and gas masses. However in the revolving kiln unit modification in solid and gas masses occur in the form of remaining calcination of the raw material behind the preheater cyclones and fuel combustion.

2.1 Combustion Equations and Chimney Gas Calculation

In the preheater cyclones gas masses emerge out of combustion and raw material calcination. Here equations regarding combustion are presented [12,13,14].

Required combustion air:

$$A = \frac{Y * \lambda * \frac{100}{23} * \left[\frac{8}{3} * Cy + Sy + \left(8 * Hy - Oy \right) \right]}{28.97} \tag{1}$$

Combustion gases:

$$\left. \begin{aligned} & CO_2, y = Y * Cy * \frac{KK}{12} \\ & CO, y = Y * Cy * \frac{1 - KK}{12} \\ & O_{2,} y = 0{,}21 * A * (\lambda - 1) \\ & N_{2,} y = 0{,}79 * A \\ & SO_{2,} y = Y * \frac{Sy}{32} \\ & H_2O, y = Y * \left[\frac{H_2O, y}{18} + \frac{Hy}{2} \right] \end{aligned} \right\} \tag{2}$$

Apart from combustion gases, CO_2 that come out of raw material calcination and raw material moisture as well as raw material crystal water vapour take place in the chimney gas. In this situation;

Total CO_2 in the chimney gas:

$$CO_2 = CO_{2,} y + \frac{44}{100} * X_0 + \frac{44}{84} * V_0 \tag{3}$$

Total amount of water vapour in the chimney gas:

$$\sum H_2O = H_2O, y + A * Xs + Fw + KKw \tag{4}$$

Total amount of chimney gas:

$$BG = CO_2 + CO + O_2 + SO_2 + \sum H_2O \tag{5}$$

2.2. Calculating $MgCO_3$, $CaCO_3$ and total CO_2 mole quantities in raw material

When the calculation is made, it is assumed that MgO exists totally in the form of $MgCO_3$ and that ignition loss occurs completely as a result of degradation of carbonates and vaporization of crystal water and respectively the mole quantities of $MgCO_3$, $CaCO_3$ and total CO_2 in the dry raw material is calculated as follows.

Quantity of $MgCO_3$ moles:

$$MCM = \frac{MgO,_F}{40} \tag{6}$$

Quantity of $CaCO_3$ moles:

$$CCM = \frac{\text{Total amount of carbonate in the raw material} - (84 * MCM)}{100} \tag{7}$$

Total quantity of CO_2 moles:

$$TCM = MCM + CCM \tag{8}$$

2.3. Mass equation at the preheater cyclone unit

Raw material in the preheater cyclone unit is partly calcined [15]. CO_2 that comes out in calcination make up combustion gases and leaking air gas flows while raw material and chimney powder establish solid flows (Figure 2 and Table 1).

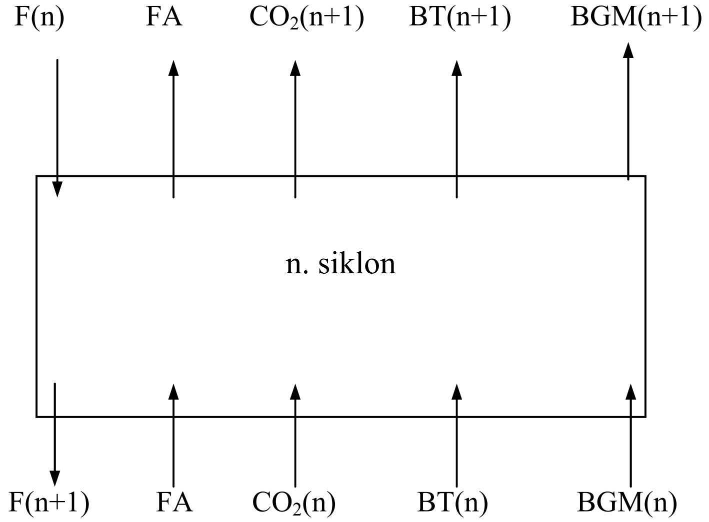


Figure 2. Schematic display of solid and gas masses that enter in and go out of the preheater cyclone unit.

