Journal of Engineering and Development, *Vol. 10, No. 4, December (2006)* **ISSN 1813-7822**

Numerical Investigation of Heat and Mass Transfer through the Preheater System in Cement Manufacturing Plant

Asst. Prof. Dr. Fouad Alwan Saleh
Mechanical Engineering Dept., College of Eng.
Al-Mustansiriya University, Baghdad, Iraq

Asst. Lect. Ahmed Kadhim Hussein
Mechanical Engineering Dept., College of Eng.
Babylon University, Hilla, Iraq

Abstract

In this study, the last part of the preheater system in a cement manufacturing plant which is called pyroclon system is studied. The study covers the amount of tertiary air from cooler and its temperature effect on temperature of calcination also its effect on the amount of fuel that is supplied to pyroclon. Also, the study of the amount of hot gases from rotary kiln and its temperature effect on the temperature of calcination, and on the amount of supplied fuel. The results of the present work explained also the effect of quantity of the raw meal that enter the pyroclon and its temperature effect on the temperature of calcination and the amount of supplied fuel .Heat balance for pyroclon system and mass balance for all preheater systems and its chemical reactions are included. Then a computer program is constructed in order to calculate temperature distribution for gases and particles along pyroclon by considering the amount of the heat lost, which is transferred from the gas to particle and from the particle to the wall, also from the gas to the wall, depending on conduction, convection and radiation in order to find the exit temperatures of gas and particles from pyroclon and to find the range of the pyroclon working for different values of gas velocities and the amount of fuel supplied.

الخلاصـــــة

في هذا البحث تم دراسة عمل منظومة المكلسن **(Pyroclon system)** *وهو الجزء الأخير من أجزاء منظومة المسخن الأولي* **(Preheater system)** *في عمليات صناعة السمنت. حيث تم دراسة تأثير كل من كمية الهواء الثلاثي القادم من المبرد* **(Cooler)***وتأثير درجة حرارته على درجة حرارة الكلسنة* **Temperature of calcination** *وتأثيره أيضا على كمية الوقود المجهز. وكذلك أيجاد كمية الغازات الحارة الداخلة إلى المكلسن و القادمة من الفرن الدوار* **Rotary kiln** *و درجة حرارتها وتأثيرها على درجة حرارة الكلسنة وكمية الوقود المجهز. كذلك تم دراسة تأثير كمية المواد الأولية* **Raw meal** *القادمة من الدولاب الأسمنتي الحلزوني* **(Cyclones)** *ودرجة حرارتها على درجة حرارة الكلسنة وكمية الوقود المجهز. في الدراسة الحالية تم عمل موازنة للحرارة والكتلة عبر الخط الإنتاجي بالكامل اخذين بنظر الاعتبار جميع التفاعلات الكيمياوية التي تحدث ضمن منظومة المسخن الأولي. بعد ذلك تم عمل برنامج لحساب توزيع درجات حرارة كل من الغاز والمسحوق على طول المنظومة التي تمت دراستها اخذين بنظر الاعتبار كميات الحرارة المفقودة والمنتقلة من الغاز إلى المسحوق ومن المسحوق إلى الجدار وكذلك من الغاز إلى الجدار وذلك بالاعتماد على طرق انتقال الحرارة بواسطة التوصيل والحمل والإشعاع من اجل إيجاد درجة حرارة خروج الغاز والمسحوق من المكلسن وبيان المدى الذي يتم فيه عملية الكلسنة لقيم مختلفة من سرعة الغازات وكميات الوقود المجهز.*

1. Introduction

The heat and mass balance across the four stages preheater system play an important role to find the effect of amount of fuel on calcination process. In pyroclon system the amount of raw meal inlet does not equal to the amount of raw meal outlet and the difference between the two quantities depends on the amount of gases between two positions. There are many factors affecting heat balance in pyroclon, such as, by pass opening, the moisture content in raw meal, amount of excess air which limits the amount of gases production in this system, also the amount of fuel, temperature of fuel and amount of temperature of raw meal [1].

The cement preheater system is considered as an important and a necessary part in the cement production process. The four-stage preheater which is studied in the present work consists of three cyclones of 5.4 m diameter, and two of 3.175 m. Typical temperatures and pressures of gas passing through the preheater system are as follows:

Table (1) Typical temperatures and pressures of gas passing through the preheater system [2]

	Pressure mm WG	Temperature °C
Gas leaving kiln	-30	1050
Gas leaving bottom cyclone	-140	822
Gas leaving lower middle cyclone	-195	667
Gas leaving upper middle cyclone	-270	575
Gas entering I.D. fan	-490	316
Meal to kiln		783

2. Fuel in the Cement Industry

Fuels may be classified as solid, liquid, and gaseous. All three states may be employed in the cement industry. The solid fuels are coal (anthracite), lignite, peat, wood, and coke. Coal and lignite are used in cement rotary kilns and in dryers. Coke is used in cement shaft kiln. Among liquid fuels there is a heavy fuel oil which is predominantly used in cement manufacturing. Natural gas is the most common gaseous fuel in use of other gases of minor importance [2]. The most important property of fuel oil is its ability to burn in the liquid state. Paraffins, olefins, napthenes and aromatic compounds are the four main groups of hydrocarbons forming fuel oils. The most significant fuel oils are:

a. Mineral fuel oil (from crude oil).

b. Caol-tar oil (from low-temperature carbonization of coal).

c. Bituminous coal-tar oil (from low-temperature carbonization of bituminous coal).

Fuel oils consist of several hundred compounds of hydrocarbons. Generally, fuel oils consist of 85-90% carbon, 5-10% hydrogen, oxygen, nitrogen, and sulfur amount of about (3-4%). In some kinds of fuel oil, the sulfur content amounts up to 3%. The heating values are within the limits of LHV = (8500-10000) kCal/kg [3]. In the present work 246000 m^3/h of exhaust gas is drawn from the preheater by a variable speed induced draught fan of (370-970) rpm driven by 1000 hp motor. The 4.2 m diameter kiln is used and its length from the cooler inlets to the feed inlets is 60m. The slope of the klin is 3.4% and the maximum speed is 3.0 rpm [1]. In **Fig.(1)** the different parts of the studied system are explained.

