The Korean Journal of Ceramice, **5**[3]296-302 (1999)

Advanced New Process Development of Two-Stage Swirl Calciner

Hyung-Suhk Suh, Choon-Keun Park, Jae-Sang Ryu and Hong-Bae Kwak
Cement Research Team Ssanyong Research Center, Teajon 305 345, Korea
(Received September 23, 1998)

The state of the art of the 2-stage swirl calciner is to make 2-stage counter gas flow in a calciner with cooler hot air. Gas flow in the calciner increases retention time of raw mix particles. Simple structure of the 2-stage swirl calciner operated optimally the rotary cement kiln. In this study, in order to decide the entrance type of the cooler air of the optimal calciner model, an entrance cooler air velocity, the input points of raw mix were analyzed in many aspects with cold model experiment and computational fluidized dynamics simulation. It was found that the entrance type of cooler air fully splits 2-stage for the optimal condition of the cold model calciner. The operation conditions were that the input feeding, the cooler air velocity and the air velocity of throat were 0.33 kg/m^3, 15 m/s and 20 m/s respectively. The performance of 150 t/d the pilot plant connected with the kiln rising duct was that volume capacity of the calciner is over 430 kg/m^3-h, decarbonation rate of raw mix apparently 90%, heat consumption 950 kcal/kg-cli and retention time of raw mix 2.4 sec. Its the best operating condition is cooler air velocity 18 m/s, the gas velocity of throat 25 m/s, feeding rate of raw mix 10 t/h. The operating experience of the pilot plant confirmed the success of scale up for over 3000 t-cli/d.

Key word : Two-stage swirl calciner, Fluidized dynamics, Decarbonation, clinker

I. Introduction

From the early 1970s, the emphases were universally on the development and on the report of various calcining process in cement plants.[1,2] The calciner process can save an energy and can manufacture a cement clinker 2~5 times than a suspension preheater(SP) kiln or a dry/wet long kiln did.[3,4] Therefore, the cement manufacturers have enthusiastically studied and developed new calciner systems.

As the calciners is a core part of new suspension preheater(NSP) kiln, the necessary conditions that the calciners should had are the function for a long retention time of raw mix particles, a stable operation, a small and simplification. When the calciner system is complicated, the performance is up, but it is not easy for stable operation of cement kiln. In case opposite to that, the performance is down, but it is comfortable for stable operation of cement kiln. The reason why it is unsatisfying the performance of the calciner is not enough a heat exchange between the particles of a raw mix and hot gas, and is insufficiently retention times under good mixing in calciner.

This study discusses the optimal type of the 2-stage swirl calciner improved existing problems about the calciner by the cold model experiments and the 150 t-cli/d pilot plant experiments with 5-stage preheater connected existing kiln 2000t/d capacity. The experiments convinced the success for scale up of 2-stage swirl calciner.

II. Foundation on the Two-stage Swirl Calciner (TSSC)

A basic function of a calciner is to increase a clinker output and to save a consumptive energy when cement clinker is manufactured in a rotary kiln. The energy for decarbonation reaction ($CaCO_3 \rightarrow CaO+CO_2$) of raw mix needs above 50% of total energy for cement clinker manufacturing in cement kiln. In an SP kiln the rate of decarbonation reaction is about 45%, but it is about 90% in an NSP kiln. Since fuel combustion, especially solid fuel, is done under fluidizing condition in the calciner, it is possible to increase clinker output and to save the energy. For the purposes of these, NSP system is world-widely supplied for cement plants by three methods as follows.

First, the position of the calciner is on a kiln inlet chamber. Decarbonation reaction of raw mix is carried out using heat source of kiln hot exhaust gas and fuel combustion heat burned by hot 3rd air from clinker cooler. The raw mix decarbonated about 90% is fed in kiln via bottom cyclone.[5]

Second, the position of calciner is separated from the kiln, so heat source is only fuel combustion heat by hot 3rd air. The raw mix decarbonated 70% in the calciner input kiln riser duct, one more decarbonates there, finally decarbonation rates is about 90%. And then the raw mix is input kiln via bottom cyclone.[6]

Third, it is similar to the first method, but fuel combustion chamber is separately connected with the calciner.