Table 1. Entering and outgoing masses in the preheater cyclone

Entering masses		Outgoing masses	
With raw material	[F(n)]	With raw material	[F(n+1)]
With chimney powder	[BT(n)]	With chimney powder	[(BT(n+1)]
With chimney gas	[BG(n)]	With chimney gas	[BG(n+1)]
CO_2 emerging out of calcination	[CO_2(n)]	CO_2 emerging out of calcination	[CO_2(n+1)]
With air leakage (false air)	[FA]	With air leakage (false air)	[FA]

2.4. Solid and gas mass equations at entry to preheater cyclones and cyclone stages

When establishing solid and gas mass equations following assumptions were taken into consideration [12,13,14]:

a-) Total amount of non-volatile oxides in clinkers is 1.0.

b-) Fuel ash combusted in the rotary kiln is entirely absorbed by the clinker

c-) Chimney powders that come out of the kiln through being dragged with the kiln gases are completely the same with clinker chemical analysis.

d-) At the entry stage the MgO in raw material is completely in the form of $MgCO_3$.

e-) $MgCO_3$ in the raw material is totally calcined in the (m-2)th cyclone

f-) R_2 amount of $CaCO_3$ is totally calcined in the (m-1)th cyclone

g-) R_1 amount of $CaCO_3$ is totally calcined in the (m-2)th cyclone

h-) P_2 amount of CaO and MgO in the whole amount of MgO in the chimney gas gets recarbonated at (m-3)th cyclone

i-) P_1 amount of $CaCO_3$ gets recarbonated at (m-4)th cyclone

Due to the fact that the total percentages of the chemical analysis of the raw material is not equal to 1.0, correction factor given below must be used.

$$UF = \frac{1}{\frac{100}{56} * CaO,_F + \frac{84}{40} * MgO,_F + SiO_2,_F + Al_2O_3,_F + Fe_2O_3,_F} \tag{9}$$

Consequently:

$$F = \frac{Uoo,_K - (Y * Ash * Uoo,y)}{UF * Uoo,_F} \tag{10}$$

In the entry to cement factory with parallel flowing preheater cyclone as well as in the cyclone stages, $CaCO_3$(X) and CaO(Y) equations are established as follows (Figure 3). By considering m=9 for four stages, m=10 for five stages and m=11 for six stages (m-2) equations can be written from n=1 to m-2.

$$X_0 = \frac{F * CaO,_F * UF}{56} \tag{11}$$

$$0.56 * \eta(n) * X(n) - 0.56 * [1 - \eta(n+1)] * X(n+1) + \eta(n) * Y(n) - [1 - \eta(n+1)] * Y(n+1) = 0.56 * X_0 \tag{12}$$

(m-1)th equation;

$$0.56 * \eta(m-1) * X(m-1) + \eta(m-1) * Y(m-1) = 0.56 * [X_0 + X(m)] + Y(m) \tag{13}$$

From n=1 to (m-5), (m-5) equations can be written as shown below;

$$\eta(n) * Y(n) - [1 - \eta(n+1)] * Y(n+1) = Y_O \tag{14}$$

In order to be able to calculate the mass equations at the parallel flowing preheater cyclone stages, it is necessary to establish equations twice as many as the number of parallel cyclones.

The last four equations are;

$$(1 - P_1) * \eta(m-5) * Y(m-5) - Y(m-4) + (1 - P_1) * [1 - \eta(m-3)] * Y(m-3) = 0\,2 \tag{15}$$

$$(1 - P_2) * \eta(m-4) * Y(m-4) - Y(m-3) + (1 - P_2) * [1 - \eta(m-2)] * Y(m-2) = 0 \tag{16}$$

$$\begin{gathered} -0{,}56 * R_1 * \{\eta(m-3) * X(m-3) + [1 - \eta(m-1)] * X(m-1)\} - \eta(m-3) * Y(m-3) + \\ Y(m-2) - [1 - \eta(m-1)] * Y(m-1) = 0 \end{gathered} \tag{17}$$

$$-0{,}56 * R_2 * \eta(m-2) * X(m-2) - \eta(m-2) * X(m-2) + Y(m-1) = 0{,}56 r_2 * X(m) + Y(m) \tag{18}$$

$MgCO_3$(V) and MgO(W) equations are arranged as follows;

$$V_0 = \frac{84}{40} * UF * F * MgO,_F \tag{19}$$

From (n=1) to (m-2);

$$\eta(n) * V(n) - [1 - \eta(n+1)] * V(n+1) - V_0 = 0 \tag{20}$$

Other equations are;

$$\eta(m-3) * V(m-3) - \frac{84}{40}[1 - \eta(m-2)] * W(m-2) - V_0 = 0 \tag{21}$$

