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ESTIMATING THE THICKNESS OF COATING IN THE BURNING ZONE OF CEMENT KILNS INCLUDING THE AGING FACTOR

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Abstract

The coat in the burning zone play an important role in cement industry and energy keeping, not only it protect the refractory bricks but also affect the type of clinkers produced so it is a good idea to make some researches about this coat

In this papers the model produced by Sepehr Sadiqhi et.al. 2011 depending on the measured process variables and scanned shell temperature, will reviewed to estimate the thickness of coating at Kufa cement kilns. The Aging factor will be entered to represent the phenomena when fused clinkers transform to solid and calculate the time required for making this coating.

The estimation of thickness in this model was depending mainly on the difference between the inside temperature gotten from the model and outside temperature measured by kiln shell scanner at burning zone. The model was applied on two kilns (2 and 3) at Kufa plants. The difference between theoretical and practical results for measuring thickness at kilns 2and 3 was 4.43 and 3.92 cm respectively , the time required for formation the stable coating was 24 hr or 960 rpm.

الموجز

إن طبقة الحماية في منطقة الاحتراق تلعب دورا مهما في صناعة الاسمنت وتوفير الطاقة، ليس فقط في حماية الطابوق الحراري ولكنها تؤثر أيضا في نوعية الكلنكر المنتج، لدلك من الجيد عمل بعض البحوث حول هده الطبقة.

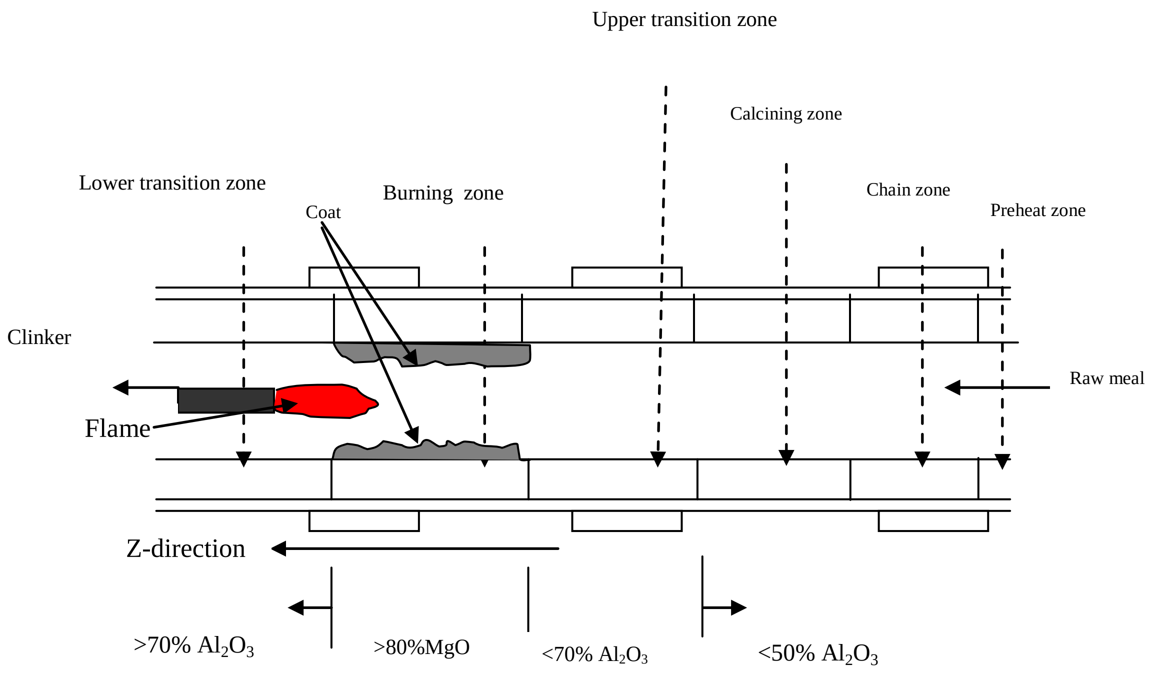
في هدا البحث فان الموديل الذي تم إنشاؤه من قبل الباحث صادقي وزملاؤه والمنشور في المجلة الكندية للهندسة الكيميائية والدي يعتمد على متغيرات العمليات المقاسة ودرجة حرارة غلاف الفرن سيتم اعتماده لقياس سمك طبقة الحماية لأفران معمل سمنت الكوفة مع إدخال عامل التقادم لتمثيل ظاهرة تحول الكلنكر السائل إلى صلب و حساب الوقت اللازم لتكوين الطبقة.

إن تحديد السمك في هدا الموديل يعتمد أساسا على فرق درجات الحرارة خارج الفرن المقاسة بواسطة ماسح الفرن الحراري وبين درجات الحرارة داخل الفرن في منطقة الاحتراق.تم تطبيق الموديل على الفرن رقم ٢ و٣ وأظهرت النتائج بان الفرق بين الجانب العملي والنظري في قياس سمك الطبقة للفرن ٢ و٣ كان ٤,٤٣ و ٣,٩٢ ، والزمن اللازم لتكوين طبقة ثابتة كان ٢٤ ساعة او ٩٦٠ دورة/دقيقة .

Key wards **: Coating , Cement kilns, Burning zone, Energy.**

1-Introduction

Coating in the burning zone ,is a mass of clinker or clinker dust particles that adheres to the lining, having changed from a liquid to a solid state, Figure 1 shows the different zones of the kiln, the zone under study and types of bricks used for each zone. Figure 2 shows the coating, brick and shell at the burning zone.



Fig(1) : The cement kiln zones and temperature distribution (Operational Parameters:(Kufa Cement Factory) , Wet Production Method , Six Stages ,Radius (5.25-5.75)m , Length (175)m, (1.5-2.25) rpm.).[Kufa Cement Plant/Kilns Department)

