International Journal of Latest Trends in Engineering and Technology
Vol.(10)Issue(3), pp.119-127
DOI: http://dx.doi.org/10.21172/1.103.21
e-ISSN:2278-621X

INVESTIGATION THE EFFECT OF CALCINATIONS DEGREE AND ROTARY KILN GASES BYPASS OPINING IN THE PREHEATING SYSTEM FOR DRY CEMENT INDUSTRIES

Hassanain Gh. Hameed[1], Zaid M. Al-Dulaimi[2], Ahmed H. Ali[3], Mohammed A. Alfahham[4]

Abstract- The preheater system is an imperative part of the dry cement production line. Besides its significant it represents the transition step from the wet to dry process for cement production. This paper studies the effect of calcinations degree occur in the preheater system and bypass of kiln gases on the heat content of the gases in the preheating system. It is found the heat content of gases is (542.035, 801.86, 1034.27 and 1192.7) kJ at 90% calcinations degree and 40% bypass of kiln gases, whereas it is(541.41, 801, 1033.2 and 1191.5) kJ at 50% calcinations degree and 40% bypass of kiln gases for Cyclones (I, II, III and IV) respectively. Also their effects on the heat content of bypass gases are presented and it is found that the calcinations degree has inversely effect with the heat content of bypass gases.
Keywords: Preheating system, Bypass of kiln gas, Calcinations degree, dry cement industry

Nomenclature

Symbols	Description	Unit
a1-4	Constants	-
By	Bypass opening	%
CPkd	Specific heat of kiln dust reaching to pre-heater	Kcal/kgclinker
CD	Kiln feed calcinations degree	%
Cm	Raw meal moisture content	%
Es	Cyclone separation efficiency	%
Gk	Ignition loss of kiln dust	%
In(i)	Total material inlet to cyclone	Kg/kgclinker
KD	Quantity of kiln dust reaching to pre-heater system.	Kg/kgclinker
M(i)	Material from cyclone (i)	Kg/kgclinker
Qby	Heat content of bypass gases	Kcal/kgclinker
Qg(i)	Heat content of gases from cyclone (i)	Kcal/kgclinker
Qs(i)	Heat content of dust from cyclone (i)	Kcal/kgclinker
Qtc	Total specific heat consumption	Kcal/kgclinker
RR	Quantity of CaCo3 in 1 kg of raw meal	%
S(i)	Dust from cyclone (i)	Kg/kgclinker
Sk	Kiln dust reaching to pre-heater	Kg/kgclinker
Tc	Cyclone temperature	K
Tk	Kiln exit gases temperature	K
Y(i)	Precipitated dust from cyclone (i)	% -

1. INTRODUCTION

Pyroprocessing section is considered the nucleus of the cement industry, because the actual formation of cement clinker occurs in the crucial part (kiln) of pyroprocessing section. It consists of the following operations: preheating the raw

[1] Power Mechanics Department, Engineering Technical Collage Najaf, Iraq
[2] Power Mechanics Department, Engineering Technical Collage Najaf, Iraq
[3] Power Mechanics Department, Engineering Technical Collage Najaf, Iraq
[4] Power Mechanics Department, Engineering Technical Collage Najaf, Iraq

materials; precalcination, burning inside the kiln; and clinker cooling [1].The cement plant and all other equipment sizes are determined based on pyroprocessing section. Typical of cement plants, pyroprocessing unit is thermal enegy intensive, accounts for about (90%) of the thermal energy used in cements production process [2]. Preheaters variety with diverse precalciners designs have come into reality and can be classified as shown in Figure (1).