$$\eta(m-2) * W(m-2) - [1 - \eta(m-1)] * W(m-1) - V_0 = 0 \tag{22}$$

$$\eta(m-1) * W(m-1) - UF * F * MgO,_F - BT(1) * W(m) = 0 \tag{23}$$

$$V = V_0 + [1 - \eta(1)] * V(1) \tag{24}$$

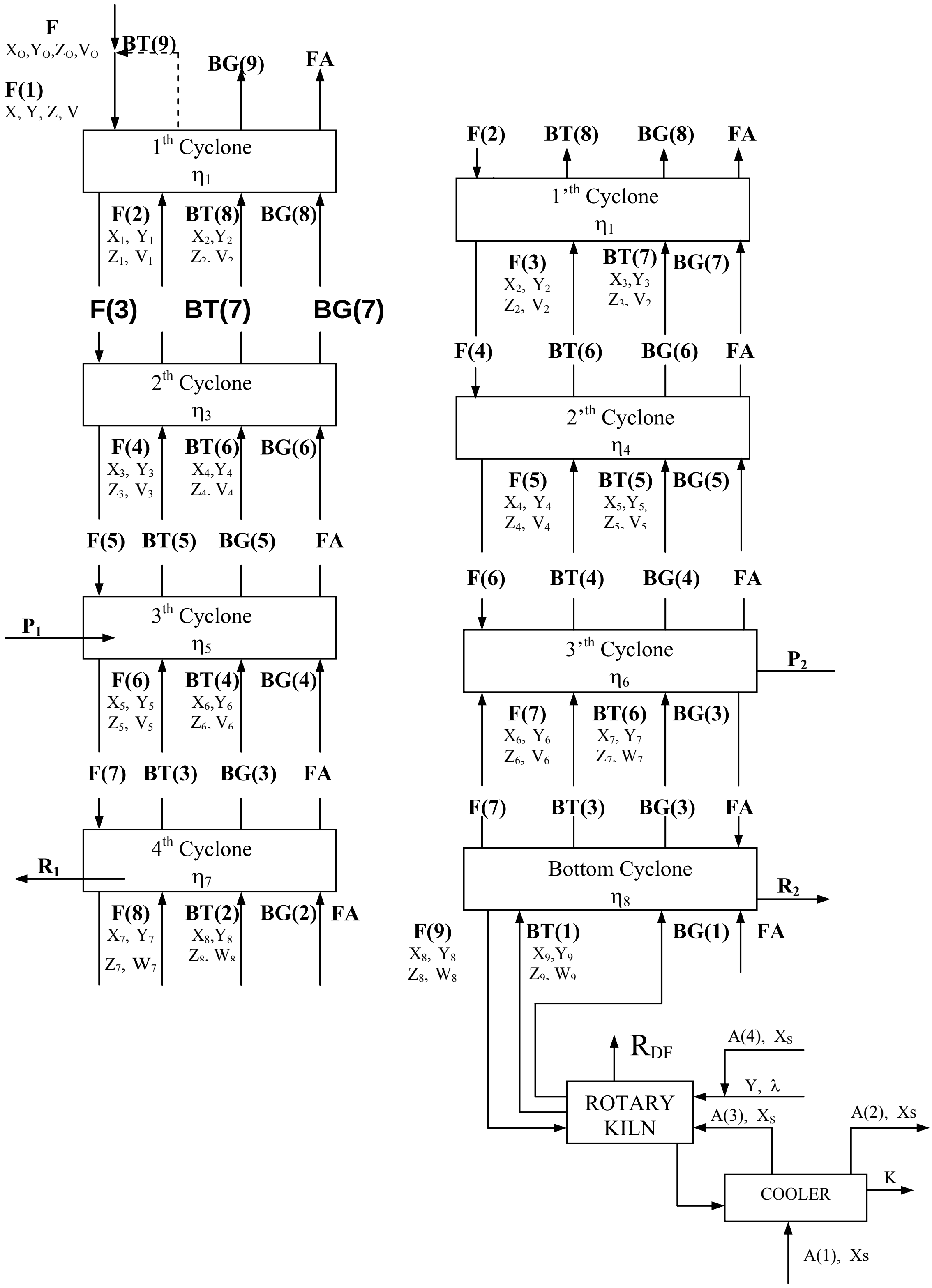
$$W(m) = MgO,_k$$

Similarly other equations concerning other oxides (SiO_2, Al_2O_3, Fe_2O_3) are written as follows;

$$Z_0 = F - (X_0 + Y_0 + V_0) \tag{25}$$

From (n=1) to (m-2);

$$\eta(n) * Z(n) - [1 - \eta(n+1)] * Z(n+1) - Z_0 = 0 \tag{26}$$



$X=CaCO_3$

$Y=CaO$

Z=Other oxides
(Al_2O_3, Fe_2O_3, SiO_2)

$V=MgCO_3$

$W=MgO$

Figure 3. Variables used in modelling for gas and solid masses at a parallel flowing preheater cyclone ,cement factory (four stages)