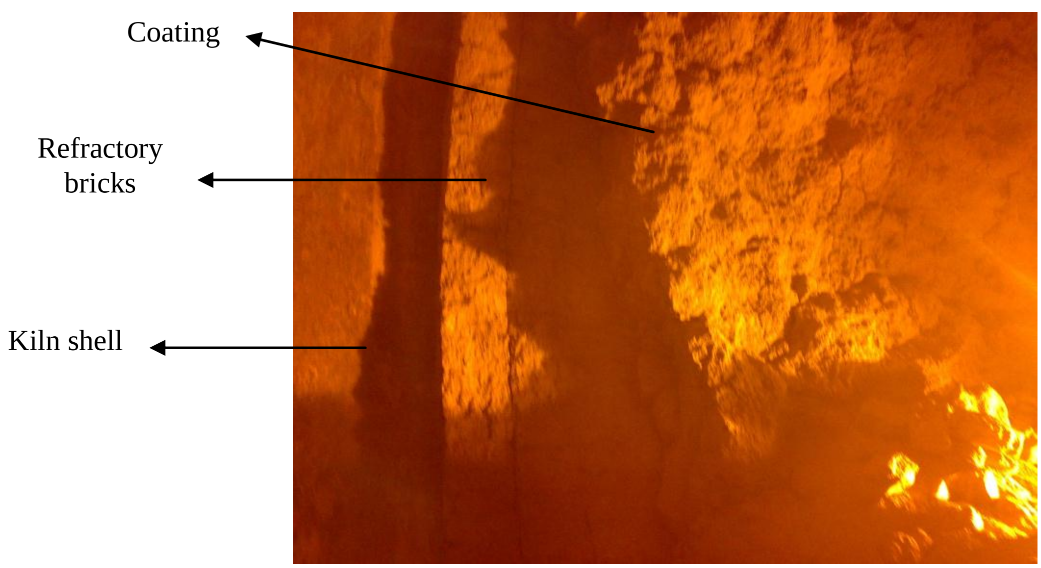


Fig.2 : The coating at the burning zone (Kufa cement plant, Kiln No. 2).

The solidified material adheres to the refractory surface when no coating exists, or adheres to the surface of coating, as long as the temperature of these surfaces is smaller than the solidifying temperature of the liquid phase. Coating continues to form until its surface reaches this solidifying temperature (define as the reference temperature). When the kiln operates under such conditions at equilibrium ,the coating will maintain itself. This mean theoretically no new coating is formed. When this temperature is exceeded ,the material on the surface of coating change again from a solid to a liquid state ,and the coating will start to come off.[Ashley 2004]

Without coating the kiln shell temperature in the burning zone goes up with the following deleterious consequences [Geraldo 2002]:

- The most refractory products would not resist temperatures above 1500°C in the presence of fluxes.
- Increased the heat losses through the refractory bricks.
- Faster alkali vapor infiltration into the refractory brick and faster kiln shell corrosion.
- A faster wear of refractory brick by clinker abrasion and thermal fatigue.

Problem Statement

The thickness of coating in the burning zone is very important for cement industry ,thin coating mean that more energy losses and refractory brick wear, thick coating partially prevent clinker from exit and hinder the cement production.

The costs of not optimum coating thickness may include:

1. Kiln downtime.
2. Removing the not good coat.
3. Reduced production (about 1000-1400 tone of clinker / day)..

Research Purpose

The main purpose of this research is to Numerically determine the optimum thickness of coating in the burning zone and make comparison with practical side and also make recommendations in order to control the thickness of coating.

Research Objectives

- Studying the formation factors of coating at the burning zone.
- Make Recommendations to control the cement kiln operation conditions in order to get the ideal thickness of coating.
- Using a numerical method previously used by Sepehr Sadiqhi et.al. 2011 depending on the measured process variables and scanned shell temperature but including the Aging factor practical data of heat generated and released and the flame length, as well as , make a comparison with the practical results.

Influencing Factors on Coating Formation and Maintenance:

Heat always travels from a place of higher temperature to a place of lower temperature. As there is a temperature drop between the coating surface and the kiln shell, the heat flows in direction of air. This heat transfer is governed to a great extent by the conductivity and thickness of both refractory and coating[].

Heat passing through the kiln shell must be constantly replenished by the flame inorder to maintain a condition of equilibrium necessary for coating formation, so that the flam play important role in coating formations.

As the coating consist of clinker material which has changed from liquid to a solid state, the amount of any kiln feed liquefies at clinkering temperature plays a very important

role in coating formation. This means that a kiln feed with a high liquid content at clinkering temperature is more effective for coating formation than a feed low in liquid.
Several variables can affect the maintenance of this coating[Goswami 2011]:

- Large fluctuations in raw meal parameters and poorly nodularized clinker can result in liquid phase segregation, which reduces the thickness and stability of the coating.
- The use of high-sulfur fuels, combined with poor combustion engineering, can lead to a higher sulfate compound volatilization and ring formation buildups.

A number of factors can cause coating to disappear completely, with a resulting tendency for the brick to become weak and friable due to thermomechanical fatigue. Amongst them are[Goswami 2009]:

- Production of high SiO_2 clinker,
- Production of sulfate-resistant clinker with 3%C_3A as result of Fe_2O_3 addition,
- Prolonged thermal overload,
- Frequent shifting of fuel type,
- White cement production.

Aging and Temperature Effects:

Materials are said to age when their properties change with time, the aging processes of a physical nature (aging due to temperature effects) will be treated in this paper .Williams, Landel and Ferry [David Roylance 2001] have proposed that the variations in relaxation time are not primarily due to thermal activation, but to thermal expansion, i.e. the expansion of free volume V_f with increasing temperatures and by using an equation proposed by Doolittle these authors derived the famous WLF equation:

$$\log a_T = -\frac{c_1(T - T_{ref(c)})}{c_2 + T - T_{ref(c)}} \quad (1)$$

$$\tau = \exp(a_T) \quad (2)$$

a_T-WLF shift factor, c_1 ,c_2 -WLF eqn. constants, T-current temperature, T_{ref} -reference temperature
τ -current shifted time.

This equation will be used to coverage the temperature effect and time required to aging phenomena which occur during transformation of coating from liquid to solid in each turn of cement kiln.

Literature Review

Sepehr Sadighi et. al. 2011 produced a model to estimate the coating thickness in the burning zone of a rotary cement kiln by using measured process variables and scanned shell temperature. Them model could simulate the variations of the system, thus the impact of different process variables and environmental conditions on the coating thickness could be analysed. They mainly derived the model from heat and mass balance equations using a plug flame model for simulation of gas and/or fuel oil burning. The heat transfer value from shell to the outside was improved by a quasi-dynamic method. They suggested that the model predicted the inside temperature profile along the kiln, then by considering two resistant nodes between temperatures of the inside and outside, the latter measured by shell scanner, it estimated the formed coating thickness in the burning zone. The estimation of the model was studied for three measured data sets taken from a modern commercial cement kiln. The results gotten confirmed that the average absolute error for estimating the coating thickness for the cases 1, 2, and 3 are 3.26, 2.82, and 2.21cm, respectively.

(Yadagri et al 2012) discussed the controlling of temperature in the burning zone and its effect on the coating formation and bricks damage.They found that the reducing in the amount of coal in cement kiln head is appropriate to reduce the wind flow and increase the outflow wind that the flame is elongate, alleviate the cement kiln temperature too high.They also found that the cement kiln material with low altitude and along the surface of refractory bricks to fall, no adhesive material divergence, fine particles, clinker fCaO high, the burning zone temperature is too low, should increase the cement kiln head and coal consumption, and increase the wind flow, a corresponding reduction in outflow wind, so that the flame is shortened, firing with relatively concentrated, increase the temperature of the burning zone, so that the clinker node grains tend to be normal.