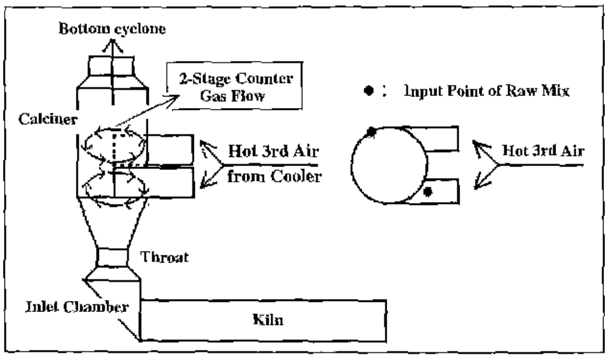


Fig. 1. Schematic diagram of two-stage swirl calciner.

Fuel combustion is mainly done, the raw mix decarbonated in the chamber moves fast to the kiln riser duct, and then decarbonated again. Finally, the raw mix decarbonated about 90% is fed the kiln via the bottom cyclone.[7]

TSSC is the same as the first method and is a simple structure shown in Fig. 1. The second or the third system has a good performance, but their structures are more complicated than the first system. The state of the art of TSSC solved a structural problem produces to make 2 stages swirl count gas flow in a calciner using hot 3rd air from a cooler, resulting in forming a simple structure and operating easily.

The 2-stage count gas flow increases the retention times of raw mix particles and coal particles in the calciner, so that it can enhance the decarbonation rate of raw mix and the combustion rate of fuel. The particles of raw mix and fuel are conflicted and mixed well by the gas flow. Fineness of raw mix as a feeding material is 10% residual 88 μm.

The development process of TSSC is shown in Fig. 2. Of this process, the most important thing is to fine an idea model of the calciner type to develop.

The study was carried out the suspension furnace test and the simulation test that helped to solve 3 dimensional space using computational fluid dynamics, besides the cold model experiments. The performance of pilot plant could be guessed by these experimental results before pilot plant test.

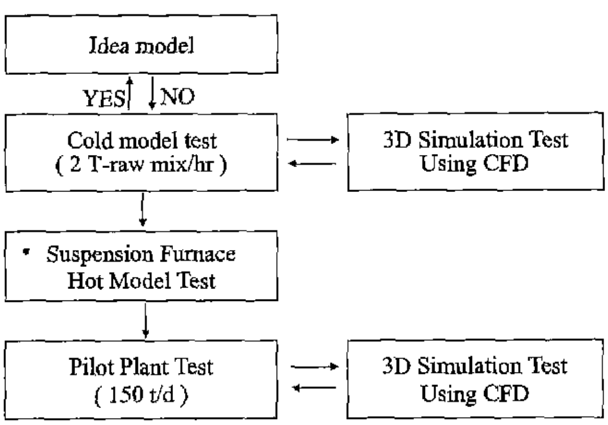


Fig. 2. The development process of TSSC.

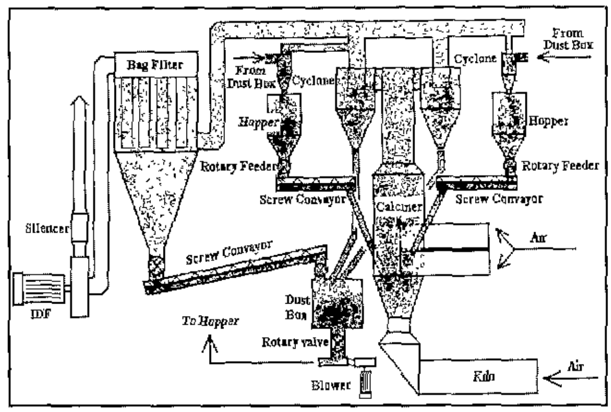


Fig. 3. Schematic diagram experimental apparatus of the cold model of TSSC.