With recent technology advances, the majority of the fuel is consumed in the calciner such that the raw material is fully calcined when it reaches the rotary kiln inlet. This has resulted in much lower energy consumption per ton of clinker produced [3]. In kilns, bypass systems of kiln dust may be required and its function removing alkalis, sulfates, and chlorides. As a result such systems produce additional losses of energy because of removing the dust sensible heat [4].The precalciner kiln system with bypasses; cement kiln dust (CKD) from the stream of main exhaust gas is come back to the raw meal. Considerable amounts of compounds of volatile inorganic can be turned away through the bypass system. In preheater system, precalciner kilns the bypass comprises of a duct which extracts a gas slip stream out of the kiln gases before the gases of kiln go into the preheater and after exit the kiln [5].

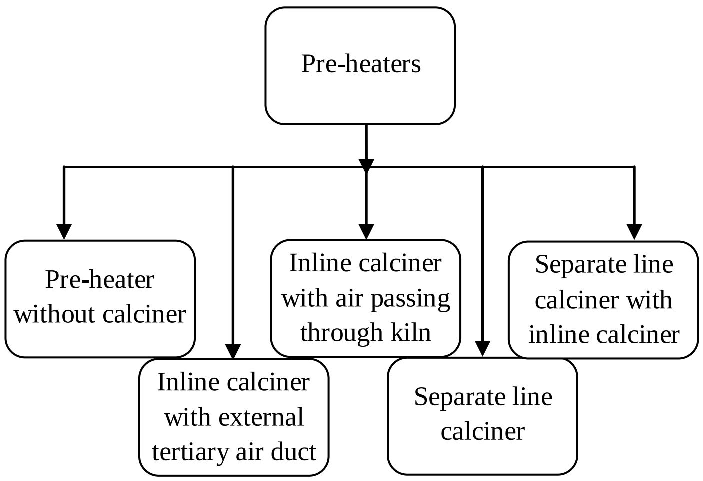

Figure 1. Pre-heaters classification with different precalciners designs.

Steinbiss [6] provided a new utilization method of waste gas heat which is provided by the systems of precalcining with bypass. It was found up to 100% of gases which exit kiln can be bypassed and utilized in a steam boiler, irrespective cooling. Also there are many researchers who have focused their studies on many subjects in the cement industry. Rotary kiln burner with pre-calcination, for serial flow, has four-stage cyclone precalciner [7].

In spite of these mentioned studies on many topics of the cement industry, it clearly needs to have more intensive studies on the waste heat of gases as well as cyclone thermal performance in the preheating system specifically. Knowledge of the heat content of gases, bypass opening and calcinations degree effects will lead to optimization in the energy saving process.

The major part of this assessment comes through investigating the effects of bypass opening, degree of calcinations and the temperature of four stage cyclones on the heat content of gases and dust from cyclones, in addition to the heat content of bypass gases.

1.1. Dry process kilns

In a recent works, the blended raw material passes the pre-heater tower to enter the kiln. At the raw meal becomes hot before it goes into the kiln because of using of hot gases from kiln and possibly the cooled clinker at the exit of cooler to heat the raw meal.

The raw meal is fed to the pre-heater at the top of tower and passes in it via the series of cyclones. Kiln hot gas and, frequently, the hot air from cooling system are blown via the series of cyclones efficiently, the raw meal gets the heat from the hot gases. The transferring heat process is efficient because of a very high surface area for the meal particles with respect to their size in addition to the large temperature difference between the high temperature gas and the low temperature cooler meal. Mujumdar et al. [8] developed initially separate models for the pyroprocessing units (preheater, calciner, rotary kiln and cooler) and then coupled these models together in order to build an integrated simulator in cement industry.

The modern clinker production systems comprise a rotary kiln, the suspension preheater and a calcinator. One of solution that improves thermal efficiency of the burning process is optimization of the cyclone heat exchanger (suspension preheater). Its efficiency of dust separation and utilization of heat substantially depends on the applied cyclones, number of their stages and it also affects thermal efficiency of the kiln. Refurbishment of existing heat exchangers entails huge financial lost due to the need to stop operation of the kiln for long downtime and high investment expenses. Therefore alternative and simpler solutions are sought to enable operation of the heat exchanger with the minimum downtimes of the kiln Kozołub et al. [9].