(June Ma et al 2012) Suggested a method to control temperature and coating of burning zone inrotary cement kiln. They found that burning zone temperature and torque measurements generate a total process error apportioned to fuel and speed control for the kiln. The control system responds to short-term process disturbances to maintain thermal stability in the kiln and the contributions of the burning zone temperature and torque measurements are modified in accordance with thermal stability. Feedback representing expected variations in the measurements is provided. Unusual or adverse conditions are sensed to generate override signals. The effect of torque in the chain section of the wet kiln is also considered in control

(Lu et al 2004) developed a computational fluid dynamics (CFD) based models to simulate rotary cement kiln But, it was not an applicable method for the coating thickness estimation in practice, because of the considerable calculation time to integrate the scanned shell temperature with the kiln model.

(Mujumdar et al.2007) developed a kinetic base models for the kiln .Such models were shown promising capabilities in capturing the overall behavior of cement kilns. However, most of the reported models did not account for the estimation of the coating thickness.

(Bokaian 1994).established a method for estimating the coating thickness which was the transient kiln model. In this method, the inside temperature of the kiln was considered as the average temperature of gas and solid. After measuring the shell temperature, the coating thickness was estimated by considering two resistant nodes between the inside and outside temperatures. The results were not reliable because there was no calculation for temperature profiles inside the kiln. Moreover, the heat transfer between the shell and the environment was calculated by a simple equation.

In this paper the model produced by (Sepehr Sadighi et. al. 2011) will applied to estimate the coat thickness with operation conditions in two kilns at Kufa cement plant but including the aging factor to calculate the time required for coating formation ,as well as, the values of flame length (m), heat generation by chemical reaction (W/m^3) and heat released by fuel combustion (J/s) will be taken practically from kiln department and chemical analysis laboratory, while in Sepehr model these values was gotten by using some equations depending on (Gorgo et al model 1983).The formed coating thickness in the burning zone will be estimated by considering two resistant nodes between the inside calculated wall temperature and the outside scanned shell temperature.

2-Method of Work (The Mathematical Model)

The system inside the burning zone is highly nonlinear because of the complex heat and mass transfer. The coating is formed on the refractory bricks after several chemical reaction and temperature differences ,as well as, it required energy for calcinations and melt formation, so that some assumptions was made to keep the structure as simple as possible and in the same time didn't affect the accuracy of the model. These assumption are:[Sepehr 2011]

- A steady-state one dimensional model was developed for calculating the wall temperature profile in the kiln.
- The inside and outside diameters of the kiln were constant.
- The specific and reaction heats were independent of temperature and they were constant along the axial direction.
- Conduction in gases and solid materials in the axial direction of the wall was neglected.
- Coefficients of convection and emissivity were independent of temperature and position.
- The height and speed of solid materials were constant at each cross-section of the kiln.
- The transported solids by gas stream were not included in the model.
- The average value of coating conductivity was assumed to be equal to 0.73W/m.^{o}C
- The conductivity of the bricks lining kiln could be estimated by Equation (3) which was correlated from the experimental data, given by the refractory vendor for the magnesite-fired brick type:

$$k_b = 3200 \times T_b^{(-0.9125)} \tag{3}$$

- The conductivity of metallic shell (carbon steel alloy) was considered equal to 43 W/m. ^{o}C
- The thickness of refectory brick was constant at the burning zone and equal to 20 cm.
- The number of scanned shell temperature points for a complete rotation of the kiln was twenty five. The temperature of each calculation point through axial position was assumed an average mathematical value of all points. The scanned shell temperatures was taken every week to capture the aging phenomena. This make our model a quasi-dynamic and allowed considering the variations in convective heat transfer coefficient dependent both on time and longitudinal distance.

The first steps for establishing our model is to make the energy balance equations for gas, solid and wall as follows:[Sepehr 2011]

For gas: $$A_g C_{pg} \rho_g v_g \frac{\partial T_g}{\partial z} = \beta_1 (T_w - T_g) + \beta_2 (T_s - T_g) + Q_{comb} \quad (4)$$

For solid : $$A_s C_{ps} \rho_s v_s \frac{\partial T_s}{\partial z} = \beta_2 (T_g - T_s) + \beta_3 (T_w - T_s) + A_s Q_c \quad (5)$$

For wall: $$\beta_1 (T_g - T_w) + \beta_3 (T_s - T_w) + \beta_4 (T_a - T_w) = 0 \quad (6)$$

Q_{comb} , Q_c are the heat released by the flame (J/s) and the heat generated by chemical reaction (W/m^3) respectively and taken from kiln department charts.(β_1, β_2, β_3, β_4) are nonlinear functions of temperatures, convection, and radiation heat transfer coefficients, and geometry which can be calculated by the following Equations [Sepehr 2011] :

Heat transfer coefficient between the gases and the inside wall is as follows:

$$\beta_1 = 1.7307 r_{in} p [f_1 + 1.73 \times 10^{-9} (1 - h_o) \varepsilon_g \varepsilon_w (T^2{}_g + T^2{}_w)(T_g + T_w)] \quad (7)$$

Heat transfer coefficient between the gases and the solid is as follows:

$$\beta_2 = 3.4314 r_{in} \sin(\frac{p}{2}) [f_2 + 1.73 \times 10^{-9} (1 - h_o) \varepsilon_g \varepsilon_s (T^2{}_g + T^2{}_s)(T_g + T_s)] \quad (8)$$

Heat transfer coefficient between the wall and the solid is as follows:

$$\beta_3 = r_{in} (2\pi - p) [f_3 + 1.73 \times 10^{-9} h \, \varepsilon_w \varepsilon_s (T^2{}_s + T^2{}_w)(T_s + T_w)] \quad (9)$$

Heat transfer coefficient between the outside wall and the ambient temperature is as follows:

$$\beta_4 = 2\pi f_4 r_{out} \quad (10)$$

The accuracy of the model will be increased by assuming that the heat-transfer coefficient of the outer shell is the sum of convective and radiative heat transfer coefficients as following:[Sepehr 2011]

$$h_{csh-a}=\frac{0.11k_a\,\mathrm{Pr}^{0.36}}{D}(0.5\,\mathrm{Re}_{\omega}^{2}+\mathrm{Re}^{2}+Gr)^{0.35} \tag{11}$$

$$h_{Rsh-a}=\{1+\frac{T_a}{T_{sh}}+(\frac{T_a}{T_{sh}})^2+(\frac{T_a}{T_{sh}})^3\}\varepsilon_{sh}\sigma T_{sh}^3 \tag{12}$$

$$h_{sh-a}=h_{csh-a}+h_{Rsh-a} \tag{13}$$

The convective and radiative heat transfer coefficients are strongly depending on temperature so that the temperatures distribution of the kiln shell will be recorded Practically by a simple device called kiln shell temperature scanner (Field located analyzer that measures the temperature of a kiln shell.) as shown in Figure 3, this device connected to computers in the control room using special software called (Data Temperature CS100).This program measure the radiation temperatures for the shell at burning zone of the kiln.