III. Experiments of Cold Model

1. Experimental Apparatus

The cold model calciner made with visual acrylic pipes can be observed fluidization phenomena of raw mix in order to get an optimal condition of the cold model like orthers.[8-10] Its size was 0.50 mø × 3.0 mL × 0.008 mT as shown in Fig. 3. Experimental apparatus was composed of rotary feeder, cyclone, bag filter and induce draft fan (IDF), pneumatic conveyor, and hopper.

2. Method of Experiments

Using experimental apparatus of fig. 3, changed feeding rates, feeding points of raw mix and the type of air entrance were changed to get optimal conditions. For the optimal conditions following results were carried out.

1) A concentration degree of raw mix in cross sectional area of cold model calciner

2) A suitable input rate of raw mix

3) A pressure loss of cold model calciner itself

4) A retention times of raw mix in the cold model calciner

The retention time of raw mix was obtained by a computer simulation test that could solve 3 dimensional analysis of a system.

As shown in Fig. 4 a), the feeding points of raw mix were two sets. One of these set ws below model+3rd air entrance and the other was on 3rd duct. Types of air entrance were divided into 3 ets-fully overlap type(FOT), half overlap type (HOT) and fully separated type (FST)-as shown in Fig. 4 b). The concentration range of raw mix was 0.33 ~ 0.63 kg/m^3(14 ~ 27 kg/min). The major study of these experments was to discover the uniformity of raw mix and its retention time in the model. The sampling points were 14 points of cross sectional area in model as shown in Fig. 5.[11] Thses points had average distance

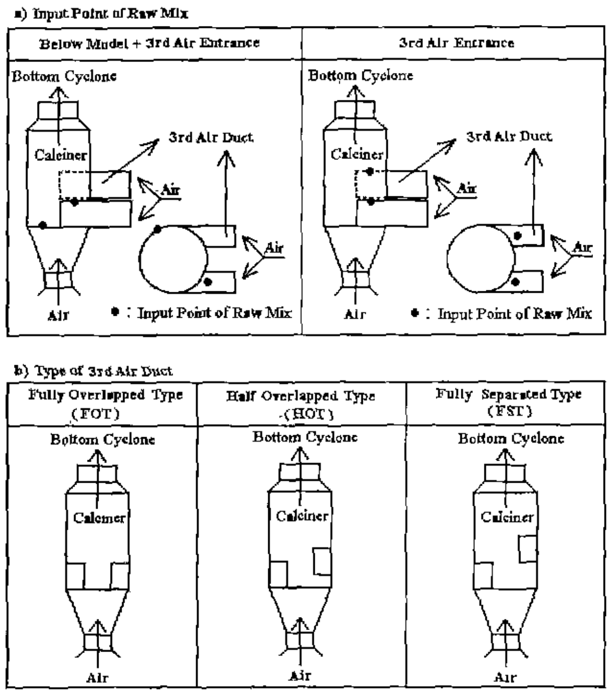


Fig. 4. The feeding points of raw mix and the types of 3rd air entrance in the cold model calciner.

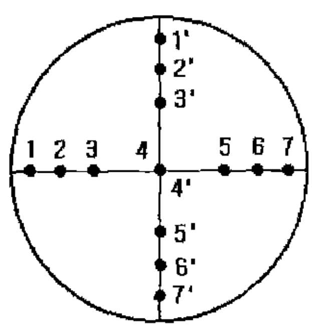


Fig. 5. the sampling points of raw mix in cross sectional area fo cold model calciner.

6 cm each other.

After the velocity of a rising air measured, the sampling of raw mix was gotten by suction of its same velocity in cross sectional area of cold model. The pressure loss was measured by difference between bottom and top of cold model.

3. Results of Cold Model Calciner Experiments

These experimental results is shown in Table 1 when experimental factor was changed the feeding rate, input point of raw mix and type of air entrance. The concentration range of raw mix of the FST was the most uniform among the three types of 3rd air duct.