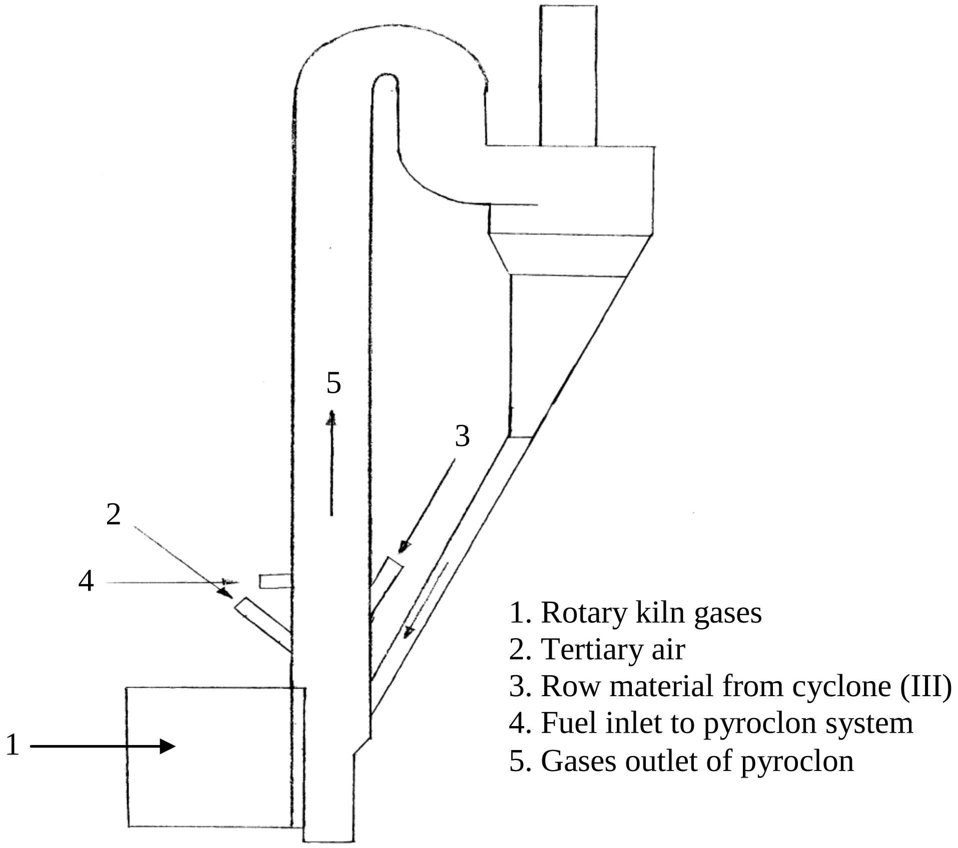

Figure (1) Different parts of pyroclon system which is studied in the current work

3. Combustion of Fuel Oil

The following fuel oil composition may be assumed, to calculate the combustion gases:

C:	85%	850 g
H_2:	12%	120 g
S:	2.4%	24 g
H_2O:	0.6%	6 g
Total	100%	1000 g = 1 kg

$C = 0.85\ kg * 1/12\ kgmol / kg = 708*10^{-4}\ kgmol$

$H_2 = 0.12\ kg * 1/2\ kgmol / kg = 0.06\ kgmol$

$S = 0.024\ kg * 1/32\ kgmol / kg = 7.5*10^{-4}\ kgmol$

$H_2O = 0.006$ kg * 1/18 kgmol / kg = $3.3*10^{-4}$ kgmol

$0.07083333\ C + 0.06\ H_2 + 0.00075\ S + 0.00033334\ H_2O + a\ O_2 + 3.76\ a\ N_2 \rightarrow X\ CO_2 + Y\ H_2O + Z\ SO_4 + 3.76\ a\ N_2$

After balancing the component of the equation then:

C: balance $X = 708*10^{-4}$ kgmol
H_2: balance $Z = 7.5*10^{-4}$ kgmol
S: balance $Y = 603.333*10^{-4}$ kgmol
O_2: balance $a = 1015.83133*10^{-4}$ kgmol
$N_2 = 3.76 * a$ = 0.381952582 kgmol

Therefore, for 1 kg fuel oil produce:

CO_2 = 3.1166 kg / kg fuel	=1.576 Nm^3
SO_4 = 0.048 kg / kg fuel	= 1.351 Nm^3
H_2O = 1.086 kg / kg fuel	= 0.016 Nm^3
N_2 = 10.8946 kg / kg fuel	= 8.698 Nm^3
Total = 15.130 kg / kg fuel	= 11.641 Nm^3

4. The Mathematical Analysis

4-1 Mass Balance

The analysis of mass balance through the four stage pyroclon system can be represented by the following equations [4]:

$$\mathbf{IR\ (1) = MK\ .\ RC_1 + S\ (2)} \quad \text{.......... (1)}$$

$$\mathbf{IR\ (2) = M\ (1)\ .\ RC_2 + S\ (3)} \quad \text{.......... (2)}$$

$$\mathbf{IR\ (3) = M\ (2) + RC_3\ .\ S\ (4)} \quad \text{.......... (3)}$$

$$\mathbf{IR\ (4) = M(3)\ .\ RC_4 + KD} \quad \text{.......... (4)}$$

where:

IR(i): represents total material inlet to cyclone (I) in kg/kg clinker

S(i): represents dust quantity from cyclone (i); kg/kg clinker and RC_1, RC_2, RC_3 and RC_4 are the reaction factors of free moisture evaporation.

Chemically bound moisture evaporation, recombination reaction and calcination reaction respectively, which is given by [5]:

$$\mathbf{RC_1 = [1 - (H_2O\ _{free\ from\ feed}) / MK]} \quad \text{.......... (5)}$$

$$RC_2 = [1 - (H_2O_{\text{chem. from feed}}) / MK] \quad \text{.......... (6)}$$

$$RC_3 = [1 + (0.44 \,.\, Cb)] \quad \text{.......... (7)}$$

$$RC_4 = [1 - (0.44 \,.\, RR \,.\, Cb)] \quad \text{.......... (8)}$$

where:

Cb: is Kiln feed calcination degree and RR is quantity of $CaCO_3$ in 1 kg of raw meal.

and,

$$M(i) = Ec(i) \,.\, IR\,(i) \quad \text{.......... (9)}$$

$$S(i) = [1 - Ec(i)\,] \,.\, IR(i) \quad \text{.......... (10)}$$

where:

Ec(i): is separation efficiency of cyclon (i).