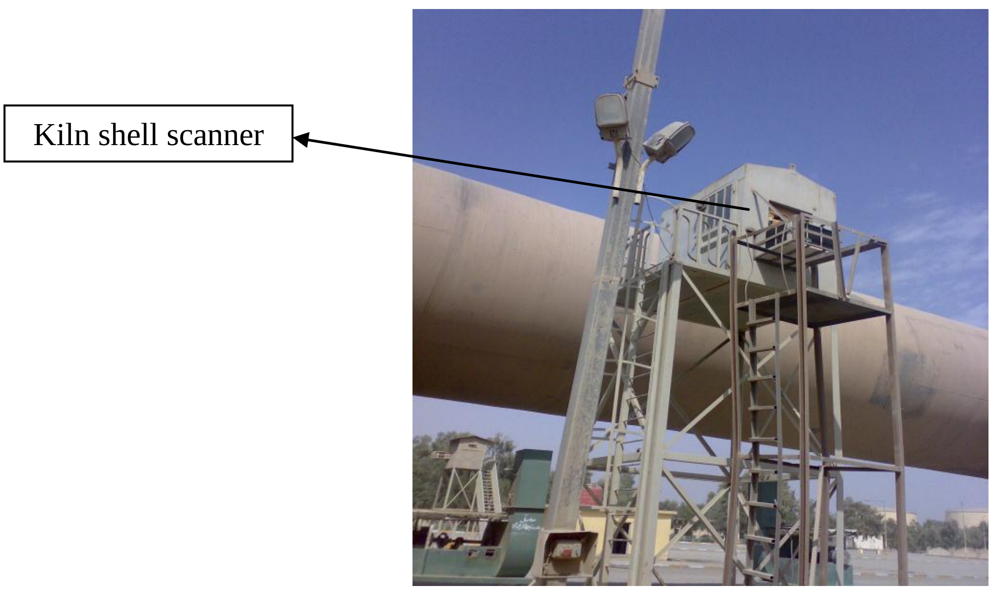


Fig 3: Kiln shell scanner

The coating formation is an accumulative process depending mainly on the reference temperature and time required to form one layer while the kiln turn around itself .When the temperature of liquid clinker reach the reference temperature (T_{ref}) it will transform to the solid state and one layer of coating will be deposited on the refractory brick and we can say it exposed to aging phenomena. WLF equation can capture the aging of coating process:

$$\log a_T = \sum -\frac{c_1(T_i - T_{ref(c)})}{c_2 + T_i - T_{ref(c)}}, \quad \tau = \exp(a_T)$$

noting that T_w =T

The burning zone was divided into “n” slice of equal size and will be calculated as:

$$n = \frac{Flame\ Length\ (FL)}{Mesh\ step\ size\ (\Delta Z)} \tag{14}$$

Flame length was taken practically from charts of kiln department. Mesh step-size obtained by meshed the length of kiln to a known number of steps, the mesh step-size will be taken=0.05m.

The previous set of differential and algebraic equations were solved by MATLAB5 software to get wall temperature. The profile of the wall temperature T_w (The temperature of the inside wall of the kiln) after solving the model will be then used to get the coating thickness by using another set of equations which will be formed in the coating equations model.

Modeling of Coating Equations:

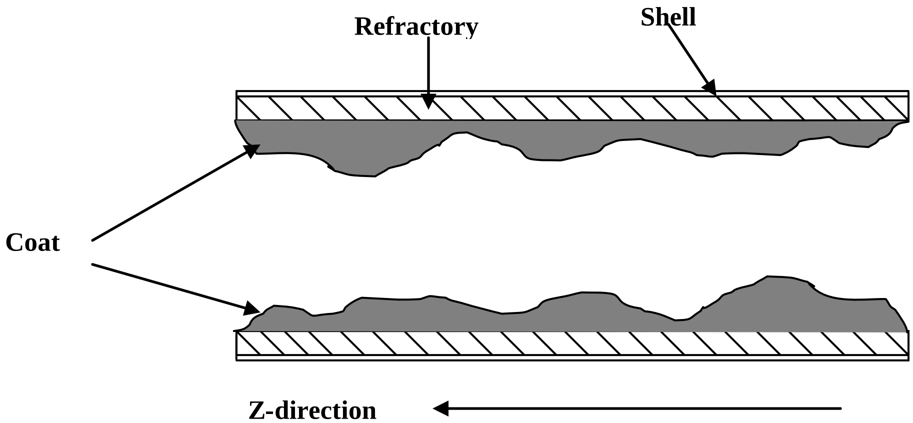
Firstly some assumptions were made to get a model ,as simple as, possible without increasing the complexity and decreasing the accuracy:

- The heat transfer through layers of the kiln wall was steady state.
- Heat flow via conduction in *z*-direction was neglected.
- In each longitudinal segment, the wall temperature in *z*-direction was lumped.

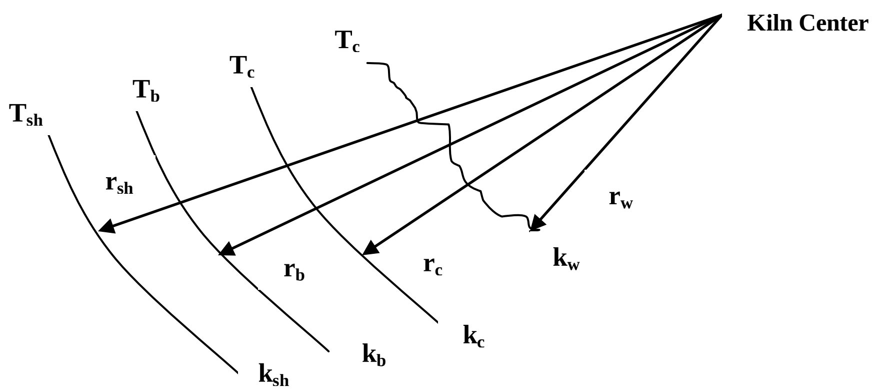
So that the heat flow equation in cylindrical coordinates (no heat generation) will be as follows [Kaminski 1977]:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} = 0 \tag{15}$$

Figure 4 shows the resistant layers between the inner wall surface and the environment.



Fig(4): (a) Wall layers in burning zone of cement kiln.



Fig(4): (b) Resistances of layers.