When a raw mix was fed into the FOT, the opposite side of the air entrance was severely more raw mix than the air input side, because the parallel cooler air input gathers the opposite side. So, the opposite side has coating of raw mix. And the HOT was almost same results with the FOT, because turbulence region of air was not enough.

Especially, when the point of raw mix was below model +air entrance the concentration was very uniform because the turbulence flow of air in the FST was enough. Owing to these phenomena, retention time of raw mix was increased very much. But raw mix was fed into only on 3rd air duct, the concentration range was not uniform. It is considered that the raw mix flowed fast up with 3rd air because the raw mix containing only 3rd air was not mixed well with the ups and the downs air of 3rd air. After all the ups air was shortening retention time of raw mix and resulting in not good for the concentration of raw mix in cross sectional area in cold model calciner.

The pressure loss of cold model is shown in Table 2. According to Table 2 the pressure loss increased with raw mix.

The retention time of raw mix and the pressure loss of cold model were calculated by computer simulation as shown in Table 3. The FST was advantageous for the

Table 2. The Pressure Loss of Cold Model (unit: mmAq)

Feeding Rates (kg/m^3)	Input Points of Raw Mix	Types of Air Entrance		
		FOT	HOT	FST
0.33	Air Entrance	35	44	43
	Below Model+Air Entrance	42	45	45
0.43	Air Entrance	42	44	45
	Below Model+Air Entrance	42	48	56
0.63	Air Entrance	52	50	53
	Below Model+Air Entrance	46	48	61

Table 1. The Concentration of Raw Mix in Cross Sectional Area in Cold Model Calciner (unit: kg/m^3)

Feeding Rates (kg/m^3)	Input Points of Raw Mix	Types of Air Entrance		
		FOT	HOT	FST
0.33	Air Entrance	0.06~0.41(0.102)	0.02~0.68(0.177)	0.04~0.78(0.135)
	Below Model+Air Entrance	0.06~0.70(0.162)	0.02~0.51(0.136)	0.04~0.20(0.068)
0.43	Cooler Air Entrance	0.04~0.72(0.189)	0.02~0.70(0.198)	0.06~0.54(0.118)
	Below Model+Air Entrance	0.08~1.18(0.278)	0.06~0.86(0.219)	0.07~0.42(0.108)
0.63	Air Entrance	0.03~1.07(0.264)	0.01~0.74(0.239)	0.07~0.59(0.135)
	Below Model+Air Entrance	0.11~1.13(0.286)	0.10~0.89(0.250)	0.08~0.48(0.156)

Notes ( ): Standard deviation. Experiment condition: the air velocities of air entrance and throat are 15 and 20 m/s, respectively.

Table 3. The Retention time of Raw Mix and the Pressure Loss Calculated by Computer Simulation

Types of Cooler Air Entrance / Items	FOT	HOT	FST
Retention Time (sec)	0.40	0.54	0.85
Pressure Loss (mmAq)	45	45	37

retention time and the pressure in Table 2.

According to the results of the experiments, the optimal type of air entrance was the fully separated type, the input position of raw mix was below model+air entrance. The conditions were feeding rate 0.33 kg/m^3, the velocities of air entrance 15 m/s and throat of model 20 m/s.

IV. The Experiments of Pilot Plant

Generally, pilot plant is employed in engineering for two main purposes. The first is as forerunner to a full-sized production plant that is not yet built. The second purpose is to protect big troubles and errors when a scale up process is run without pilot plant. In this case, the scale up factors will be got by the pilot plant experiments. The chef study of pilot plant for TSSC is to select a stable operating condition and to predict any troubles under the good performance.

1. The Pilot Plant of TSSC

The pilot plant was designed and constructed according to the results of cold model experiments. Its designed feeding rates of raw mix was 15 t/h with preheater of 5 stages cyclones connected to existent plant of capacity 1850t/d as shown in Fig. 6, like dual combustion & denitration precalciner(DD) process.[12] A raw mix and a coal were fed by pneumatic method using a precise constant feeding weigher, respectively. It was easy to control the pilot plant by computer system in the control room.