1.2. Pre-heater kilns system of four stage cyclone

Cyclone separators are applied to extraction of large particles for the purpose of control contamination of air as well as for smooth course of technological processes. Application to harsh conditions includes such processes as separation of coal dust downstream coal pulverizes at power plants or dehydration of materials at drying systems. They can be also used as gas reactors or heat exchangers. Operation principle of cyclone dust separators consists in employment of centrifugal force cause by vortex movement of fluids. The multiphase blend of fluid and solids is supplied to the upper part of a cyclone. Vortex low of the blend through the cyclone leads to concentration of the solid phase nearby walls of the outermost cylinder. Since the descending spiral shape of the low channel the deposited solids are transferred downwards to the discharge port. In turn, the fluid phase is reversed and then transferred upward where it is released outside the unit through outlet channel aligned with the central axis of the unit [10].

The cyclone stages number is selected to be suitable for the individual application. Dependent on moisture content of materials and fuels which have to be dried via the remaining heat of exhaust gas, cyclone stages are decided whether 2, 3, 4, 5 or 6 can be used. Pre-heater kiln system of four stage cyclone was the standard technology in the 1970s. Pressure drop of pre-heater system is approximately the same of a modern pre-heater system of 5-stage with precalciner as a result of the older design of cyclone used in earlier years. Already the calcination is about 30% completed when the meal goes into the rotary kiln [11] observed that the pressure drop in the cyclone is more influenced by increase in the concentration of dust. However it was observed a slight dependence between dust collection efficiency and concentration of dust.

1.3. Gas bypass system uses

Besides raw materials, the fuels containing sulphur, chlorine and alkalis are being provided for the kiln system, the internal circulation which takes place between the kiln and the pre-heater acts as a cycle of enrichment. Deposit formation in the kiln inlet area, the calciner and the bottoms of two stages are caused in a cycle at higher concentrations. As a uniform operation of kiln with minimization of disturbances is the basis for the clinker production of efficient energy, because of coating formation, shut downs should be avoided. Hence alkalis and chlorine high circulation and to sulphur of lower extent enforces the gas bypass use at the inlet of kiln. The hot raw material and hot gas removal leads as a result to a higher specific energy consumption of about (6-12 MJ/ tons) clinker per percent of removed gas at the inlet of kiln [12]. The waste gas amount which discharged to the pre-heater is reduced with bypass operations. As well as this gas temperature is lowered [6].

1.4. Calcinations degree effects

Already it has been indicated that the temperature influences the hydraulic lime or cement produced nature at which it effects on the calcination significantly. Generally at slight calcinations, the quickest-setting cements are produced and extended calcination those which have the greatest strength. Barr et al. [13] showed the relation of both, the observed temperature and patterns of calcination to the processes of heat transfer which control the kiln performance and to provide methods of realistic calculation for kiln design.

1.5. Theoretical Analysis

There are many factors affecting heat balance in pre-heater, such as, bypass opening, calcinations degree in pyroclon system, the moisture content in raw meal and amount of excess air which limits the amount of gases production in this system. The mass balance of each phase (raw meal and gases) is affected by the reactions taking place in each cyclone. In each cyclone the amount of raw meal does not equal the amount of raw meal outlet and the difference between two quantities results to be the difference in gases amount between two positions (inlet and outlet). The mass and heat balances are described mathematically by a system equations depending upon many factors. The Mathematical analysis of mass balance across the four stage cyclone as following [14, 15 and 16]:

$$In(1) = Mk \times Rc_1 + S(2) \tag{1}$$

$$In(2) = M(1) \times Rc_2 + S(3) \tag{2}$$

$$In(3) = M(2) \times Rc_3 + S(4) \tag{3}$$

$$In(4) = M(3) \times Rc_4 + KD \tag{3}$$

Where Rc1, Rc2, Rc3and Rc4 are the reaction factors of free moisture evaporation chemically bound moisture evaporation, recarbonation reaction and calcinations reaction respectively.