The boundary conditions according to Fig 3b can be written as follow:

1-Coating layer $r_1 = r_c$, $T_1 = T_c$, $r_2 = r_w$, $T_2 = T_w$

2-Refractory layer $r_1 = r_b$, $T_1 = T_b$, $r_2 = r_c$, $T_2 = T_c$

3-Shell layer $r_1 = r_{sh}$, $T_1 = T_{sh}$, $r_2 = r_b$, $T_2 = T_b$

The heat flow passed from inside the kiln to outside for each layer considering the above boundary conditions and using Equa.15 can be written as follows:

1-Heat flow from wall to coat: $$Q_{w-c} = \frac{2\pi \Delta Z k_c (T_w - T_c)}{\ln(\frac{r_c}{r_w})} \quad (16)$$

2-Heat flow from coat to brick: $$Q_{c-b} = \frac{2\pi \Delta Z k_b (T_c - T_b)}{\ln(\frac{r_b}{r_c})} \quad (17)$$

3-Heat flow from brick to shell: $$Q_{b-sh} = \frac{2\pi \Delta Z k_{sh} (T_b - T_{sh})}{\ln(\frac{r_{sh}}{r_b})} \quad (18)$$

4-Heat flow from shell to air: $$Q_{sh-a} = 2\pi \Delta Z r_{sh} h_{sh-a} (T_{sh} - T_a) \quad (19)$$

$$Q_{total} = Q_{w-c} = Q_{c-b} = Q_{b-sh} = Q_{sh-a} \quad (20)$$

The inside wall temperature of the kiln (T_w) was calculated by solving Equations (4)-(14) simultaneously. Then, by using Equations (20),(19),(18) and (17) Q_{total}, T_b, and T_c could be calculated, respectively. Finally the coating thickness (th_{coat}) in each step (ΔZ) can be estimated by calculating r_w from Equation (16) and implementing of that in the following Equation:

$$th_{coat} = r_c - r_w \quad (21)$$

To compare the theoretical and practical data of coating thickness , absolute average error (AAE) from the following equation were calculated:

$$AAE = \frac{abs(th_{coat}^{theo} - th_{coat}^{pract})}{N_t} \quad (22)$$

3-Results and Discussion

Data input:

C_{pg} = 1173.82 (J/kg. °C),C_{ps} =1089.97 (J/kg. °C),$f_1 = f_2 = f_3 = f_4$ =22.71 (W/m. °C) h_o =0.0757, p=(3π/2), r_{in} = 5.1 (m), r_{out} =5.2 (m) ,r_c=4.9 m, ρ_g =0.24 (kg/m^3), ρ_s =905 (kg/m^3)ΔZ =0.05 (m), ε_{sh} =0.5, ε_b =0.8, ε_w =0.9 , σ= 5.6697 x 10^{-8} W/m^2. °C ^{4},FL_1=12 m, FL_2=11 m, brick thickness=20 cm, Burning zone Length =35 m, k_{sh}= 43 W/m. °C, k_c=0.73 W/m. °C, k_b-function of reference temperature as in Eqau.(3), T_a=30°C,T_{sh} – measured from kin shell scanner (Fig. (5),(6)), v_g=3.2 (m/s), v_s=2.1 (m/s) ,Q_c=45000 (W/m^3) ,Q_{comp}=92(J/s) ,c_1= 18 ,c_2=1000 °C, $T_{ref(c)}$= 901°C.

Coating thickness will be estimated at the burning zone only (from the burner toward the middle of the kiln) as no coating is found in others zones . Temperature inside the kilns (T_w) was calculated from equations (4)-(14) because it was impossible to be measured by any instrument. The practical work was started in 9 March 2011 when a the maintenance process Figure 5 (replacing of magnesia in burning zone) was finished for kiln No.2&3.The time required to study the coating in this paper was about 6 months. Then after shutdown and cooling the kilns, the thickness of coating were measured in various positions.

Figures 6,7 represent the first and second kiln shell temperature distribution. It was shown that the position of temperature is approximately constant along the radial direction than the axial direction. This depending to the position of bricks and coating from the burner flame ,as well as, the thickness of coating in various positions of burning zone. The shell temperature in any required point on the surface could be correlated by making an interpolation between the curve points of figures 6,7 as in the following Eqns.:

Kiln No. 1 $T_{sh(1)}(z) = -0.0818\, z^4 + 2.3452\, z^4 - 17.628\, z^2 + 18.732\, z + 303.5$ (23)

Kiln No. 2 $T_{sh(2)}(z) = -0.0723\, z^4 + 1.92\, z^4 - 16.594\, z^2 + 17.457\, z + 301.4$ (24)

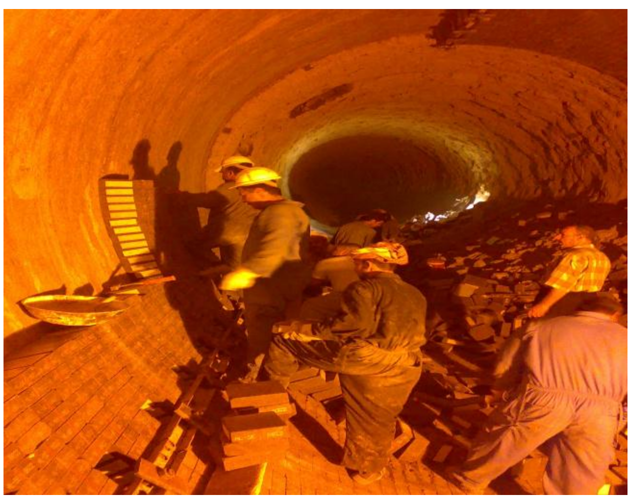


Fig 5 :Refractory Brick Re-building at Kufa Cement Factory (Kiln No.2).