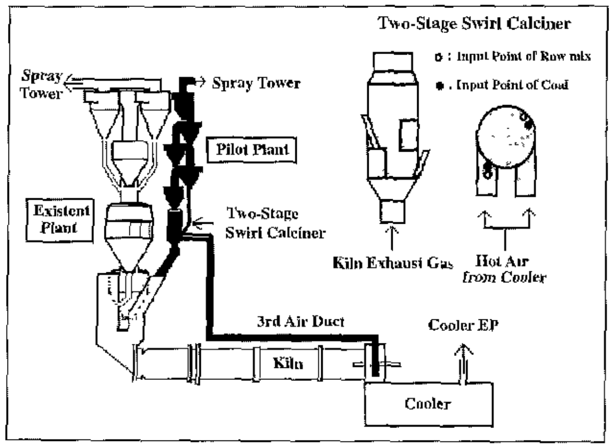


Fig. 6. The schematic diagram of pilot plant.

2. Results and Discussion of Pilot Plant Experiments

The experiments were carried out in order to study an optimal operation and scale up factors. The optimal operation studies were as follows;

1) A proper decarbonation of raw mix and a combustion rates of coal,

2) A operating condition of pilot plant, especially its calciner and preheater,

Table 5. Revamping the Cross Sectional Area of Tertiary Ducts

Items	1st Revamping	2nd Revamping	3rd Revamping	4th Revamping
Input Velocity of 3rd Air (m/s)	11	39	21	20
Gas Temp. of Bottom Cyclone Outlet (°C)	850	810-865	810-865	840-860
O_2 in Gas of Bottom Cyclone Outlet (%)	7.0	2.0-4.0	5.0	3.0-4.0
Kiln Exhaust Gas Temp. (°C)	795	800-850	793	780-800
O_2 Con. in Kiln Exhaust Gas (%)	8.4	3.0-5.0	4.5	3.0-4.0
3rd air Temp. (°C)	650-700	650-700	650-700	550-650
Decarbonation Rates of Raw Mix (%)	87.2	50.2-75.3	65.0-85.5	82.0-95.0
Problems and Causes	-Cause clogging of raw mix in 3rd duct; Low 3rd air velocity -High O_2% in Kiln exhaust gas; Leakage air input	-Low decarbonation; High 3rd air velocity, Performance loss of 2-stage swirl gas flow	-Chute clogging of 2-stage cyclone; By coating of bottom cyclone inlet, calciner exhaust gas flows to 2-stage cyclone chute	No Problems
Revamping	-Reducing cross sectional area of 3rd duct -Kiln inlet sealing	-Magnifying cross sectional area of 3rd duct	-Removing coating -Magnifying cross sectional area of chute	None

3) A input velocity of hot air from cooler and kiln exhaust gas

4) A suitable thermal load of its calciner

For the scale up factors ;

1) Its calciner characteristics for feeding rates of raw mix

2) Its calciner characteristics for feeding rates of coal

3) Its calciner characteristics for a gas velocity of its calciner inner body

2.1. Results for an Operating Condition of Pilot Plant

The main purpose of an operating condition test was to improve problems when a scale-up plant was operated someday. And then a good calciner was finally to born through these experiments.

In these experiments, hot raw mix was clogged in the 3rd air duct and the chutes of 2-stage cyclone. And hot raw mix containing the unburned coal was direct falling to kiln rising duct. Revamping the cross sectional area of 3rd air ducts and the chutes of 2-stage cyclone improved these problems as shown in Table 5. From Table 5, it was known that the adequate velocity of 3rd air from cooler has a very important role to decide the performance of pilot plant. When its velocity was low, low conveying ability of 3rd air often occurred clogging in tertiary duct of pilot plant. The characteristic of 2-stage swirl gas flow in claciner was missed when its velocity was high. Retention time was decreased, heat exchange efficiency was low between raw mix and hot gas.

Finally, the optimal operating conditions were shown in Table 6. And heat balance was shown in Table 7.