$$Rc_1 = [1 - (H_2O_{free}\, fromfeed) / Mk] \tag{5}$$

$$H_2O_{free}\, fromfeed = \frac{100 - Mk}{100 - C_m} - Mk \tag{6}$$

$$Rc_2 = [1-(H_2O_{chem.}\ fromfeed)/Mk] \tag{7}$$

$$H_2O_{chem.}\ fromfeed = [1+\frac{KD}{KD-Mk}]\times (0.00075\times SiO_2 + 0.0035\times Al_2O_3) \tag{8}$$

$$Rc_3 = [1+(0.44\times RR\times CD)] \tag{9}$$

$$Rc_4 = [1-(0.44\times RR\times CD)] \tag{10}$$

To balance the materials with dust across each cyclone-

$$M(i) = E_s(i)\times In(i) \tag{11}$$

$$S(i) = In(i) - M(i) \tag{12}$$

The raw mail inlet to rotary kiln after separation in cyclone (IV), by using the material balance around the preheater system as follow:
Mass inlet to preheater = mass outlet from preheater to (rotary kiln + lost to atmosphere)-

$$MK + KD = [M(4)/(RC_1\times RC_2\times RC_3)] + Sl \quad (13) \tag{13}$$

$$M(IV) = (Rc_1\times Rc_2\times Rc_3)\times[MK+KD-Sl] \quad (14) \tag{14}$$

$$Sl = S(I)\left[\frac{1}{Rc_1}\left(1-\frac{S(II)}{Inl(I)}\right)+\frac{1}{Rc_2}\left(1-\frac{S(II)}{Inl(I)}\right)\right] \tag{15}$$

Also, for cyclone (III)-

$$M(III) = MK\times[1+(By\times sk\times(1-G_k))+S(II)] \tag{16}$$

$$KD = (1-By)\times sk\times(1-G_k) \tag{17}$$

By used the general energy equation [$Q = \dot{m}Cp\,(Tc)$]
to calculate the heat balance across each cyclone and (bypass opining)-

$$Qg(i) = [a_1\times Q_{tc}\times(1-By)+a_3\{1-(1-CD)\times By)\}]\times Tc(i)+[a_2\times Q_{tc}(1-By)+a_4\{1-(1-CD)\times By\}]\times Tc^2(i) \tag{18}$$

$$Qs(i) = S(i)\times(0.206+8\times10^{-5}\times Tc(i))\times Tc(i) \tag{19}$$

The value of heat lost by gasses exit kiln by (bypass opening)-

$$Q_{By} = By\times[(Bf\times a_1\times Q_{tc}+a_3(1-CD)+Cp_{kd}\times sk)\times T_k+(Bf\times a_2\times Q_{tc}+a_4(1-CD))\times T_k^2] \tag{20}$$

Where :
a1=4.532*10-6 (1/K)
a2=0.721*10-6 (1/K2)
a3=0.1173 (Kcal/kgclinker. K)
a4=4.077*10-5 (Kcal/kgclinker. K2)
Cpkd=0.1945+5.55*10-6 *Tk
SiO2=13 %
Al2O3=2.49 %

Table 1. Operation conditions values for preheater system.