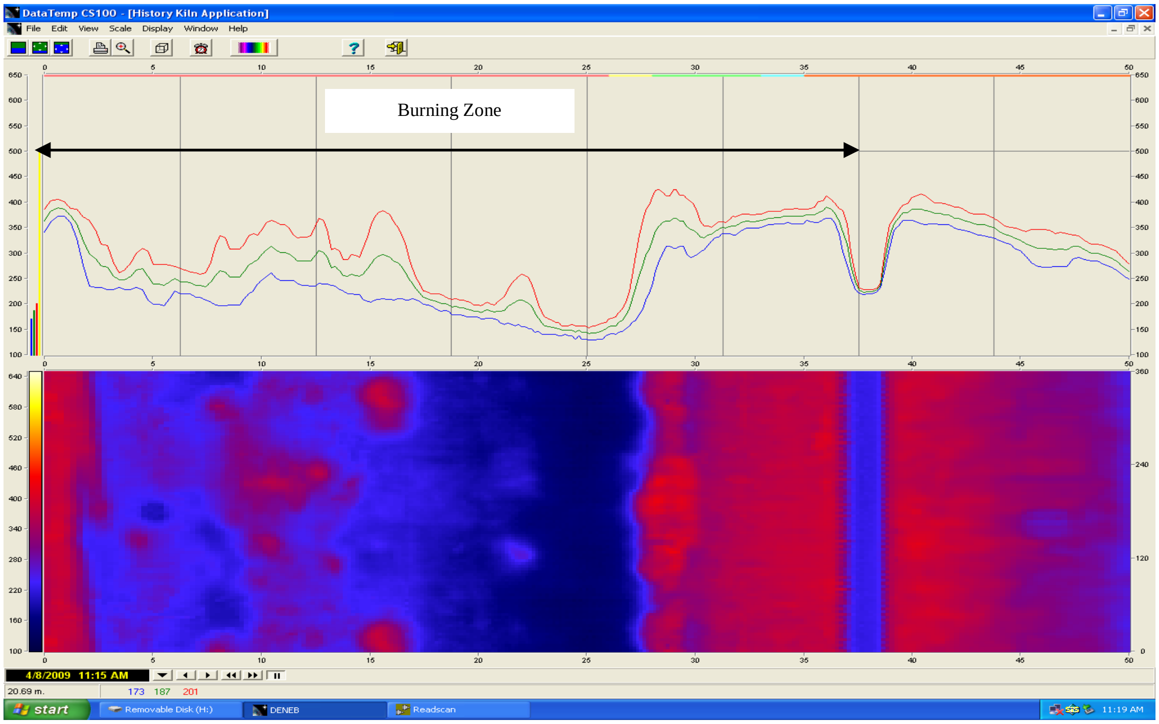


Fig 6 : The First Kiln Shell Temperature distribution.

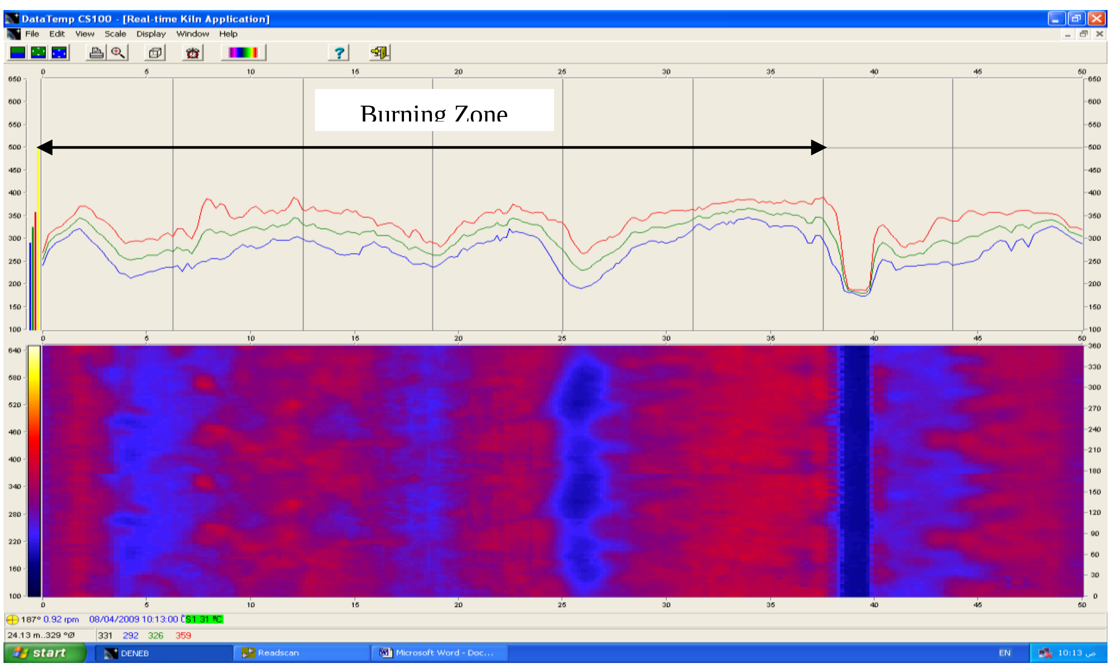


Fig 7 : The Second Kiln Shell Temperature distribution.

The temperatures profiles for gas ,solid and wall for kiln 2&3 are showed by Figures 8 and 9 .The shape of these curves was in agreement with Sadiqi Model. Besides, it could be seen that the temperature pick points of gas, solid and wall curves were at the end of the flame. This phenomenon was reported in the experimental data of some researchers (Witsel et al.,2000).

