Energy Optimization by Replacing Heavy fuel oil with Natural Gas in Hormozgan Cement Calciner-Line 1

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***Abstract*- Mazot has negative environmental effects compared with gas fuel. Mazot is employed as a secondary fuel in some cement plants located in Iran. Besides, replacing Mazot with natural gas (NG) not only reduce pollutant emission, but also save huge amount of money for those companies. Hormozgan Cement Plant operates two clinker kilns, each comprises of 5-stage FCB inline calciner kiln at a typical raw meal feed rate of 225t/h. The calciner burns 86% natural gas and 14% Mazot. In the present study, we will show how computational fluid dynamic (CFD) can be aided us to simulate the calciner of the cement plant and propose a cost-effective solution to replace Mazot with NG. At the end, it is demonstrated that not only the plant can operate with 100% NG, but also its production rate can increase with the new proposed configuration. Furthermore, the specific fuel consumption rate reduces. After this simulation, one of proposed cases implemented on the plant and results showed that by removing Mazot, production rate remained constant and specific heat consumption reduced as the simulation results.**

Keywords - CFD, Hormozgan Cement Plant, Calciner, Natural Gas Combustion

1. INTRODUCTION

A calciner is a combustion chamber placed at a lower stage in the preheater. About 60% of the fuel supply is usually fired in that chamber, with the combustion air being derived from the clinker cooler. The use of calcining systems allows the rotary kiln to be shortened because a high degree of decarbonation can be obtained at the kiln entrance, typically of the order of 90%. On the other hand, the production capacity of existing kilns can be enhanced by adding a calciner. When one compares the situation of an existing kiln with a given diameter, one can see that the production can be roughly multiplied by two when a cyclone tower with a precalciner is added to that kiln.

Several types of calciners are used through the world, differing from the flow in the devices (up- or down-flow, with or without a vortex flow), the design of the air, fuel and material supply to the device.

As regard as cement industry is a high consumer of energy and has an importance role in CO_2 production, continuous improvement of energy efficiency in the cement production process is needed. In order to make the cement industry more greener and lower about the CO_2 emission, increase of the energy efficiency comes first, followed by using of the other fuel that has lower emission such as renewable energy [1]. In the recent years, some researchers are studied this issue. Mikulčić and et al. [2] investigated the potential of CFD to design calciner and improvement of its performance. In this paper, calcination process was modeled mathematically and it was used to develop a commercial code to improve geometry of calciner. Deshmukh and et al. [3] simulated fluid flow and coal fuel by using CFD in the calciner and investigated dilution such as Nox and Sox. Chinyama and et al. [4] showed that calciners and reaction taking place in it could be modeled by simple models. They studied different decomposition reactions of calcium carbonates. Fidaros et al. [5] studied transport process in the calciner parametrically by numerical method. The numerical model was based on the solution of the Navier–Stokes equations for the gas flow, and on Lagrangean dynamics for the discrete particles. They optimized operations for the calciner by parametric study. Hu and et al. [6] conducted a three-dimensional numerical simulation of dual combustion and denitration process in pre-calciner for cement production. The fluid phase was expressed with RNG k–ε two-equation model in Euler coordinate system and the solid phase was expressed with particle stochastic trajectory model in Lagrange coordinate system. Iliutaa and et al. [7] conducted Simulations with a heterogeneous model of an in-line low-NOx calciner, based on non-isothermal diffusion-reaction models for char combustion and limestone calcination combined with a kinetic model for NO formation and reduction. They concluded carbon monoxide was a key component for the reduction of NO and reliable data for the kinetics of NO reduction by CO over CaO were very important for the prediction of the NO emission.

Although it is previously proved that burning Mazot has negative environmental effects compared with gas fuel [8], Mazot is employed as a secondary fuel in some cement plants located in Iran. Besides, replacing Mazot with natural gas (NG) not only reduce pollutant emission, but also save huge amount of money for those companies. NG is cheaper and more accessible than Mazot in the Iran and replacing Mazot with NG reduces additional expenses for storing, preheating, and pumping of Mazot.

In a cement plant in the Iran (Hormozgan), the calciner operates with 86% NG and 14% Mazot. It is an old plant that was designed to run with Mazot completely. They have tried to replace Mazot with NG based on on-site trial and error, although they have failed to eliminate Mazot. When they eliminate Mazot and used NG instead, the plant experienced significantly detrimental effects like high temperature and CO emission at the preheater exit. Therefore, they had to reduce their kiln feed rate in order to stabilize the process. Therefore, the company has invited MEEMCO/FCT not only to conduct a survey including site visit and preliminary calculation to explore the present working principles of its preheater, but also to eliminate Mazot completely without any negative side-effect on production rate and pollutant emissions.

In the present study, we will show how computational fluid dynamic (CFD) can be aided us to simulate the calciner of the cement plant and propose a cost-effective solution to replace Mazot with N.G. At the end, it is demonstrated that not only the plant can operate with 100% NG, but also its production rate can increase with the new proposed configuration. Furthermore, the specific fuel consumption rate reduced. By and large, the plant earns around 146,000 € because of replacing Mazot annually. Also, MEEMCO/FCT estimates that their investment return at most in 5 months.

2. GEOMETRY AND MESH

Hormozgan Cement Plant operates two cement kilns, each comprises of 5-stage FCB inline calciner kiln at a typical raw meal feed rate of 225t/h. The calciners burn 86% natural gas and 14% Mazot. However, the cheaper cost of natural gas as compared to Mazot has encourage the client to find a way to operate the calciner with 100% natural gas.