Table 6. The Optimal Operating Conditions of Pilot Plant

Specification			Optimal Operating Conditions
Items	Target	Practice	
Output of Calciner volume (kg/m^3-hr)	Over 430	450	1) Feeding rate of raw mix : 10 (T/hr)
Decarboation Rate of Raw Mix (%)	Over 85	88.5	2) Cooler air velocity : 20 ~ 25 (m/s)
			3) Kiln throat velocity : 27 ~ 30 (m/s)
			4) feeding rate of coal in cal. : 50 ~ 60 (%)

Table 7. Heat Balance of Pilot Plant Under Optimal Condition (unit: kcal/kg-clinker)

Input Heat		Output Heat	
1. Sensible heat of raw mix	9.6	1. Preheater exhaust gas losses	211.0
2. Sensible heat of coal	0.9	2. Losses with dust of exhaust gas	5.1
3. Sensible heat of fresh air	2.4	3. Losses with hot raw mix	199.5
4. Sensible heat of kiln exhaust gas	223.3	4. Evaporation of water of raw mix	0.1
5. Sensible heat of cooler air	93.4	5. Decomposition of kaolin	12.3
6. Combustion heat of coal	620.2	6. Decarbonation heat of raw mix	418.0
7.		7. Losses due to radiation, convection and rest	103.9
Sum	950.0	Sum	950.0

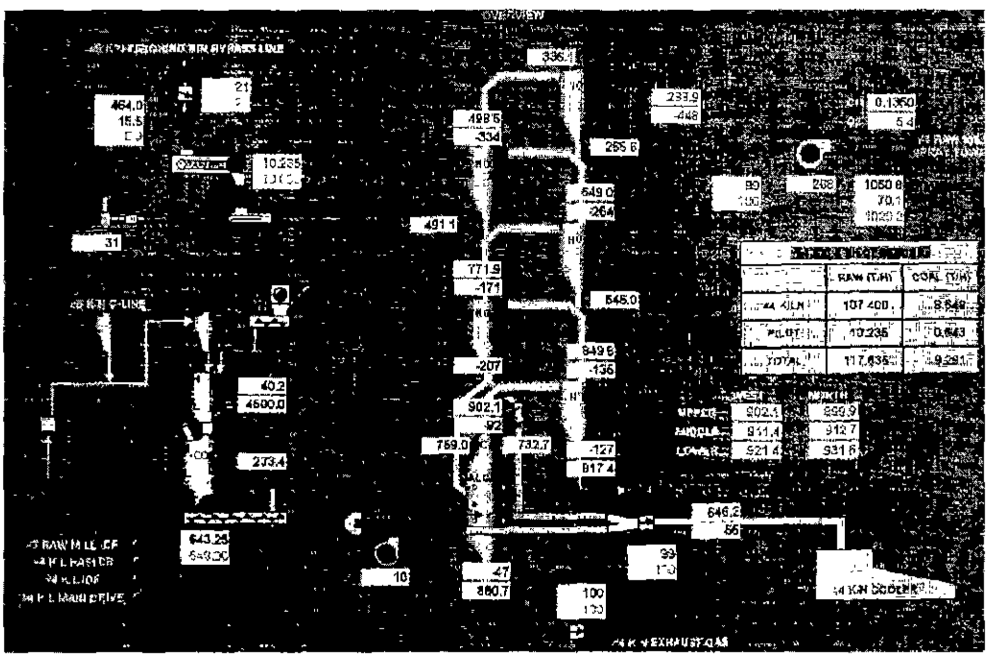
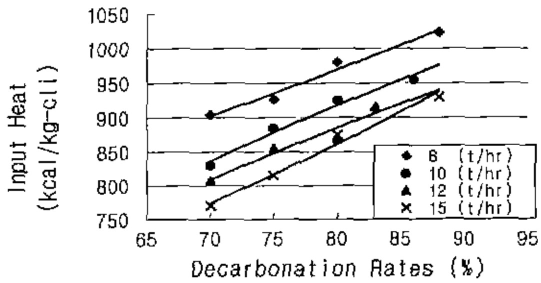
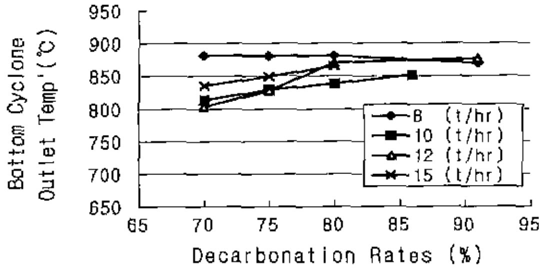