Description	symbol	Value	Unit
Kiln exit gasses temperature	Tk	1150	oC
Kiln dust reaching to pre-heater	Sk	0.19	Kg/kgclinker
Ignition loss of kiln dust	Gk	5.95	%
Quantity of raw meal needed to produce (1kg)of clinker without dust circulation	MK	1.92	Kg/kgclinker
Ambient temperature	Ts	40	oC
Quantity of CaCo3 in 1 kg of raw meal	RR	85	%
Total specific heat consumption	Qtc	870	Kcal/kgclinker

Raw mail moisture content	Cm	0.7	%
The Cyclone Design Separation Efficiency	Es(I)	95	%
	Es(II)	80	%
	Es(III)	65	%
	Es(IV)	55	%
Percentage of fuel burning in rotary kiln	Bf	40	%

2. RESULTS AND DISCUSSION

The amount of heat contained in waste gases, which are relatively large, constituting major losses in heat balance for the burning process. Furthermore it is true for cement production plant where large quantities of bypass gas extracted from the inlet of kiln, because the temperature of this gas is considered high in this component of system. As shown in Figures 2-5 that the heat content of gases are decreased with increased in bypass opening at constancy of calcinations degree for cyclones (I,II,III and IV) respectively. And at stability of bypass gases it is found the heat content of gases are directly proportional with respect to calcinations degree. The waste gas amount which comes from the pre-heater correspondingly decreases with bypass gas increasing proportioning and the bypass gas temperature is lowered.

Both effects cause the relatively low loss of heat in the waste gas. The amount of waste gas and its temperature would alike be reduced if part of the intermediate gas is removed from the process.

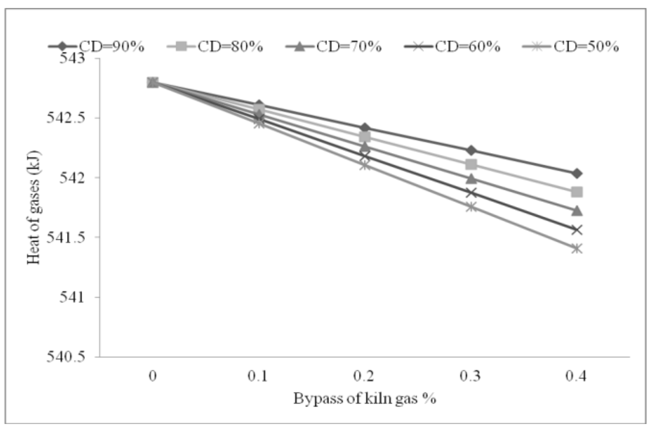

Figure 2. Gases heat of cyclone(I) as a function of calcinations degree.

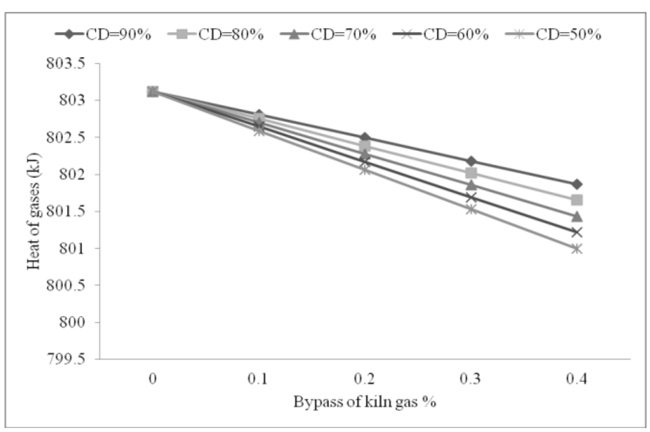

Figure 3. Gases heat of cyclone (II)as a function of calcinations degree.

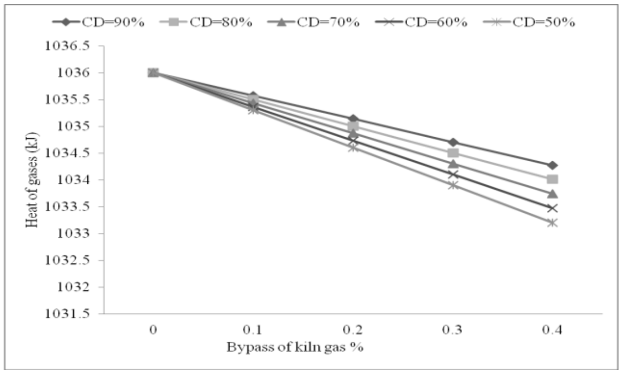

Figure 4. Gases heat of cyclone III as a function of calcinations degree.