In this study, our aim is to propose modifications to achieve the following goals:

- To minimize or eliminate any usage of Mazot in the calciner as a secondary fuel.
- To reduce unburnt hydrocarbons and pollutant emissions at the calciner outlet.

The calciner has four burners which one of them used Mazot. All of them have 20 MW power approximately. Location of burner in the calciner and meal inlet is shown in the *Fig. 1*. All details of the calciner specifications are considered in this void model, comprising burners, mean inlets and contractions. All burners are located at the top of the vortex chamber. Furthermore, there are two inlets located in riser duct and calciner vessel in order to inject raw meal into the domain.

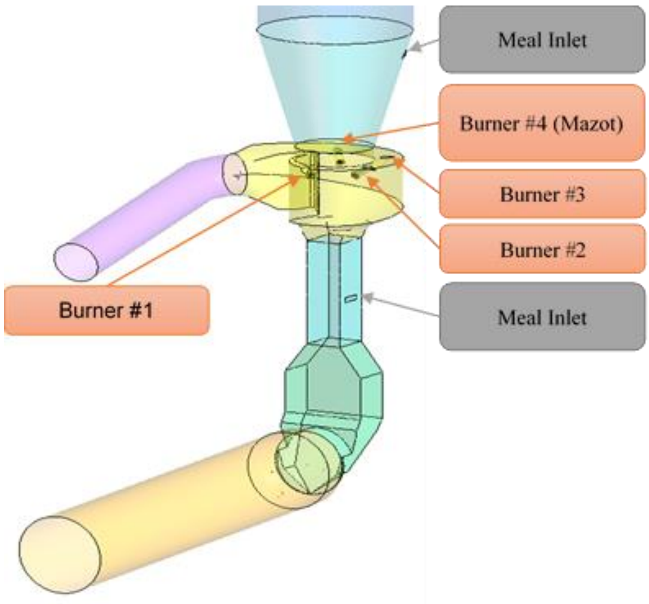

Fig. 1. Arrangement of burners and meal inlets

This computational domain consists of almost 6.2 M hexahedral and tetrahedral cells. Hybrid technique mesh generation is used to generate desired grid for the domain. Some critical regions are highlighted in *Fig. 2* to demonstrate the smoothness and accuracy of generated grid for such important sections. Mesh generation is done by Ansys Meshing 17.2.

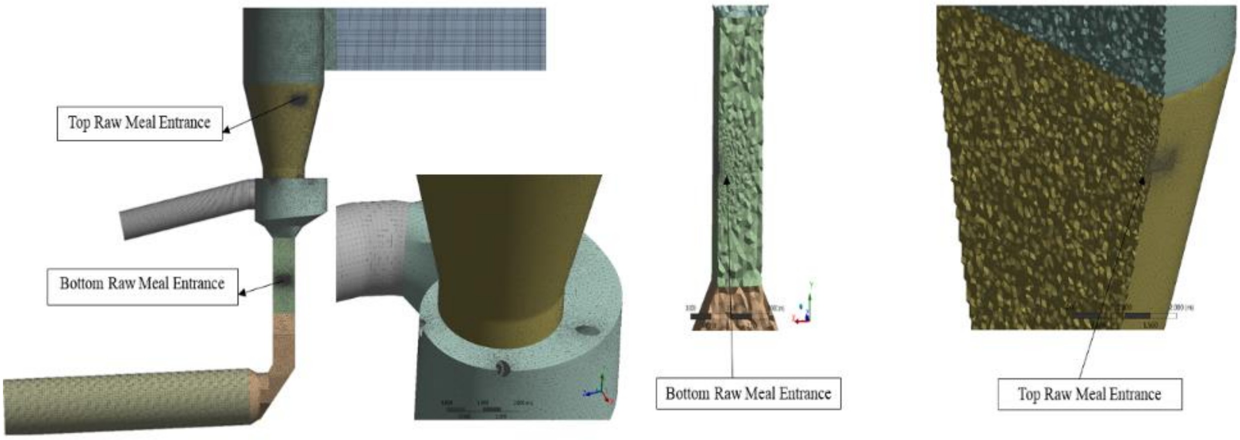

Fig. 2. Mesh distribution in base case geometry

3. NUMERICAL METHOD

Simulation is done by Fluent 17.2. k-ε realizable is selected for turbulence model that seems to be suitable as regard as complicated process in the calciner. Finite Rate/Eddy Dissipation model is used to combustion modelling. Following reaction is consider to this simulation.

$$CH_4 + 1.5\ O_2 \rightarrow CO + 2\ H_2O \tag{1}$$
$$CO + 0.5\ O_2 \rightarrow CO_2 \tag{2}$$
$$C_2H_6 + 2.5\ O_2 \rightarrow 2\ CO + 3\ H_2O \tag{3}$$
$$C_{19}H_{30} + 26.5 O_2 \rightarrow 19\ CO_2 + 15\ H_2O \tag{4}$$

According to these reactions, CO can get in the simulation. Gas density is considered as incompressible ideal gas. Radiation model is Discrete Ordinates (DO). It is used Euler method to multiphase model. Euler-Euler is a complex model in numerical simulation that is not used in previous studies. Schiller-naumann model is used to drag force model between solid particle models. The impact factor is considered 0.9 and gun model is used to heat transfer model between particles. Reaction of solid particles are considered as follow.

$$CaCO_3 \rightarrow CaO + CO_2 \tag{5}$$

This reaction is named calcination. The boundary conditions is considered by using site survey data gathering as well as mass and heat balance calculations. Some of this data is presented in following table.