The overall mass balance for pyroclon system is given by:

$$M_3 + S_3 + KD = IR(4) \quad \text{.......... (11)}$$

$$m_{ioses} = M_3 + S_3 + KD - IR(4) \quad \text{.......... (12)}$$

where:

$$KD = (1 - B_y)\,.SK\,(1 - GK) \quad \text{.......... (13)}$$

in this equation KD means the quantity of kiln dust reaching to preheater system in kg/kg clinker, B_y is By pass opening and GK is ignition loss of kiln dust.

4-2 Heat Balance

The balance of the pyroclon system is considered as follows, see **Fig.(1)**

The heat input to pyroclon by fuel is calculated by:

$$Q_1 = m_f \,.\, Cp_f \,.\, (T_f - T_{ref}) + m_f \,.\, \Delta H_c \quad \text{.......... (14)}$$

The heat input to pyroclon by hot goses kiln is given by:

$$Q_2 = m_g \,.\, Cp_{hg} \,.\, (T_{hg} - T_{ref}) \quad \text{.......... (15)}$$

The heat input to the pyroclon by raw meal from cyclone (III) is calculated according to the following equation:

$$\mathbf{Q_3 = m_s \cdot Cp_s \cdot (T_s - T_{ref}) \quad \ldots\ldots (16)}$$

The heat input to pyroclon by tertiary air that comes from clinker cooler is calculated as follows:

$$\mathbf{Q_4 = m_a \cdot Cp_a \cdot (T_a - T_{ref}) \quad \ldots\ldots (17)}$$

The heat exit of pyroclon to cyclone is calculated by heat balance according to the following equation:

$$\mathbf{Q + Q_2 + Q_3 + Q_4 - Q_{losses} = Q_5 \quad \ldots\ldots (18)}$$

To find temperature of pyroclon at bottom (temperature of calcination) the following equation will be used:

$$\mathbf{Q_1 + Q_2 + Q_3 + Q_4 = Q_5 \quad \ldots\ldots (19)}$$

where:

Q_{losses}: are neglected, and
Q_1: Heat input to pyroclon from fuel.
Q_2: Heat input to pyroclon from hot gases.
Q_3: Heat input to pyroclon from raw meal.
Q_4: Heat input to pyroclon from tertiary air.
Q_5: Heat inside of the pyroclon.

4-3 The Heat Input to Pyroclon by Fuel

To calculate heat input to pyroclon by fuel the following equation is used [6]:

$$\mathbf{Cp_f = 0.40241 + 8.0918 {*} 10^{-5}\, T_f + 5 {*} 10^{-8} {*} T_f^{2}\ [kcal/kg.C°] \quad \ldots\ldots (20)}$$

where:

Cp_f: is a specific heat of the fuel oil which have specific weight of [0.75-1] at temperature 15C° and
T_f: is the temperature of fuel at [0-120] C°.

The heating value of the fuel (HV) is given by [7]:

$$HV = 12957 - 3228\ \gamma_{fuel\ at\ 15C°} - 70\ S$$

where:

S: is specific fuel consumption in Kcal /kg.

4-4 The Heat Input to Pyroclon by Hot Gases from Kiln

To calculate the heat input to pyroclon by hot gases from kiln, the following equation is used.

$$\overline{C}p = a + bT_g + CT_g^{-2} \quad \ldots\ldots (21)$$

where:

T_g: temperaturace of gas in (k), and,

$(\overline{C}p)$: Specific heat for any gas in (cal/gmol.C°) and,

(a, b, c): are constants found from **Table (2)**.

$$Cp_g = \frac{M_{CO_2} * Cp_{CO_2} + M_{H_2O} * Cp_{H_2O} + M_{N_2} * Cp_{N_2} + M_{O_2} * Cp_{O_2}}{M_{hg\,Total}} \quad \ldots\ldots (22)$$

where:

Cp_g: specific heat of hot gases.

$M_{hg\ Total}$: Mass flow rate of hot gases from kiln in kg/s.

Table (2) Values of constants (a, b and c) for hot gases from kiln [6]

Gas	a	$b*10^{-3}$	$c*10^{-5}$
CO_2	10.57	2.1	-2.06
N_2	6.83	0.9	-0.12
O_2	7.16	1	-0.40
H_2O	7.3	2.46	0.0
SO_2	11.04	1.88	-1.84

4-5 The Heat Input to Pyroclon from Raw Meal

To calculate the heat input to pyroclon from raw meal, the following equation is used [8]:

$$\overline{C}p = d + eT_p + fT_p^{-2} \quad \ldots\ldots (23)$$

where:

T_p: is temperature of particle (k) and (d, e, f) are constants given at **Table (3)**.

Table (3) Values of constants (d, e and f) for hot gases from kiln [7]

Solid	d	$e*10^{-3}$	$f*10^{-5}$
$CaCO_3$	24.98	5.24	-6.2
Fe_2O_3	23.49	18.6	-3.55
SiO_2	11.22	8.2	-2.70
MgO	1.018017	0.977	-0.0225
Al_2O_3	3.748708	15.526	-2

and,

$$\mathbf{Cp_s} = \frac{\begin{pmatrix} M_{Al_2O_3} * Cp_{Al_2O_3} + M_{MgO} * Cp_{MgO} + M_{SiO_2} * Cp_{SiO_2} + \\ M_{Fe_2O_3} * Cp_{Fe_2O_3} + M_{CaCO_3} * Cp_{CaCO_3} \end{pmatrix}}{M_{sTotal}} \quad \text{..........} \ (24)$$

where:

M_{sTotal}: quantity of raw meal and $(\overline{C}p_s)$ is specific heat for any powder in (cal/gmpl.C°).

4-6 The Heat Input to Pyroclon from Tertiary Air

To calculate the heat input to pyroclon from tertiary air, the following equation is used.

$$\overline{C}p_a = G + HT_a + IT_a^{-2} \quad \text{..} \ (25)$$

where:

T_a: is the temperature of tertiary air in (k)

$(\overline{C}p_a)$: Specific heat for any gas inside the air in (Cal/gmol.C°), while G, H and I are constants which is given in **Table (4)**.