Other equation is;

$$\eta(m-1) * Z(m-1) - BT(1) * Z(m) - Z_0 = 0 \tag{27}$$

$$Z = Z_0 + [1-\eta(1)] * Z(1) \tag{28}$$

At the entry and cyclone stages the quantity of raw material and the chimney powder are calculated as follows:

$$F(1) = X + Y + Z + V \tag{29}$$

BT(1) =A percentage of the clinker within the gas outlet of the rotary kiln

$$BT(2) = [1-\eta(m-1)] * [X(m-1) + Y(m-1) + Z(m-1) + W(m-1)] \tag{30}$$

From N=1 to (m-2);

$$F(n+1) = \eta(n) * [X(n) + Y(n) + Z(n) + V(n)] \tag{31}$$

$$BT(n+2) = [1-\eta(m-1-n)] * [X(m-1-n) + Y(m-1-n) + Z(m-1-n) + V(m-1-n)] \tag{32}$$

From n=(m-1) to m;

$$F(n) = \eta(n-1)[X(n-1) + Y(n-1) + Z(n-1) + W(n-1)] \tag{33}$$

At the entry and cyclone stages the other oxides (SiO_2, Al_2O_3, Fe_2O_3) in raw the material are calculated one by one as follows:

$$SiO_{2,F}(m) = \frac{[1+BT(1)] * SiO_{2,k} - Y * Ash * SiO_{2,y}}{F(m)} \tag{34}$$

$$SiO_{2,F}(m-1) = \frac{[1+BT(2)] * SiO_{2,k} - Y * Ash * SiO_{2,y}}{F(m-1)} \tag{35}$$

$$Al_2O_{3,F}(m) = \frac{[1+BT(1)] * Al_2O_{3,k} - Y * Ash * Al_2O_{3,y}}{F(m)} \tag{36}$$

$$Al_2O_{3,F}(m-1) = \frac{[1+BT(2)] * Al_2O_{3,k} - Y * Ash * Al_2O_{3,y}}{F(m-1)} \tag{37}$$

$$Fe_2O_{3,F}(m) = \frac{[1+BT(1)] * Fe_2O_{3,k} - Y * Ash * Fe_2O_{3,y}}{F(m)} \tag{38}$$

$$Fe_2O_{3,F}(m-1) = \frac{[1+BT(2)] * Fe_2O_{3,k} - Y * Ash * Fe_2O_{3,y}}{F(m-1)} \tag{39}$$

A molar amount of CaO and CO_2 during at the and of calcination process in the rotary kiln

$$CaO,_{cal}(1) = 0{,}56 * \eta(m-1) * X(m-1) \tag{40}$$

$$CO_{2,cal}(1) = \frac{CaO,_{cal}(1)}{56} \tag{41}$$

CaO and CO_2 that emerge out of the calcination in the (m-1)th cyclone

$$CaO,_{cal}(2) = 0{,}56 * [\eta(m-2) * X(m-2) + BT(1) * X(m) - X(m-1)] \tag{42}$$

$$CO_{2,cal}(2) = \frac{CaO,_{cal}(2)}{56} \tag{43}$$

CaO, MgO and CO_2 that emerge out of the calcination in the (m-2)th cyclone

$$CaO,_{cal}(3) = 0{,}56 * \{\eta(m-3) * X(m-3) - [1-\eta(m-1)] * X(m-1) - X(m-2)\} \tag{44}$$

$$MgO = \frac{40}{84} * \eta(m-3) * V(m-3) \tag{45}$$

$$CO_{2,cal}(3) = \frac{CaO,_{cal}(3)}{56} + \frac{MgO}{40} \tag{46}$$

CaO and MgO recarbonated in the (m-3)th cyclone and CO_2 preserved through recarbonation:

$$CaO,_{rcar}(1) = P_2 * \{\eta(m-4) * Y(m-4) + [1-\eta(m-2)] * Y(m-2)\} \tag{47}$$

$$MgO,_{rcar} = [1-\eta(m-2)] * W(m-2) \tag{48}$$

$$CO_{2,pre}(1) = \frac{CaO,_{rcar}(1)}{56} + \frac{MgO,_{rcar}}{40} \tag{49}$$

CaO recarbonated in the (m-4)th cyclone and CO_2 preserved through recarbonation:

$$CaO,_{rcar}(2) = P_1 * \{[1-\eta(m-5)] * Y(m-5) + [1-\eta(m-3)] * Y(m-3)\} \tag{50}$$

$$CO_{2,pre}(2) = \frac{CaO,_{yrcar}(2)}{56} \tag{51}$$

Visible calcination proportion in the (m-1)th cyclone:

$$r_g(1) = \frac{\frac{100}{56} * Y(m-1)}{X(m-1) + \frac{100}{56} * Y(m-1)} \tag{52}$$