Table 1. Inlet boundary conditions

Boundary Name	Unit	Flow Rate	Temperature (oC)
Tertiary Air	Nm3/h	64,062	872
Kiln and Riser Flue Gas	Nm3/h	786,88	1100
Meal Inlet	t/h	248.269	813

The hot meal is split between the calciner and riser feed chutes by 70% and 30%, respectively. The hot meal particle size distribution used in this study is based on Rosin-Rammler size distribution extracted from hot meal sieve residues. In the present study, all details of refractories and walls are included to accurately determine heat transfer through the calciner. To such aim, the outside surface temperature of the computational domain measured by infrared thermometer during site survey is used as thermal boundary conditions in numerical simulations. The averaged value of the outside wall temperature is shown in *Fig. 4*. It should be mentioned that all mechanisms of heat transfer are considered in the present investigation including; convection, diffusion and radiation.

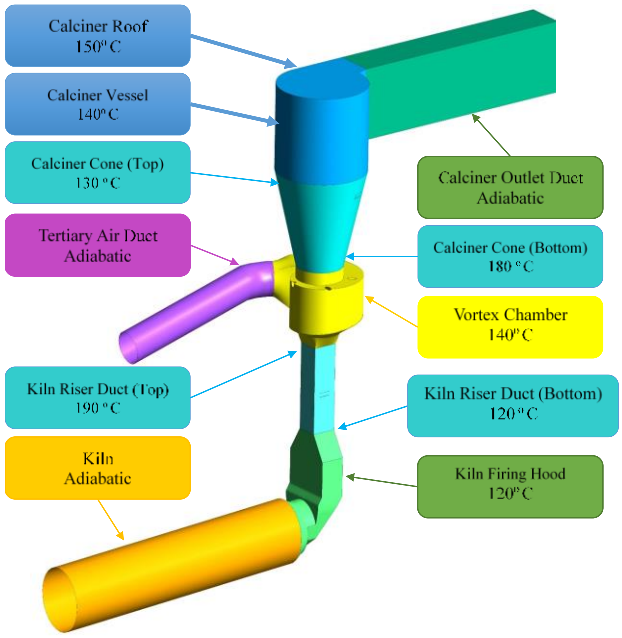

Fig. 3. CFD Model Surface Temperatures for Calculation of Heat Loss

In the base case (Mazot & Natural Gas) condition, three burners operate with 100% natural gas, while one burner utilizes Mazot. Operating conditions of the burners are calculated and are summarized in *Table 2*.

Table 2. Burner Operating Condition in Base Case (Mazot & Natural Gas)

Burner	Volume flow rate		
	Primary Air (Nm3/hr)	Natural Gas (Nm3/hr)	Mazot (lit/hr)
#1	1173	2,427	0
#2	1173	2,427	0
#3	1173	2,427	0
#4	1173	0	1,050
Total	4,692	7,281	1,050

As regard as presented boundary conditions and models in this section, simulation is done and the results are validated in next section.

4. VALIDATION

In this section, the currently utilized condition of the calciner is simulated to evaluate overall features of the combustion and calcination processes in the calciner as well as the probable problems in combustion or calcination. The main outputs of the base case CFD simulations are compared with experimental date from site survey in *Table 3*.

In an attempt to validate the present results, the obtained numerical results are compared with the experimental site survey data, as below:

• The exit gas temperature in the model is 975°C and is quite close to the corresponding value measured at site (950°C). Therefore, error is 2.6%.

• The exit value of LOI in model is 7.74, but measured value is 6.48. This 19.4% error value is high, but it should be noticed that in CFD modelling LOI is calculated in the calciner outlet while in the reality, it is measured in the cyclone 5 outlet.

Table 3. Comparison of simulation results and site survey data

Properties	Simulation	Experimental
Natural Gas (Nm3/h)	7,280	7,280
Mazot (lit/h)	1,050	1,050
Calciner Outlet Temperature (°C)	975	950
Calciner Outlet LOI (%)	7.74	6.68

According to this comparison, it seems results of numerical simulation are reliable and they can show problems correctly.

5. Results

Fig. 4 plots spatial distributions of methane and carbon monoxide mole fractions (in PPM) at several planes of the riser duct and calciner. Results show that CH4 mole fraction is quite high at the downstream regions of the calciner. Therefore, we expect that there is huge amount of unburnt hydrocarbons at the calciner outlet.

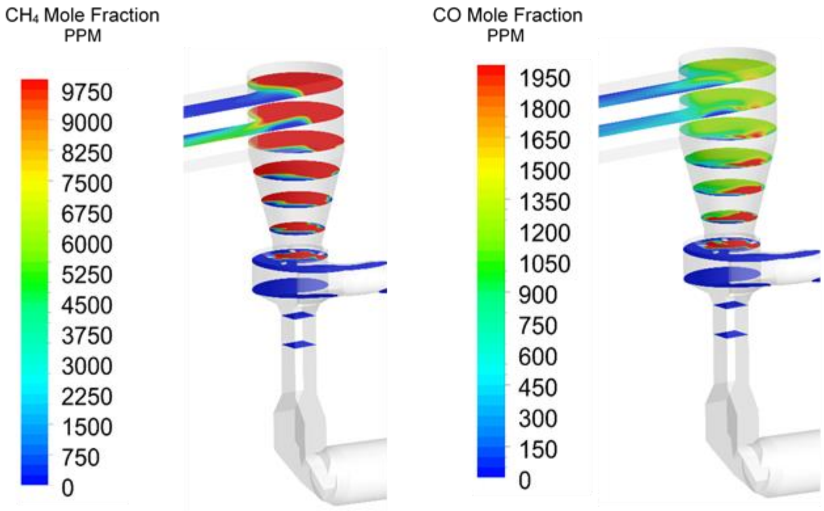

Fig. 4. Spatial Distributions of CH4 and CO Mole Fractions at Several Planes of the Kiln and Calciner for the Base Case (Mazot & natural)

The concern is why the unburnt hydrocarbon is high in the calciner outlet. In order to answer this question, consider *Fig. 5*, plotting spatial distribution of oxygen at several planes of the riser duct and calciner. Results show that oxygen mole fraction is very low in the calciner, which results in incomplete combustion. Therefore, the unburnt hydrocarbon at the calciner outlet is due to lack of oxidizer especially in the meal inlet section on the calciner (among burner #1, #2, and #3). This problem is shown in the *Fig. 6*.