Table (4) Values of constants (G, H and I) for a tertiary air from cooler [7]

Gas	G	$H*10^{-3}$	$I*10^{-5}$
O_2	7.16	1	-0.40
N_2	6.83	0.9	-0.12

where:

$$\overline{C}p_a = \frac{M_{O_2} * Cp_{O_2} + M_{N_2} * Cp_{N_2}}{M_{air}} \quad \text{...} \ (26)$$

The heat at the bottom of pyroclon (Q_5) may be found as follows:

$$\mathbf{Q_5 = M_5 * Cp_5 * (T_k - T_{ref})} \quad \ldots\ldots \text{(27)}$$

from which:

$$\mathbf{T_k = [Q_5 / (M_5 * Cp_5)] + T_{ref}} \quad \ldots\ldots \text{(28)}$$

where:

Cp_5: represents the specific heat at bottom of pyroclon and it is given by:

$$\mathbf{Cp_5 = \frac{M_s * Cp_s + M_g * Cp_g + M_a * Cp_a + M_f * Cp_f}{M_{Total}}} \quad \ldots\ldots \text{(29)}$$

where:

$$\mathbf{M_{total} = M_s + M_g + M_a + M_f} \quad \ldots\ldots \text{(30)}$$

4-7 Heat Transfer through the Pyroclon

Inside the pyroclon the heat may be transferred to several directions as follows:

1. to the walls from particle to particle.
2. from gas to particle.
3. from gas to wall.

The transfer of heat takes place by convection, conduction and radiation. From the energy equation for two phase (gas and particle) we found [9]:

For Gas Phase:

$$\varepsilon \rho_g C_g \left(u_{gz} \frac{\partial T_g}{\partial z} + v_{gr} \frac{\partial T_g}{\partial r} \right) + \frac{\partial Q_{cg}}{\partial r} + h_{gp} A_p \left(T_g - T_p \right) = Q_5 \quad \ldots\ldots \text{(31)}$$

For Particle Phase:

$$(1-\varepsilon) \rho_p C_p \left(u_{pz} \frac{\partial T_p}{\partial z} + v_{pr} \frac{\partial T_p}{\partial r} \right) + \frac{\partial}{\partial r} \left(Q_{cp} + Q_r \right) - h_{pg} A_p \left(T_g - T_p \right) = 0 \quad \cdots \text{(32)}$$

In the above two equations, the coordinates (x, y) may be replaced by (r, z) in the mathematical analysis. The temperature distribution at any point for gas and particle (T_g and T_p) of the pyroclon which can be computed numerically as follows:

The boundary condition of pyroclon is:

at z = 0

$$T_{g(i,j)} = 900 - J \quad \ldots\ldots (33)$$

$$T_{p(i,j)} = 915 - J \quad \ldots\ldots (34)$$

at $r = r_{py}$

$$h_g\left(T_g - T_w\right) = k_g \frac{\partial^2 T_g}{\partial x^2} \quad \ldots\ldots (35)$$

In this equation k_g is thermal conductivity of gas in W/m.k. Equations (31) and (32) are solved numerically by finite difference method as follows:

For Gas Phase:

$$T_{g(i+1,j)} = \frac{-2r_{py}h_g(1-f)}{(r_j^2 - r_{j-1}^2)\varepsilon\rho_g C_g}\left(T_w - T_{g(i,j)}\right)\frac{\Delta z}{u_{gz(i,j)}} - \frac{2h_{gp}\,\Delta z}{3d_p\,\varepsilon\rho_g\,C_g u_{gz(i,j)}}\left(T_{g(i,j)} - T_{p(i,j)}\right) + \frac{Q_5\,\Delta z}{\varepsilon\rho_g\,C_g u_{gz(i,j)}} + T_{g(i,j)} - \frac{\nu_{gr(i,j)}}{u_{gz(i,j)}}\frac{\Delta z}{\Delta r}\left(T_{g(i,j+1)} - T_{g(i,j)}\right) \quad \ldots\ldots (36)$$

For Particle Phase:

$$T_{p(i+1,j)} = \frac{3h_{gp}\,\Delta z}{2d_p\,(1-\varepsilon)\rho_p C_p u_{pz(i,j)}}\left(T_{g(i,j)} - T_{p(i,j)}\right) + \frac{-2r_{py}\,(fh_p + h_r)\Delta z}{(r_{(j)}^2 - r_{(j-1)}^2)(1-\varepsilon)\rho_p C_p u_{gz(i,j)}}\left(T_w - T_{p(i,j)}\right) + \frac{\nu_{pr(i,j)}}{u_{pz(i,j)}}\frac{\Delta z}{\Delta r}\left(T_{p(i,j+1)} - T_{p(i,j)}\right) + T_{p(i,j)} \quad \ldots\ldots (37)$$

The particle area A_p is computed from:

$$A_p = \frac{(\pi/4)d_p^2}{4/3\,(\pi/8)d_p^3} = \frac{3}{2d_p} \quad \ldots\ldots (38)$$

where:

dp: is diameter of particle.

Equations (31) and (32) may be solved for gas convection heat transfer with wall to give:

$$\frac{\partial Q_{cg}}{\partial r} = \frac{\pi d_p h_g (1-f) \Delta z (T_w - T_g)}{\pi (r_j^2 - r_{j-1}^2) \Delta z} \quad \dots\dots (39)$$

for simplification this equation becomes:

$$\frac{\partial C_g}{\partial r} = \frac{2 r_p h_g (1-f)}{(r_j^2 - r_{j-1}^2)} \left(T_w - T_g\right) \quad \dots\dots (40)$$

where the coefficient (f) is usually given as a function of average volumetric solid concentration (C) [10] as follows:

$$f = 3.5\, C^{0.37} \quad \dots\dots (41)$$

where:

f : is average time of volumetric solid concentration in sec.

Equation (35) can be solved for the gas connective heat transfer coefficient h $_g$ to give:

$$h_g = \frac{k_g}{d_p} (0.009 P_r^{1/3} A_r^{1/2}) \quad \dots\dots (42)$$

where:

$$P_r = \frac{C_g \mu_g}{k_g} \qquad \textbf{(Prandtle number)} \dots\dots (43)$$

$$A_r = \frac{g d_p^3 (\rho_p - \rho_g) \rho_g}{(\mu_g)^2} \qquad \textbf{(Archimedes number)} \dots\dots (44)$$

Equations (31), (32) can be solved for the gas particle heat transfer coefficient h_{gp}:

$$h_{gp} = \frac{k_g}{d_p} (2 + 0.4 Rep^{0.5}) \quad \dots\dots (45)$$

where:

$$Rep = d_p * w_s * \rho_g / \mu_g \qquad \textbf{(Reynolds number)} \dots\dots (46)$$

To find $\left[\frac{\partial}{\partial r}(Q_{cp}+Q_r)\right]$ which is given in Equation (32) the following formula may be used:

$$\frac{\partial}{\partial r}(Q_{cp}+Q_r)=\frac{\pi d_{py}\,\Delta z\,(fh_p+h_r)}{\pi(r_j^2-r_{j-1}^2)\Delta z}\left(T_w-T_p\right) \quad \text{.................................. (47)}$$