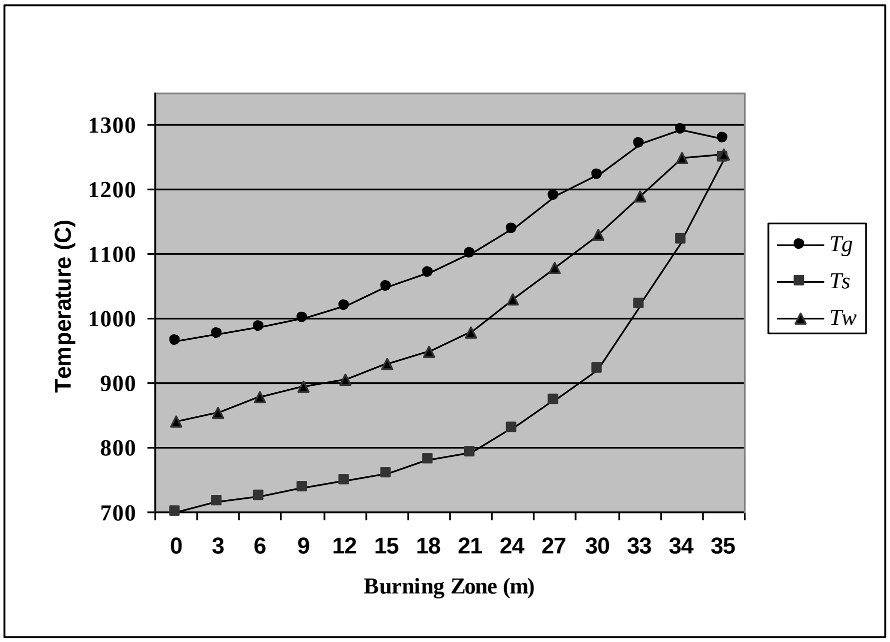


Fig. 8: The temperatures profile for kiln No.2

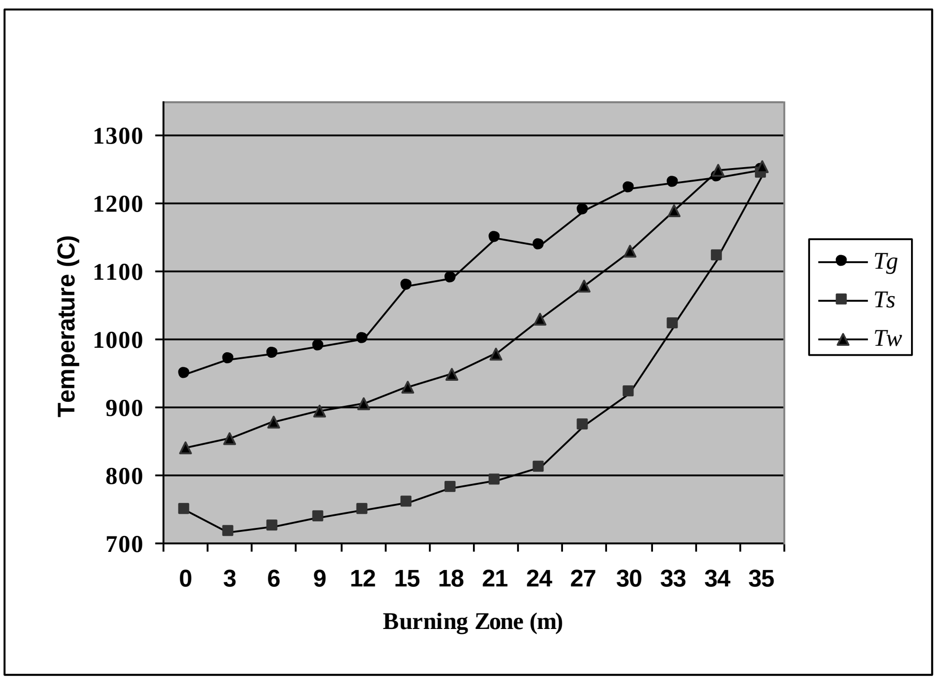
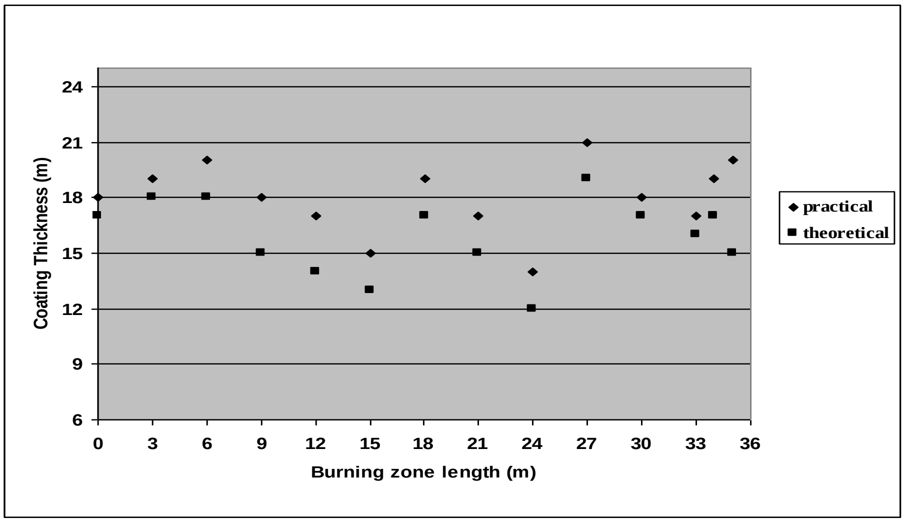
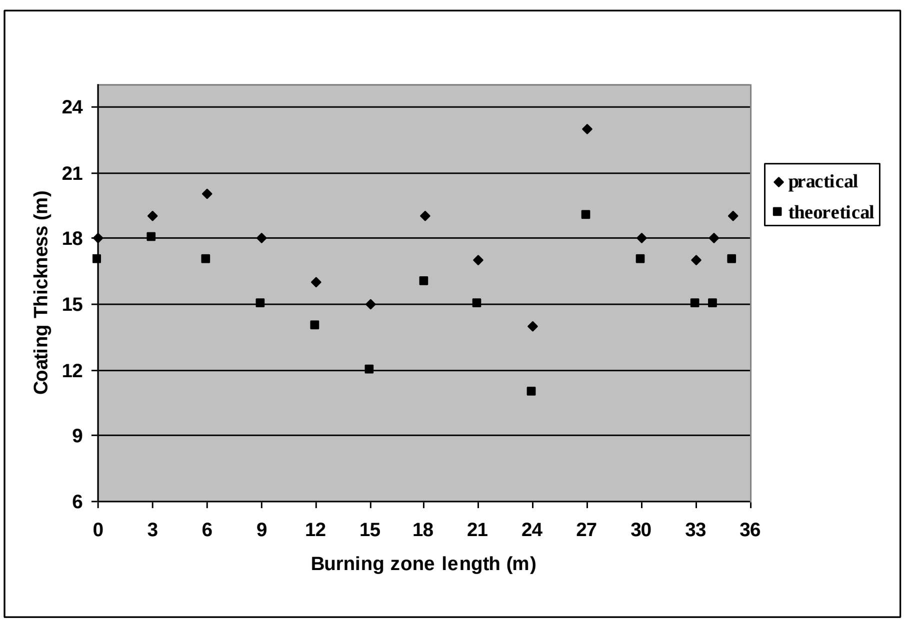


Fig. 9: The temperatures profile for kiln No.3.

The comparison of theoretical and practical data of coating thickness was showed in Figures 10,11 for kilns 1 & 2 respectively. The theoretical data showed an acceptable compatibility with the practical data especially in the region near the flame zone where the thickness of coating was more important than the other sections. The Absolute Average Errors (AAE) for the kilns 2 and 3 were 4.43 and 3.92cm, respectively. The main source of this error may be due to the instability of the created coating before the flame. The unstable coating layers in this region were prone to collapse during shutting down and cooling procedures. Another source of the error might be assuming constant coating conductivity at 0.73W/m.^{o}C for all sections which might be changed from 0.5 to 1W/m. ^{o}C.



Fig(10): Comparison of actual coating thickness with the theoretical data for kiln No.2.



Fig(11): Comparison of actual coating thickness with the theoretical data for kiln No.3.

The variations in shell temperature measured by kiln shell scanner showed in Figures 6 and 7 are of course the reason of the alteration of the coating thickness. Figures 10 and 11 illustrated when there was increasing in shell temperature, there was proportional decreasing in coating thickness and vice versa. the curves of Figures 10,11 proved that to maintain the coating thickness in ranges of 20-25 cm (which is ideal for the protection of refractory in all areas of the burning zone), the shell temperature should be held between 200-250 °C. According to equations 1-2 ,the theoretical value for time required to make a constant coating in the kiln No.2 is about 24 hr or 960 rpm.

The coating thickness can be correlated with time in each times that data taken from kiln shell scanner. In each times the wall temperature and coating thickness were calculated.

Figure12,13 showed the relation between time and coating thickness in kilns 2 and 3 respectively. It is shown that there are a rapid coating thickness progress in the period 3-16 weeks of coating life. It is recommended to make some researches to discuss this phenomena.