Fig. 7 shows the inlet flue gas path line from kiln and T.A. coloured by CH4 mole fraction. As the figure shows, there is a large vortex in the calciner close to the calciner meal inlet (Among burner #1, #2, and #3). This vortex helps the fresh reactants to burn appropriatly in the calciner by circulating the hot combustion product from the downstream region to the fresh reactant. The current condition is appropriate when Mazot is not removed. However, if Mazot is removed, all conditions will change and oxidizer will be very low to burn fuel and CO will increase.

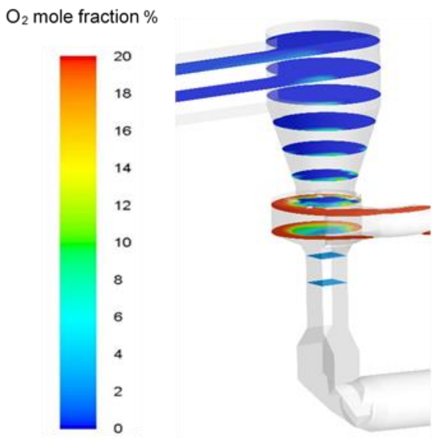

Fig. 5. Spatial Distribution of Oxygen Mole Fraction at Several Planes of the Calciner for the Base Case (Mazot & Natural Gas)

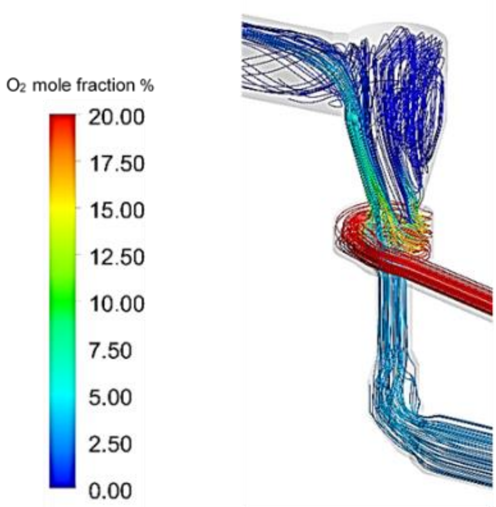

Fig. 6. Flow Path Line from TA and Kiln Coloured by O2 Mole Fraction (%) for the Base Case (Mazot & Natural Gas)

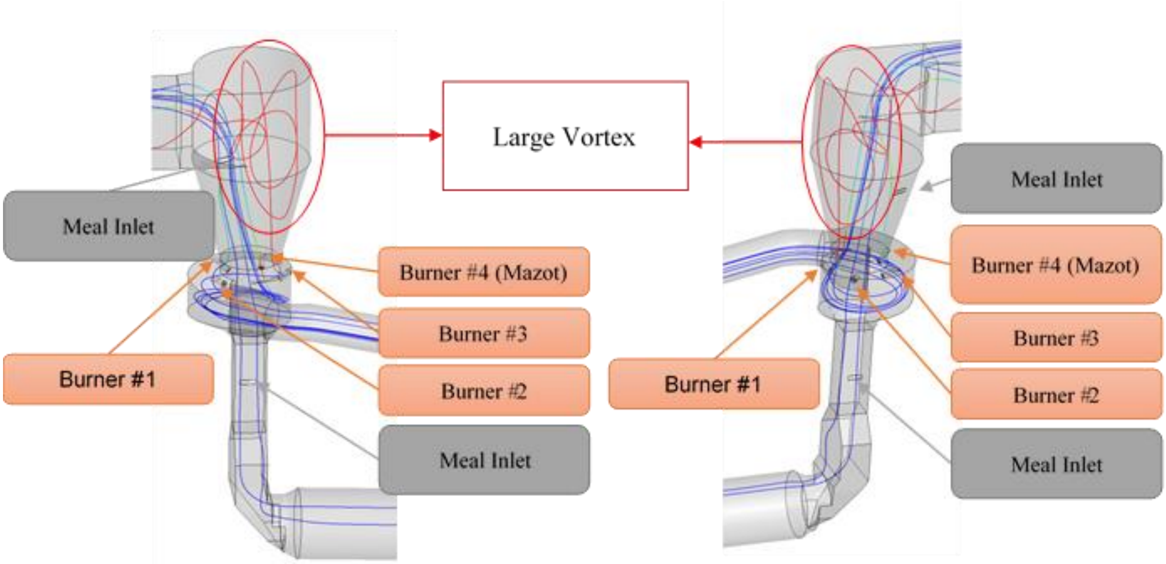

Fig. 7. Flow Path Lines from the T.A. and Kiln Colored by CH4 Mole Fraction for the Base Case (Mazot & Natural Gas)

In an attempt to overcome current problems in Hormozgan plant calciner, 21 proposed cases have been simulated to evaluate the most effective modifications to reduce unburnt fuel and fuel consumption in the calciner. The proposed modifications include optimizations of burner locations, burner configurations, and adding excess air to the calciner. Based on the client request and for the sake of brevity, the most effective cases are presented in this paoer, including:

• The first proposed case (PC1): To add an excess air fan to the burners (*Fig. 8*).