For simplification this equation can be simplified as:

$$\frac{\partial}{\partial r}(Q_{cp}+Q_r)=\frac{2r_{py}\,\Delta z\,(fh_p+h_r)}{(r_j^2-r_{j-1}^2)\Delta z}\left(T_w-T_p\right) \quad \text{...................................... (48)}$$

where the heat transfer coefficient of particle h_p can be written as:

$$h_p = 3\,\pi(1-\varepsilon) * k_g / d_p \quad \text{.. (49)}$$

where: the coefficient (ε) represents the porosity which has the value of (0.6-0.8) according to [11]. Also, the heat transfer coefficient of radiation h_r is given by:

$$h_r=\frac{\sigma(T_b^4-T_w^4)}{\left(\frac{1}{\zeta b}+\frac{1}{\zeta w}-1\right)(T_b-T_w)} \quad \text{... (50)}$$

where the value of (T_b) is calculated using the equation given in [12]:

$$T_b = \varepsilon\, T_g + (1-\varepsilon)\;T_p \quad \text{.. (51)}$$

and T_w is temperature of wall.

The value of (ζw) and (ζb) are taken from [9] as follows:

$\zeta w = 0.38$

$\zeta b = 0.0911$

and $\sigma = 5.67 * 10^{-8}$ $W/m^2.k^4$ (Stefan-Boltzman coefficient)

5. Results and Discussion

The discussion of the present results is divided into six sections and they are explained as follows:

5-1 The Effect of Amount of Tertiary Air

The results of calculations of the heat input to pyroclon from tertiary air are presented in **Figs.(1,2, and 3)**.

Figure (1) shows the overall fuel consumption of pyroclon as a function of temperature of calcination for the operation range of temperature of air. For amount of air equal to 1 kg/s, it is clear from this figure that when the temperature of calcination increases then amount of fuel is increased. The **Figs.(2 and 3)** are similar to **Fig.(1)** but each figure have amount of fuel different and these figures shows, when the amount of air increase the divergent between curves that represent the relation between (m_f) and (T_k) are increased.

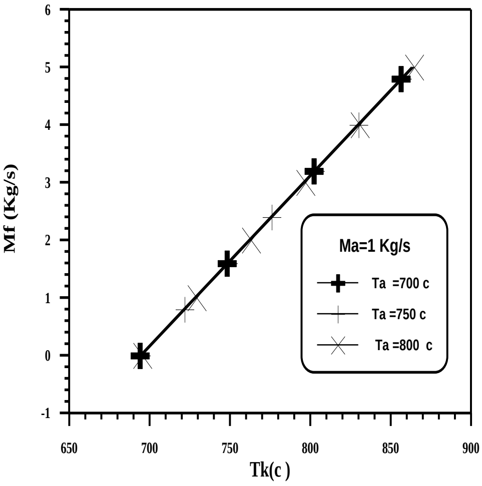

Figure (1) The effect of amount of fuel on temperature of calcination

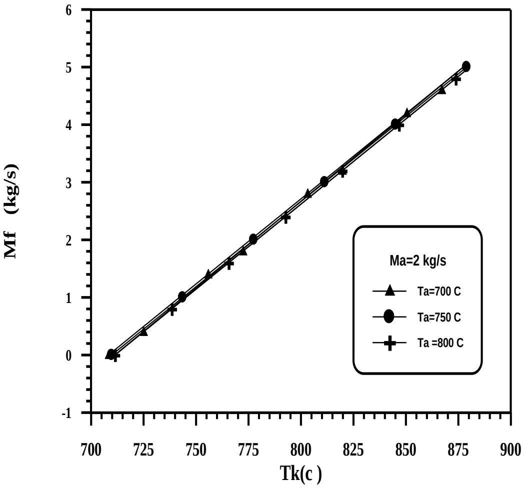

Figure (2) The effect of amount of fuel on temperature of calcination

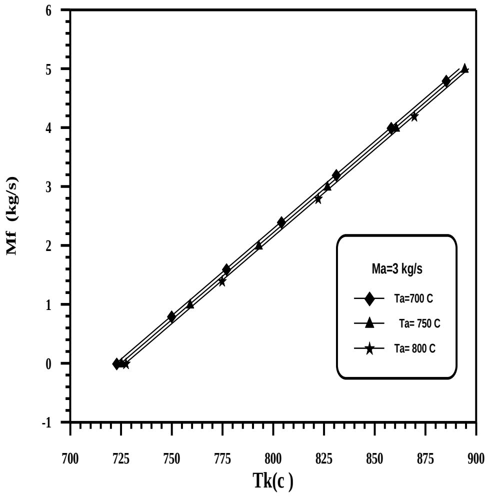

Figure (3) The effect of amount of fuel on temperature of calcination

5-2 The Effect of Amount of Hot Gases

Figures (4, 5 and 6) explain the influence of the amount of hot gases and its temperature on the overall fuel consumption of pyroclon. These figures represent the relation between (m_f) and (T_k), which state that when the amount of fuel increased the temperature of calcination increases also. **Figure (4)** explains if the amount of hot gases increases the amount of fuel decreases to reach the same temperature of calcination. This figure is drawn when temperature of hot gases equal (T_{hg}= 1000 °C). **Figures (5)** and **(6)** are similar to **Fig.(4)** and which shows that when temperature of hot gases increases, the amount of fuel decreases to reach the same temperature of calcination.