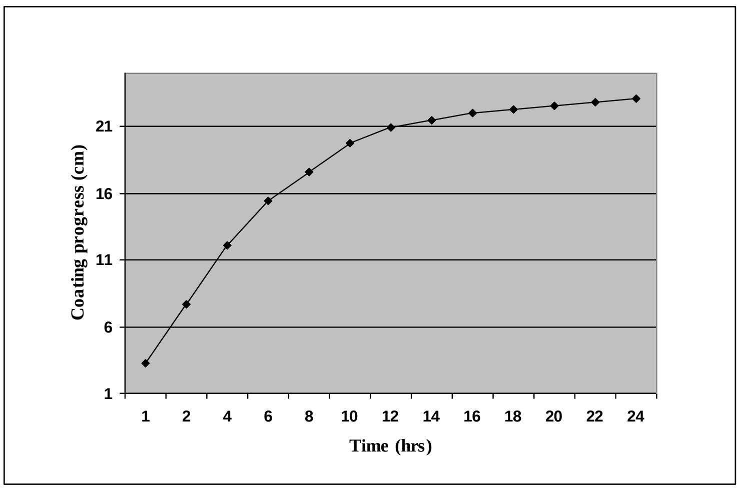


Fig. 12: The relation between time and coating thickness in kiln 2 .

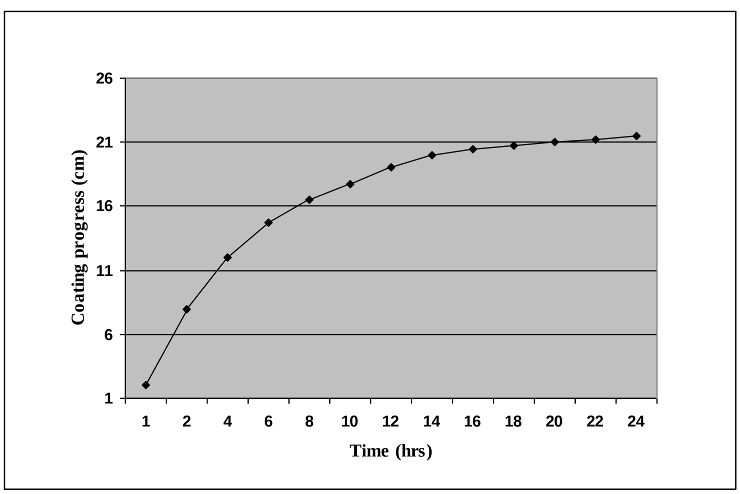


Fig 13:The relation between time and coating thickness in kiln 3 .

4-Conclusions and Recommendations:

- The coating thickness was estimated by using a heat transfer resistant model in adjacent to cylindrical layers. The mathematical steady-state model used previously by Sadighi et. al. 2011 was formulated to estimate the temperature profile of the inner surface of the wall of cement kiln .
- The first step for making the model was done by calculating the temperature profile along the kiln length and the measured temperature profile of the outer surface .
- It was concluded that the difference between the estimated values by model with practical data could be from the coating conductivity in the burning zone and the breaking down of unstable coating during shutting down and cooling process
- The comparison of model results and two sets of data which were gathered from Kufa industrial kilns, confirmed that the model had good capability to calculate the coating thickness.
- The results of curves demonstrated that to have an acceptable coating thickness from the viewpoint of solid flow along the kiln and refractory protection, the shell temperature between 200-250◦C was satisfactory.
- Lower temperature cause in hindering for movement of solids along the kiln and the upper value is harmful for the refractory layer.
- It is shown that there are a rapid coating thickness progress in the period 3-16 weeks of coating life and it is recommended to make some researches to discuss this phenomena.
- The theoretical value for time required to make a constant coating in the kiln No.2 is about 24 hr or 960 rpm.
- It is recommended to make researches about designing the flame of kiln shell to get the suitable temperatures profiles and in turn the ideal coating thickness.

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Appendix

A_g area of gas at given cross section (m^2)
A_s Area of solid at given cross section (m^2)
A_w area of wall at given cross-section (m^2)
C_{pg} specific heat of gas products 1173.82 (J/kg.^{o}C)
C_{ps} specific heat of solid 1089.97 (J/kg.^{o}C)
C_1,C_2-WLF Equation constants.
f_1 coefficient of conduction—gas to wall 22.71 (W/m.^{o}C)
f_2 coefficient of conduction—solid to gas 22.71 (W/m.^{o}C)
f_3 Coefficient of conduction-wall to solid 22.71 (W/m.^{o}C)
f_4 coefficient of conduction-wall to outside air 22.71 (W/m.^{o}C)
h_o fraction of radiation 0.0757
$h_{sh\rightarrow a}$ heat transfer coefficient of shell surface to air (W/m^2.^{o}C)

k_b conductivity of the lining break or refractory (W/m.°C)
k_c conductivity of coating (W/m.°C)
k_{sh} conductivity of shell body (W/m.°C)
N_t number of measured points in each case.
p angle subtended by surface of solid (3π/2)
Q_c heat generated by chemical reaction (W/m^3)
Q_{comb} heat released by fuel combustion (J/s)
$r_{in,}$ inside radius of kiln 5.1 (m)
r_{out} ,r_{sh} outside radius of kiln 5.2 (m)
r_b radial distance from kiln center to shell surface (m)
r_c radial distance from kiln center to refractory surface (m)
r_w radial distance from kiln center to coating surface (m)
T_a air temperature (°C)
T_b temperature of lining brick (°C)
T_c temperature of coating (°C)
T_g gas temperature (°C)
T_s solid temperature (°C)
$T_{ref(c)}$ Coating reference temperature (°C)
T_{sh} temperature of shell surface (°C)
T_w inside wall temperature of the kiln (°C)
v_g velocity of gas (m/s)
v_s velocity of solid (m/s)
$\beta_1, \beta_2, \beta_3, \beta_4$ heat transfer coefficients (W/(°C))
ρ_g density of gas 0.24 (kg/m^3)
ρ_s density of solid 905 (kg/m^3)
ΔZ solver step-size (m)
ε -the emissivity of the system,0.5 for shell,0.8 for brick,0.9 for coating

σ the constant of Stephan-Boltzmann (5.6697 x 10^{-8} $W/m^2.°C^4$).

Gr- Grashof number = $(d^3 \rho^2 g\, \alpha\, \Delta T/\mu^2)$

Pr-Prandtl number (Pr) = $(c_p \mu/k)$

Re –Renold No. $Re= \rho\, u\, d / \mu$

μ viscosity Pa.s, α- coefficient of thermal expansion which for gases = l/T by Charles' Law., g- the gravitational acceleration =9.8 m/s^2.

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