• The second proposed case (PC2): To add an excess air fan and a FCT burner to the burners and the riser duct, respectively (*Fig. 9*).

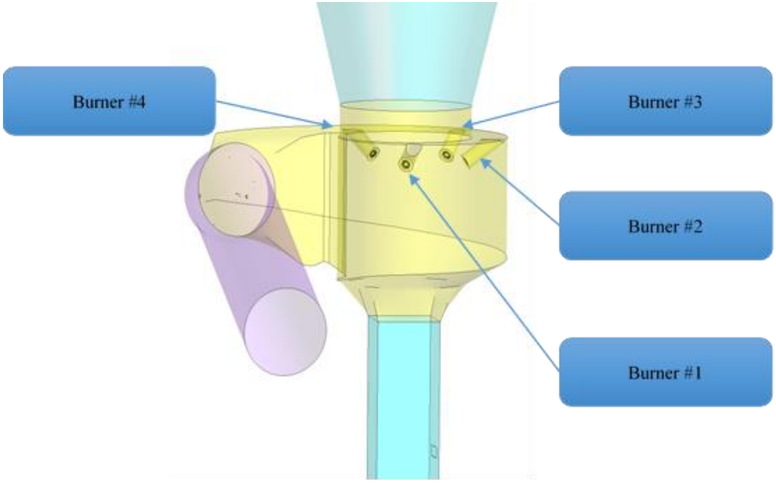

Fig. 8. Proposed Cases 1 (PC1-No burners changing, to add an excess air fan to the burners.)

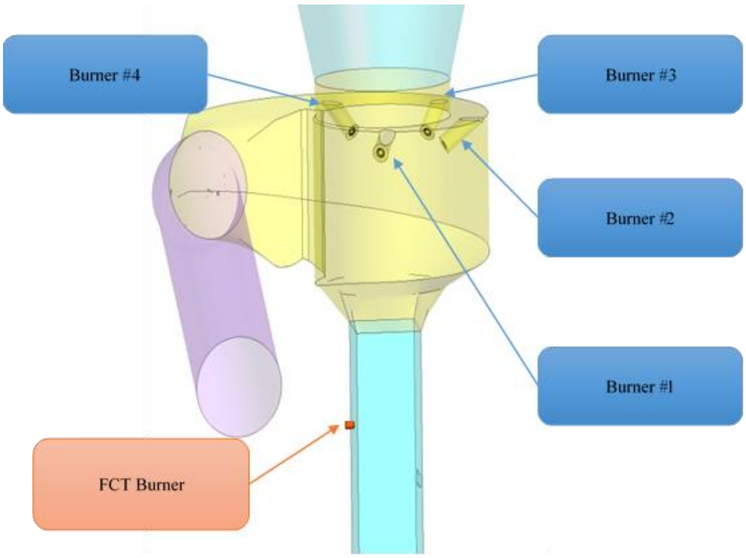

Fig. 9. Proposed Cases 2 (PC2-No burners changing, to add an excess air fan to the burners and add one FCT burner)

Operating conditions of the burners in the above-proposed cases are summarized in *Table 4*. As it is mentioned before, one of the main objectives of the present investigation is to eliminate Mazot from the calciner operation. To such aim, liquid fuel is replace by Natural Gas in a way to keep the calciner total heat consumption rate constant.

Table 4. Burner Operating Condition in the Proposed Cases

Burner	Volume flow rate			
	PC1		PC2	
	Primary Air (Nm3/hr)	Natural Gas (Nm3/hr)	Primary Air (Nm3/hr)	Natural Gas (Nm3/hr)
Burner #1	1,923	2,000	1,923	1,838
Burner #2	1,923	2,000	1923	1,837
Burner #3	1,923	2,000	1,,923	1,837
Burner #4	1,923	2,000	1,923	1,837
FCT Burner #1	0	0	0	800
Total	7,692	8,000	7,692	8,149

Fig. 10 and *Fig. 11* show spatial distributions of CO and CH4 mole fractions at several planes of the calciner in the base case and the proposed cases. Results show that fuel reacts faster in the downstream region of the calciner in all the proposed cases as

compared to the base case. Therefore, CO mole fraction is quite lower in the proposed cases in the downstream region of the calciner as compared to the base case. Hence, it can be concluded that combustion process is much better in the proposed cases. Therefore, based on *Table 5*, both proposed cases not only reduce the fuel consumption by 5-6% as compared to the base case, but also they can decrease both unburnt hydrocarbons and CO mole fraction by 98-99% in the present calciner.

Fig. 12 shows flow path line from TA and kiln colored by O2 mole fraction in the investigated cases. Results show that in the proposed cases, there is more O2 in the large vortex section. It means that there will be lower unburnt fuel from the combustion process in the proposed cases than the base case. In the base case and PC1, there are considerable amount of O2 in the riser flue gas which does not participate in the combustion process. In order to utilize such oxygen, in the second proposed case, a burner is located in the riser duct. The results (outlet unburnt fuel and CO) clearly show that combustion is improved considerably in the proposed cases as compared to the base cases.