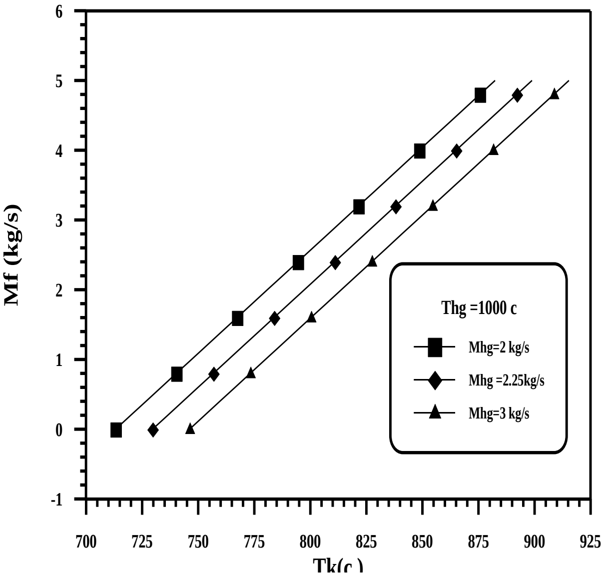

Figure (4) The effect of amount of fuel on temperature of calcination

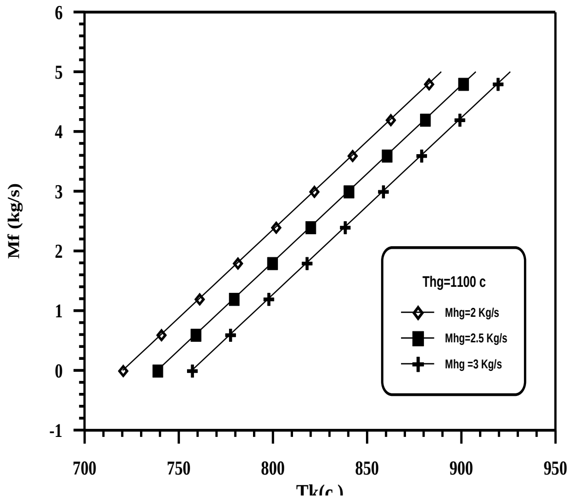

Figure (5) The effect of amount of fuel on temperature of calcination

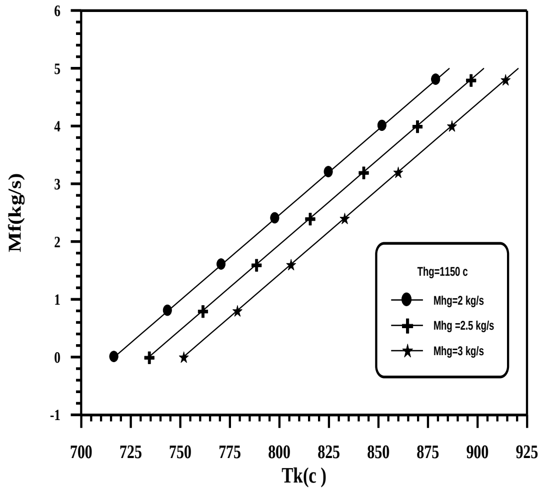

Figure (6) The effect of amount of fuel on temperature of calcination

5-3 The Effect of Amount of Raw Meal

The results of calculations of the heat input to pyroclon system from the raw meal that input to the pyroclon system from cyclone (III) after removed ($H_2O_{chem.}$ and H_2O_{free}) during preheater system present in **Figs.(7,8 and 9)**.

Figures (7), **(8)** and **(9)** show the effect of raw meal and amount of it on temperature of calcination to reduce amount of fuel consumption of pyroclon. These figures represent the relation between (m_f) and (T_k), and that when amount of fuel is increased the temperature of calcination increases too. **Figure (7)** explain if the amount of raw meal increases the amount of fuel consumption decreases to reach the same temperature of calcination. In this figure when the temperature of raw meals equal (T_{rm}= 700°C). **Figures (8)** and **(9)** are similar to **Fig.(7)** and from it we show also that when temperature of hot gases increases the amount of fuel decreases to reach the same temperature of calcination

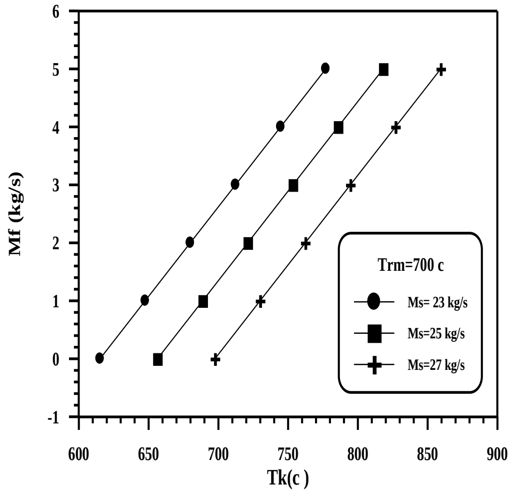

Figure (7) The effect of amount of fuel on temperature of calcination

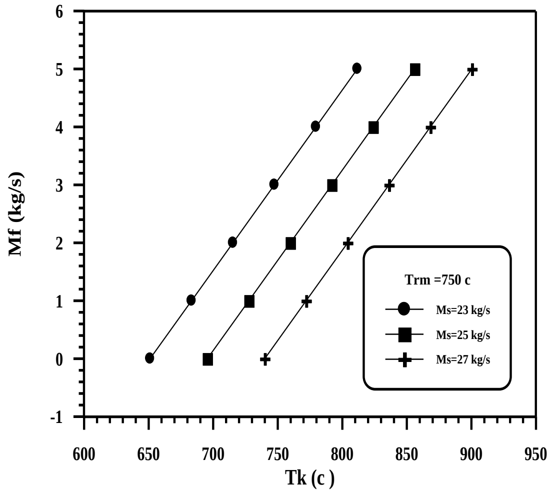

Figure (8) The effect of amount of fuel on temperature of calcination

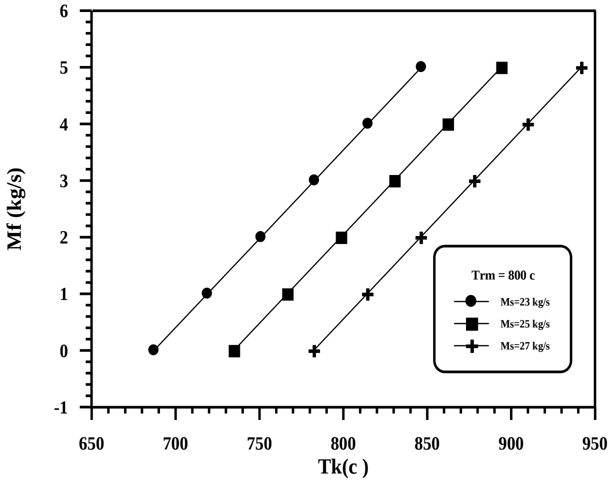

Figure (9) The effect of amount of fuel on temperature of calcination

5-4 The Distribution of Temperature of Gases and Particle along Pyroclon

The results of calculation of temperature distribution of gases and particles are presented in **Figs.(10 to 19)**.