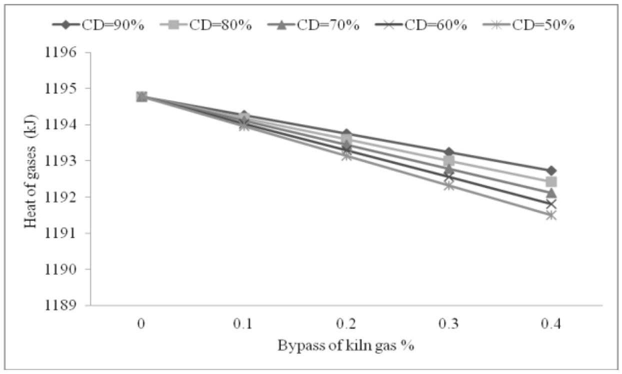

Figure 5. Gases heat of cyclone IV as a function of calcinations degree.

While Figures 6-9 represent the effect of cyclones (I, II, III and IV) temperature on the heat content of gases respectively. It is noticed the heat content of gases decreased with increasing of cyclone temperature. Also in these figures, the bypass effect is inversely proportional relating to heat content of gases.

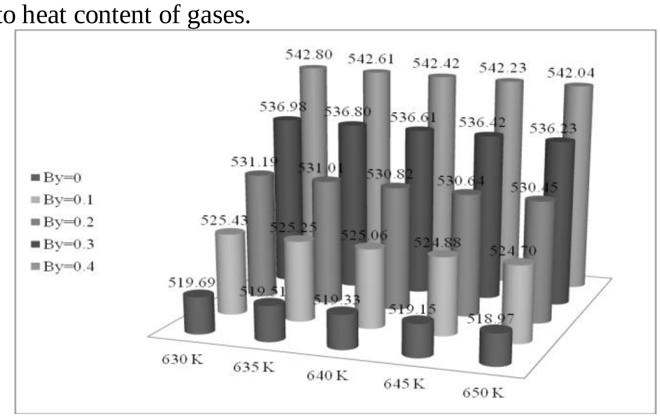

Figure 6. Gases heat of cyclone (I) as a function of bypass of kiln gases.

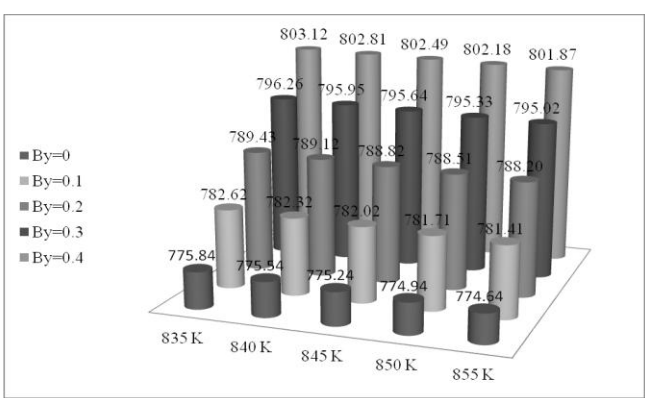

Figure 7. Gases heat of cyclone (II) as a function of bypass of kiln gases.