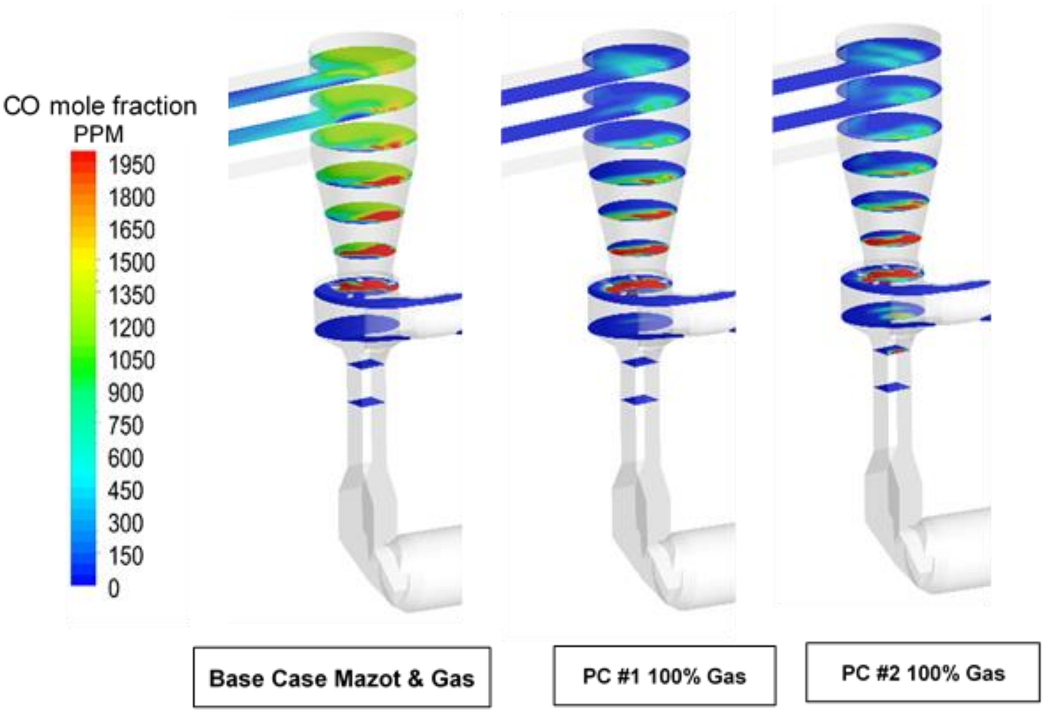

Fig. 10. Spatial Distributions of CO Mole Fraction at Several Planes of the Kiln and Calciner

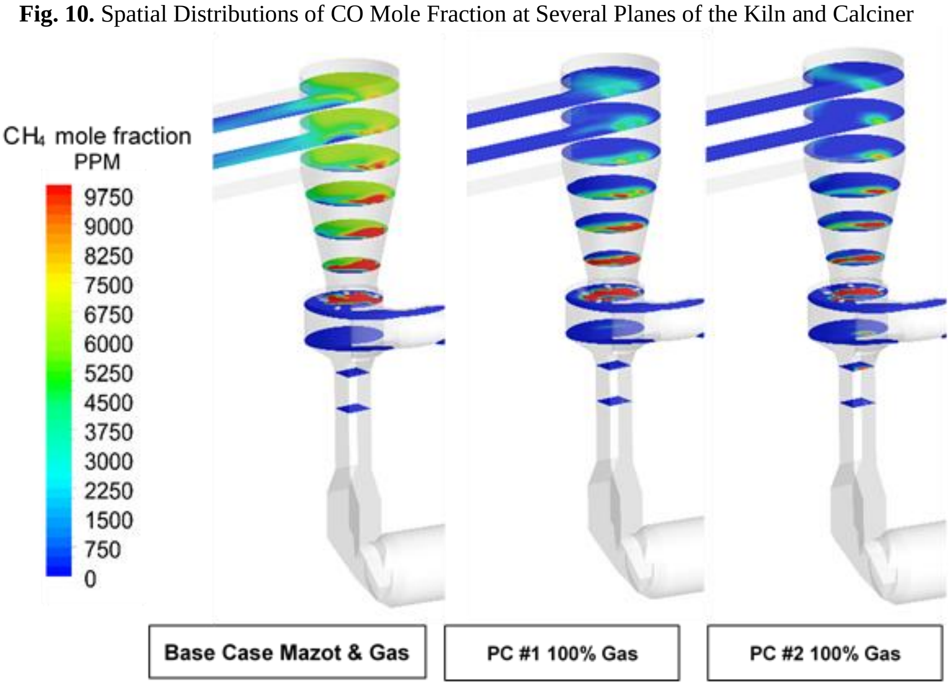

Fig. 11. Spatial Distributions of CH4 Mole Fraction at Several Planes of the Kiln and Calciner

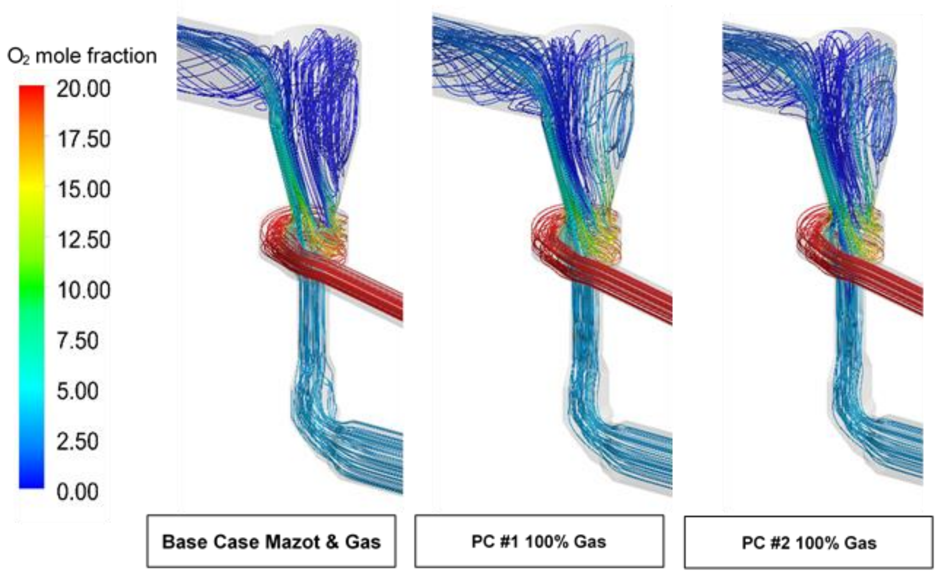

Fig. 12. Spatial distributions of O2 mole fraction at several planes of the kiln and calciner