Visible calcination proportion in the (m-2)th cyclone:

$$r_g(2) = \frac{\frac{100}{56} * Y(m-2)}{X(m-2) + \frac{100}{56} * Y(m-2)} \tag{53}$$

In this situation CO_2 quantities in the chimney gas at cyclone stages are calculated as follows:

CO_2 (1) = combusted +CO_2.cal (1) ………………………... (R_{DF} exit)

$CO_21(2) = \frac{CO_2(1)}{2} + CO_{2,cal}(2)$ ………………………… (m-1)th cyclone exit

$CO_22(2) = \frac{CO_2(1)}{2} + CO_{2,cal}(3)$ ………………………… (m-2)th cyclone exit

$CO_21(3) = CO_21(2) - CO_{2,pre}(1)$ ………………………… (m-3)th cyclone exit

$CO_22(3) = CO_22(2) - CO_{2,pre}(2)$ ………………………… (m-4)th cyclone exit

In other cyclones chimney gas remains constant and no modification takes place in its components.

3. CONCLUSIONS AND DISCUSSION

An appropriate computer program for this mathematical modelling has been prepared for the cement factory with parallel flowing preheater cyclone. Through entering data in the program regarding normal quality coal, high quality coal (with high specific heat value] and fuel-oils; gas and solid flows in cyclone stages as well as their quantity and compositions at entry to the cyclone and the cyclone stages can be achieved. Achieving these consequences makes it possible to make more comfortable and realist energy equations at each cyclone stage and cement production unit. It is possible to see the calcination proportions at rotary kiln and bottom cyclone group as well as recarbonation quantities at the cyclone group right over the bottom cyclone along with the negative and positive effects of these proportions over energy equations. It is supposed that discussing the consequences of this program here in this article will highly expand the volume of this article. Therefore, this issue will be taken in another study. In order to calculate the chemical analysis of the raw material at the entry and cyclone stages as well as clinker's chemical analysis, it is either required to calculate the raw material analysis by taking the clinker's chemical analysis as the basis and by going backwards or by taking chemical analysis of entry raw material as the basis and going forwards. In order to maintain desired quality of clinker we recommend that you take the clinker analysis as the basis that will facilitate appropriate raw material ratio preparation.

Symbols:
Ash: Fuel ash (%)
BG: Chimney gases
BT: Chimney powder
FA: Leaking air entering the system through entry-exit impermeablity (Kmol)
Fw: Humidity ratio in the raw material (Kmol)
KK: Combustion efficiency (%)
KKw: Crystal water amount in the raw material (kmol)
P: Cyclone stage recarbonation ratio (%)
R: Cyclone stage and rotary klin calcination ratio (%)
R_{DF}: Rotary kiln
Xs: Proportional humidity of the air (gr/Kmol.air)
λ: Excess air coefficient (%)
η (n): Cyclone efficiency (%)

Subscripts:
cal: (CaO, MgO, and CO_2) what comes out of calcination
F: Raw material
K: Clinker
rcar: recarbonation (CaO and MgO
re: preserved (CO_2)
rg: Visible (calcination ratio)
Y: Fuel

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SEMENT İSTEHSALININ ENERJİQƏNAƏTLİ TEXNOLOGİYASI

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Sement istehsalında ilk dəfə olaraq müxtəlif komponentlərin: $CaCO_3$, CaO, $MgCO_3$ (və ya MgO) və digər oksidlərin kütlə nisbətlərinin seçilməsinin riyazi modelləşdirilməsi işlənilmişdir. Modelləşdirilmədə sobada reaksiya nəticəsində əmələ gələn bərk cisim və qaz hallarının kütləsində əmələ gələn dəyişikliklər nəzərə alınır. Kütlə nisbətlərinin optimal seçilməsi istehsalın enerjiyə qənaət rejimini təmin edir.

ЭНЕРГОСБЕРЕНАЮЩАЯ ТЕХНОЛОГИЯ ПРОИЗВОДСТВА ЦЕМЕНТА

АХМЕТ КОЛИП, АХМЕТ ФЕВЗИ САВАШ, МЕХМЕТ БАХАТ

Впервые разработано математическое моделирование подбора массовых пропорций различных компонентов: CaCO3, CaO, MgCO3 (или MgO) и других окислов при производстве цемента. Моделирование учитывает изменения в массах в твердых и газовых состояниях, происходящие в результате реакций в обжиговой печи. Оптимальный подбор массовых пропорций обуславливает энергосберегающий режим производства.