5-5 The Distribution of Temperature of Gases along Pyroclon

Figures (10) to **(14)** shows the temperature distribution of gases along pyroclon and the effect of velocity of gases towards height of pyroclon (VGZ) and amount of fuels on temperature distribution along pyroclon. **Figure** (**10**) shows the temperature distribution of gases along pyroclon when (VGZ= 1 m/s) and (m_f = 5kg/s). where y-axis represents the height of pyroclon in (cm) and x-axis represents radius of pyroclon in (cm) and curves inside the figure represents temperature distribution along pyroclon where all curves represents isothermal line. This figure shows that temperature decreases towards height of pyroclon and also decreases towards radius of pyroclon. **Figure (11)** and **(12)** are similar to **Fig.(10)**, but it is show temperature distribution of gases along pyroclon when (VGS = 1 m/s) and m_f = 4 kg/s for **Fig.(11)** and m_f = 3 kg/s for **Fig.(12)**. From these figures we find that when amount of fuel increase the temperature at top of pyroclon increase, this lead to improve pyroclon performance. **Figures (13)** and **(14)** are similar to **Fig.(10)**, but it is show temperature distribution of gases along pyroclon when (m_f = 5 kg/s) and (VGZ = 1.2 m/s) for **Fig.(14)** and (VGZ = 1.5 m/s) for **Fig.(14)**. This figure show when (VGZ) increase the temperature at top of pyroclon decrease.

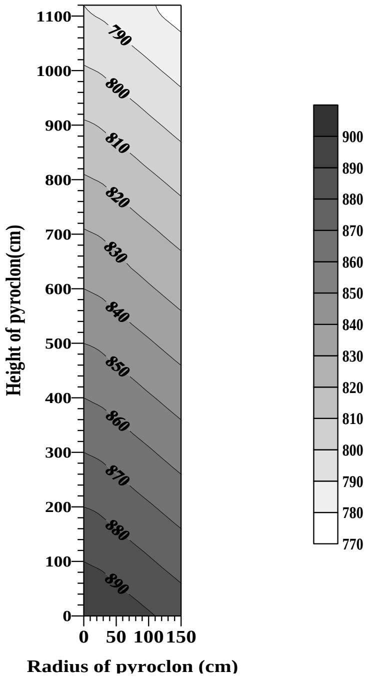

Figure (10) Temperature distribution of gases along pyroclon VGZ=1 m/s, Mf=5 Kg/s

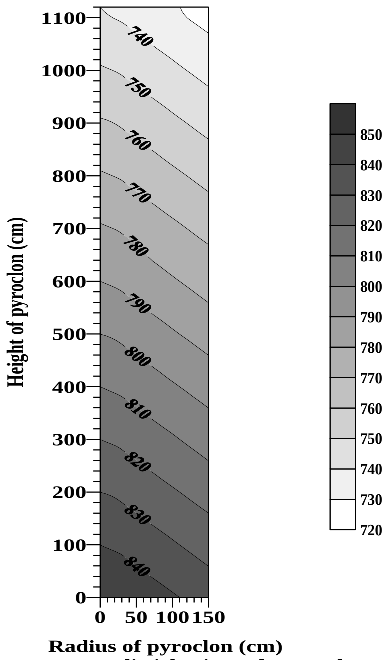

Figure (11) Temperature distribution of gases along pyroclon VGZ=1 m/s, Mf=4 Kg/s

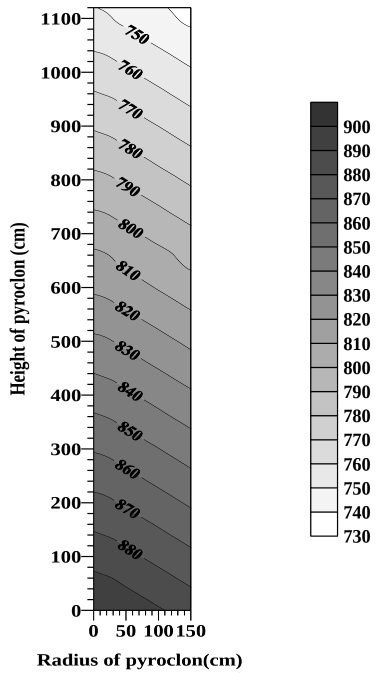

Figure (12) Temperature distribution of gases along pyroclon VGZ=1.3 m/s, Mf=5 Kg/s

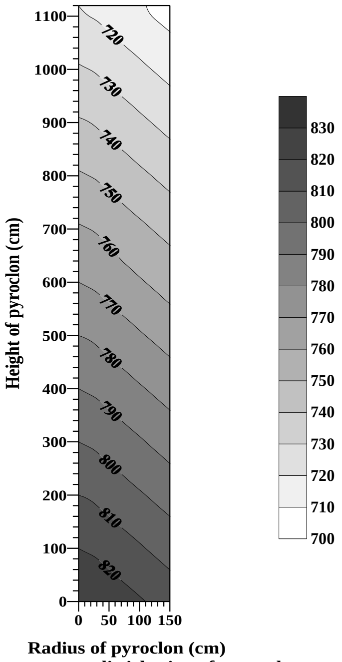

Figure (13) Temperature distribution of gases along pyroclon VGZ=1 m/s, Mf=3 Kg/s

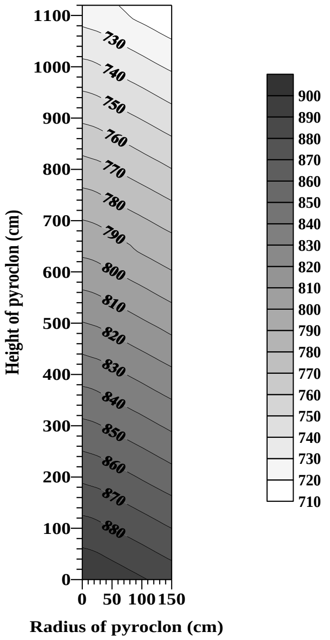

Figure (14) Temperature distribution of gases along pyroclon VGZ=1.5 m/s, Mf=5 Kg/s

5-6 Distribution of Temperature of Particles along Pyroclon

The results of the calculation of temperature distribution of particle along pyroclon are presented in **Figs.(15)** to **(19).**Figure (**15**) shows temperature distribution of particle along pyroclon when (VGZ = 1 m/s) and (m_f = 5 kg/s). From this figure we show that temperature decreases towards height of pyroclon and also decrease towards radius of pyroclon. **Figure**

(16) and **(17)** are similar to **Fig.(15)**, but it is show temperature distribution of particle along pyroclon when (VGZ = 1 m/s) and (m_f = 4 kg/s) for **Fig.(16)** and (m_f = 3 kg/s) for **Fig.(17)**. This lead to improve pyroclon performance. **Figure** (**18**) and (**19**) are similar to **Fig.(16)**, but it is show temperature distribution of particles along pyroclon when (m_f = 5 kg/s) and (VGZ=1.2 m/s) for **Fig.(18)** and (VGZ=1.4 m/s) for **Fig.(16)**.This figure show that when (VGZ) increases the temperate at top of pyroclon decrease.