Fig. 13 shows spatial distribution of axial velocity at various sections of the computational domain. Despite negligible differences between the base case and proposed cases, velocity distribution looks similar in all investigated cases. Hence, it can be concluded that proposed modifications have no effect on the residence time.

In order to compare the above-investigated cases quantitatively, *Table 5* summarizes the most important specifications of the reacting flow field with meal at the calciner outlet for the investigated cases. Results show that combustion characteristics are enhance significantly in the proposed cases, while the calcination degree is kept almost constant during the modifications. Reduction of unburnt hydrocarbons and CO emission at the calciner outlet in the proposed cases as compared to the base case is a clear manifestation of the combustion enhancement. Results show that the unburnt hydrocarbons reduce, respectively, by 98 and 99 % in the proposed cases #1 and 2 as compared to the base case. More interestingly, the fuel consumption in the proposed cases #1 and 2, reduces respectively by 6 and 5% as compared to the base case. Such fuel saving decreases the site energy expenses, significantly.

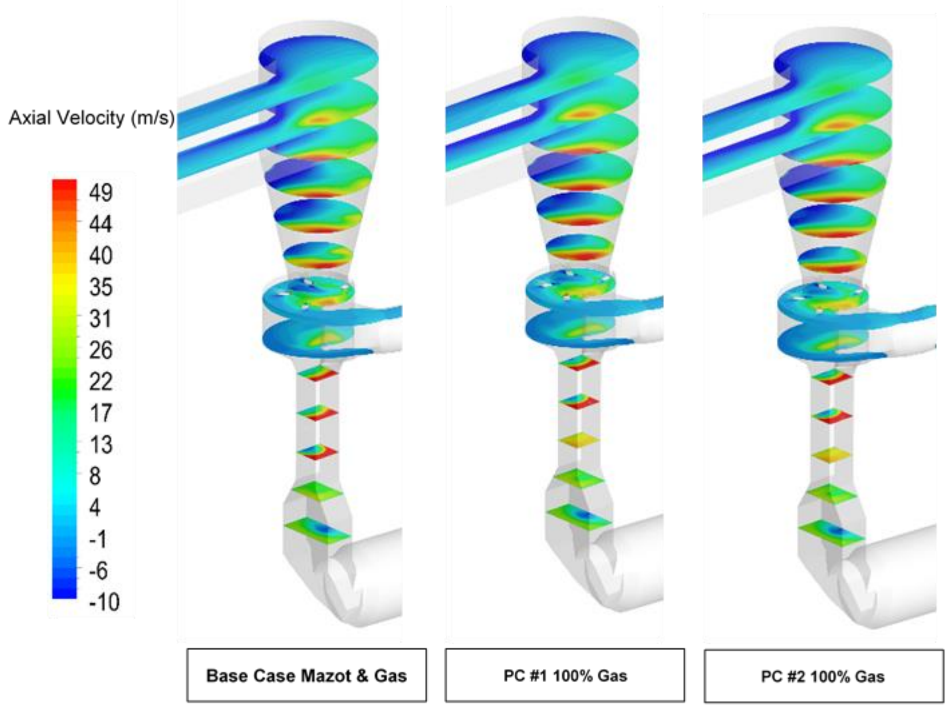

Fig. 13. Spatial Distributions of Axial Velocity at Several Planes of the Kiln and Calciner

Table 5. Summary of Base and Proposed Cases Results

Properties	Base Case Natural Gas & Mazot	PC #1 100% Natural Gas	PC #2 100% Natural Gas
Fresh Feed Rate (t/h)	225	225	235
Natural Gas (Nm3/h)	7280	8000	8149
Mazot (L/h)	1050	0	0
Calciner Outlet Temperature (°C)	975	970	952
Calciner Outlet LOI (%)	7.74	8.11	7.83
Calcination Degree @ Calciner Outlet (%)	84.4	83.53	82.56
C19H30 (Mazot) Mole Fraction (ppmv)	0	0	0
CH4 Mole Fraction (ppmv)	2174	<500	<100
C2H6 Mole Fraction (ppmv)	<10	<100	<100
CO Mole Fraction (ppmv)	479	24	29
O2 Mole Fraction (%)	0.85	1.33	1.36
Fuel Consumption (As compared to the base case (100% Natural Gas))	-	-6 %	-5 %
Unburnt Fuel (As compared to the base case (N.G. and Mazot))	-	-98 %	-99 %

According to presented simulations, payback of proposed cases are studied in *Table 6*. As it can be seen in this table, the revenue of Mazot removing is only item that is investigated in this section. Proposed case #2 increases production rate about 5% and so the revenue of PC#2 is the highest and it seems to be the most economical case to do in site.