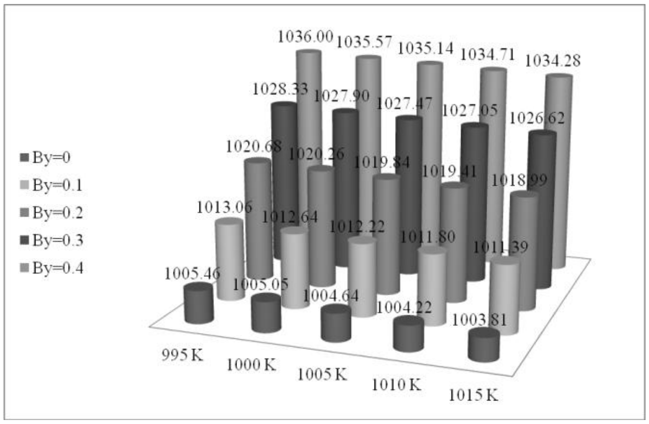

Figure 8. Gases heat of cyclone (III)as a function of bypass of kiln gases.

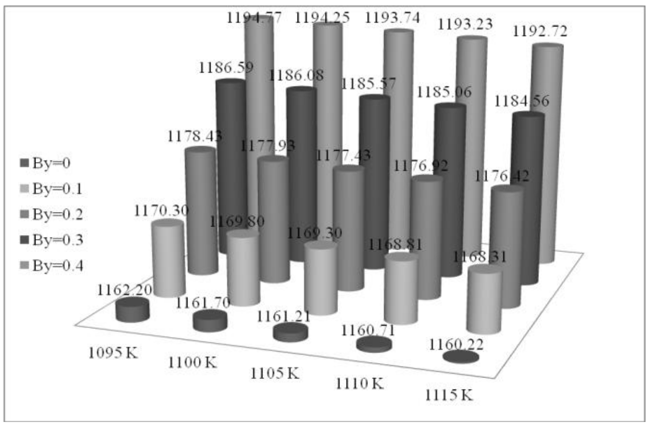

Figure 9. Gases heat of cyclone (IV) as a function of bypass of kiln gases.

Figures 10 and 11 show the slightly increasing in the heat content of gases and dust due to increasing in the cyclone series respectively. The increasing value in heat content of gases is estimated at 1% with every 5 K increasing in the series of cyclones temperature. Whereas the estimation of increasing in the value of dust heat content is 0.9% with every 5 K increasing in temperature of each cyclone.

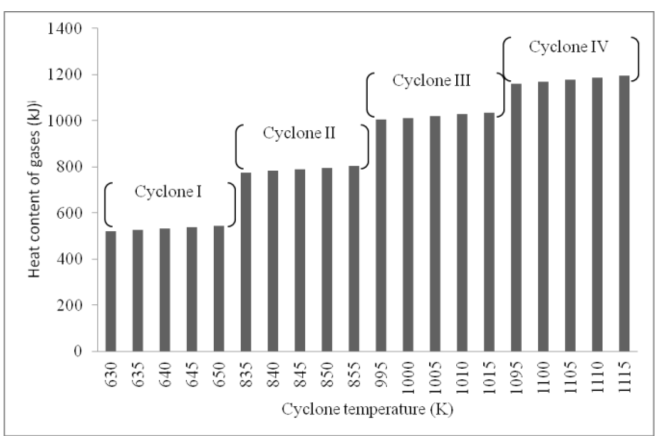

Figure 10. Effect of cyclone temperature on the heat content of gases.