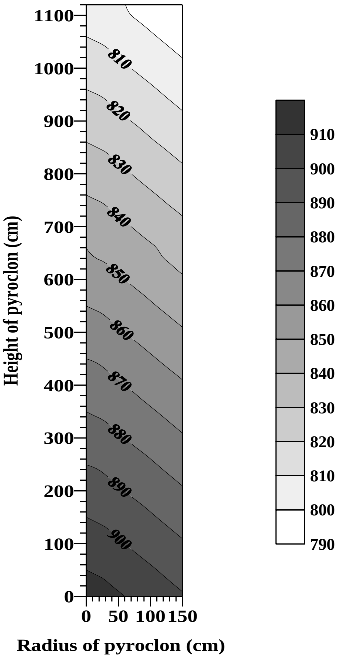

Figure (15) Temperature distribution of gases along pyroclon VGZ=1 m/s, Mf=5 Kg/s

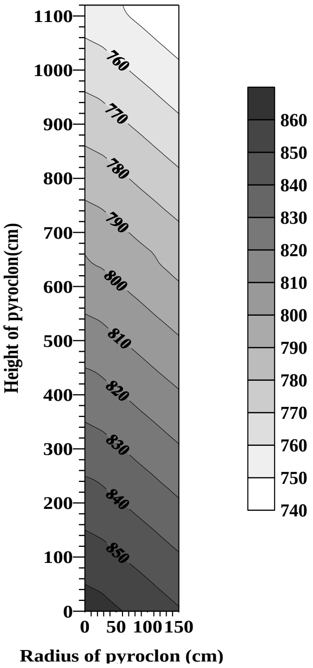

Figure (16) Temperature distribution of gases along pyroclon VGZ=1 m/s, Mf=4 Kg/s

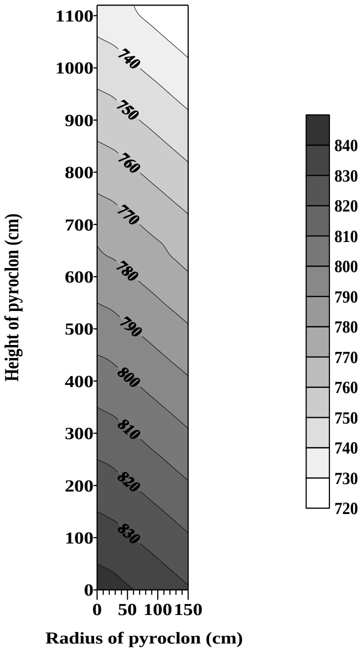

Figure (17) Temperature distribution of gases along pyroclon
VGZ=1 m/s, Mf=3 Kg/s

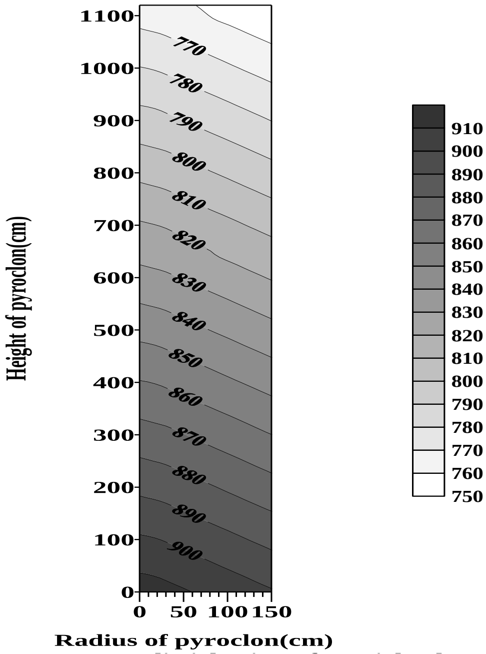

Figure (18) Temperature distribution of gases along pyroclon
VGZ=1.3 m/s, Mf=5 Kg/s

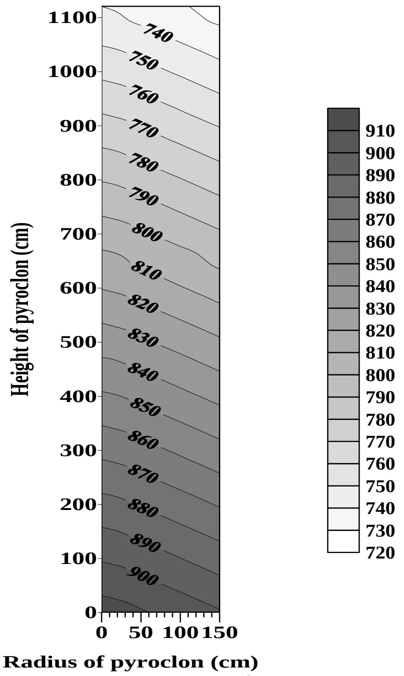

Figure (18) Temperature distribution of gases along pyroclon VGZ=1.5 m/s, Mf=5 Kg/s

6. Conclusions

1. The amount of tertiary air and its temperature has a large effect on the pyroclon efficiency since it has an important effect on the temperature calcinations.
2. The amount of hot gases and its temperature has an effect on the pyroclon efficiency more than the amount of tertiary air and its temperature, because the temperature of hot gases is higher than the temperature of tertiary air.
3. The amount of raw meal and its temperature has an important effect on the pyroclon efficiency more than the amount of hot gases and the tertiary air. But the increase of the amount of raw meal without the increase in its temperature will cause a reduction in the value of the temperature of calcination.
4. The amount of fuel has a large effect on temperature distribution along the pyroclon, due to the effect of the temperature at the bottom of the pyroclon.
5. When the amount of fuel increase, the temperature of gases and particles increases also.
6. The velocity of gases toward the height of pyroclon has a large effect on the temperature distribution along the pyroclon. The reason due to its effect on the temperature at the top of pyroclon. Also, the increase of the velocity causes a reduction in gas residual time inside pyroclon.

7. References

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