Table 6. Benefits of presented cases

Item	Mazot in Calciner (lit/h) – 225t/h feed rate	Natural Gas in Calciner (Nm3/hr)	Natural Gas in Calciner (KNm3/day)	Fuel Price in Calciner (MRial/day)	Daily Benefit from Removing Mazot and Reducing Fuel Consumption in Calciner (MRial/day)	Annual Benefit from Removing Mazot and Reducing Fuel Consumption in Calciner (GRial/year) (based on 303 work day in a year)
Base case	1,050	7,280	175	293	0	0
PC #1	0	8,000	192	230	63	19.1
PC #2*	0	8,149	196	233	60	18.2

*In this table, annual benefit of production rate increasing is not considered. Production rate will increase about 5% in this case.

6. Implementation on Site

According to presented solutions to the client, the first option was chosen because it was cheaper. In this option, there was not necessary to buy a new equipment. Therefore, it was economical option for the client. There was a standby fan in the site. The fan was connected to the calciner primary air pipe and started to work (*Fig. 14*). This implementation took some times and Mazot removed gradually. The result of Mazot eliminating can be seen in *Fig. 15* and *Fig. 16*. Implemented modifications not only cause to eliminate Mazot, but also reduce the specific heat consumption (SHC).

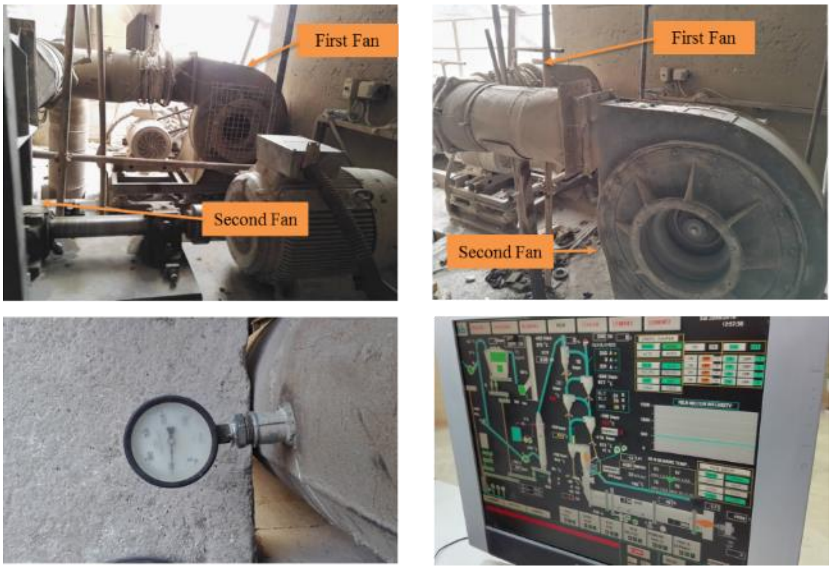

Fig. 14. Adding second fan to calciner burner primary air pipes

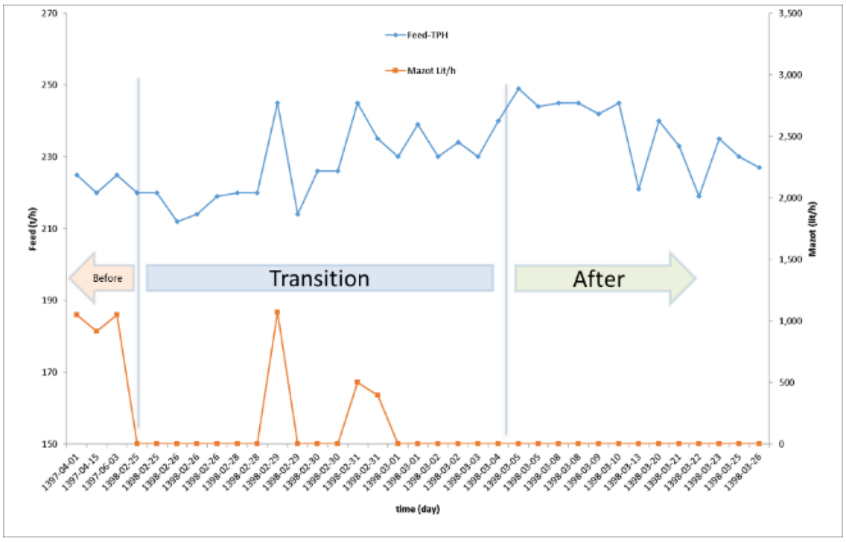

Fig. 15. Feed Rate and Mozot Flow Rate Before/After Modification

Fig. 16. Specific Heat Consumption and Calciner Burner Flow Rate Before/After Modification

7. Conclusion

In the present study, Hormozgan calciner reacting flow field is investigated using numerical method to characterize main problems in Hormozgan Cement Plant. To do so, first, currently utilized conditions of the calciner were simulated. Obtained results showed that calciner operating with Mazot/natural gas suffers from high unburnt hydrocarbon. In an attempt to overcome such problems in this calciner, various optimizations were carried out. Based on these optimizations, two cases were selected in which both combustion are improved as compared to the base case. Obtained results show that

- All proposed cases reduce the calciner fuel consumption, Temperature, CO emission and unburnt fuel at the calciner outlet.
- Adding primary air fan in proposed cases will increase volume flow gas in the calciner outlet about 2%. Therefore, RPM of ID fan should be increased about 2%. However, if cyclone leakages seals, it will be compensate.
- The second proposed case, in which FCT burner is located on riser duct, can reduce unburnt fuel by orders of magnitude.
- The second proposed case can increase production rate while fuel consumption of it is almost like first proposed case and lower of base case.

After this simulation, Client chose the first proposed case because it was cheaper. This implementation took some times and Mazot removed gradually. Implemented modifications not only cause to eliminate Mazot, but also reduce the specific heat consumption (SHC). No additional load is forced on ID fan. So, production rate remained constant after modification.

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