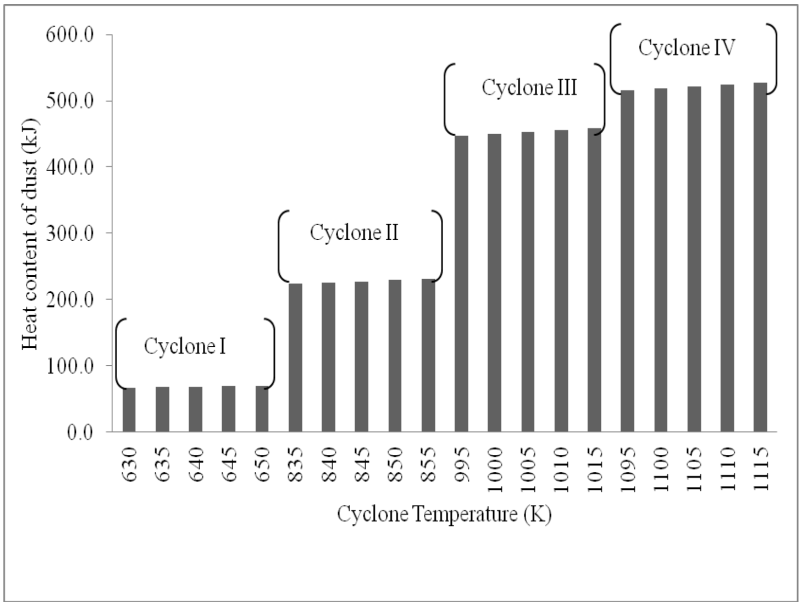

Figure 11. Effect of cyclone temperature on the heat content of dust.

Figure 12 indicates the effect of the calcinations degree on heat content of bypass gases at differ Note that the degree different bypass opening. It is shown the bypass gases heat content increases of calcinations degree decreasing and bypass opening increasing. But with the stability of the value of bypass opening, the degree of calcinations decreases with the increasing in bypass gases heat which are passed through the bypass opening. And this shows that the calcination process basically needs to temperatures of up to (950 oC). Also increasing the waste heat via bypass opening will lead to a decrease in the amount of the total energy required for calcination.

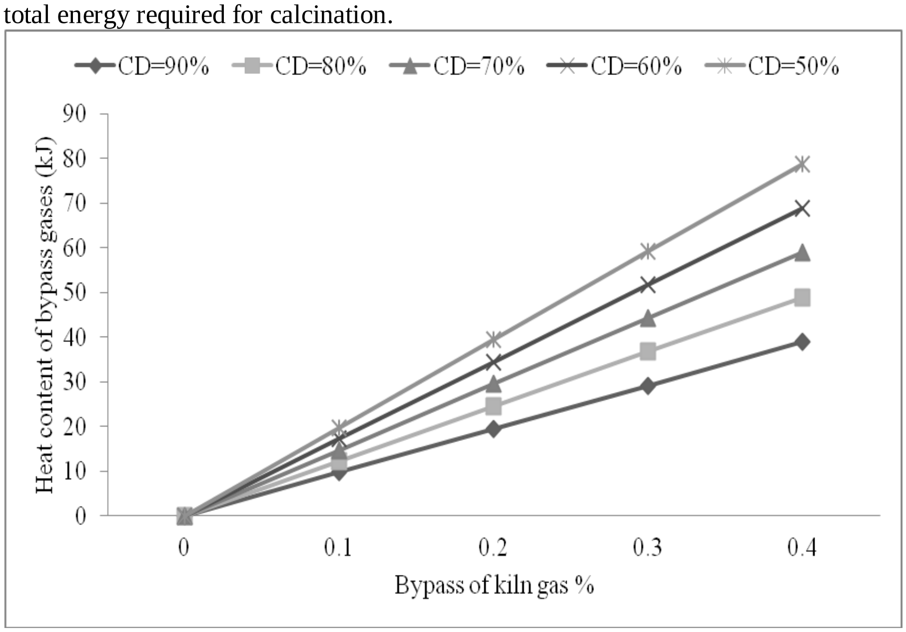

Figure 12. Effect of calcinations degree on the bypass gases.

3. CONCLUSIONS

The results can be summarized in some points as following:

Increasing of bypass opening value plays a major role on the calcinations process, because of its high proportion up to about (89- 97%) takes place in the pre-heating system in dry process for cement production.

Increasing of calcinations degree with constancy of bypass opening value will lead to increase the heat content of gases, whereas at stability of calcinations degree, decreasing of bypass opening value will increase of gases heat content.

The series of cyclones temperature increasing will slightly increase about 1% of heat content of gases and 0.9 % of the dust heat content.

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