Fig. 7. The overview of pilot plant in control room under operating.



a) The relationship between decabonation rates and input heats



b) The relationship between decabonation rates and temperatures of bottom cyclone outlet.

Fig. 8. According to the change of feeding rates, the relation of decabonated rates, input heat and temperature of a bottom cyclone outlet.

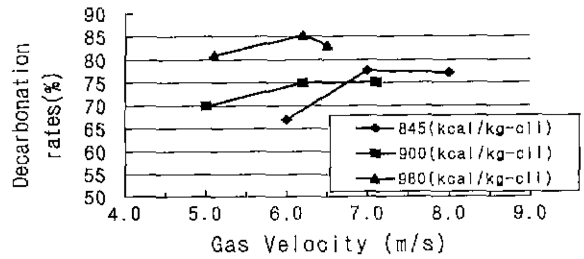


Fig. 9. The relation between decarbonation rates and gas velocity in TSSC.

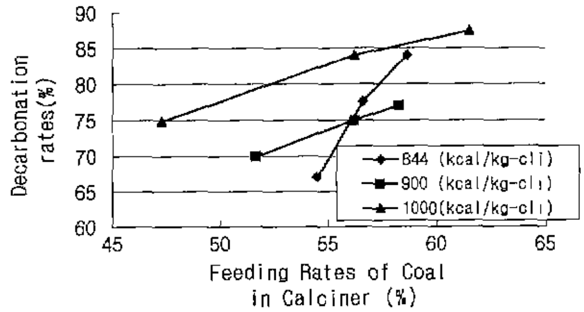


Fig. 10. The relation between feeing rate of coal and decarbonation rate of raw mix.

Fig. 7 shows an example of optimal operation condition as a computer monitor figures in a control room.

2.2. Experiment for Scale Up Factors

1) The performance of TSSC as increasing feed rates of raw mix

The feed rate of raw mix was one of the important factors for determining calciner volume capacities with a proper decarbonation rate. The feed rates fluctuated in range 8~15 t/hr in this experiment, and then an optimal feed rate was decided with a decarbonation rate as shown in Fig. 8.

According to Fig. 8, The input heat is strongly dependent on the feed rates. But when raw mix had over 90% decarbonation rate it is possible to build up the sticky raw mix in cyclone. According to this result, it was considered that the capacity of TSSC was raw mix 10 t/hr.

2) The characteristics of a gas velocity in TSSC

The diameter of calciner is one of the most important factors too like feeding rate of raw mix, because gas velocity in calciner affects retention time of raw mix and heat transfer between raw mix and hot gas in calciner. Fig. 9 is shown in decarbonation rate of raw mix fluctuated a gas velocity in calciner.

As shown in Fig. 9, when its velocity was 6~7 m/s in TSSC it was possible to get a high decarbonation rate of raw mix, but overheats introduced a high gas volume, a fast gas velocity in it and coating on the wall of it. So, raw mix was decreased decabonation rate with abnormal heat transfer phenomena and low retention time in it.

3) The characteristics for feed rate of coal input in TSSC

This experiment shows the fluctuation of decarbonation rates for feeding rate of coal input in TSSC as shown in Fig. 10. The more feeding rate of coal, the more decarbonation rates of raw mix. According to this result, the proper feeding rate of coal was below 60% among total input heat.

3. The Comparison Experiment with Simulation Test of Pilot Plant

One of two main target of simulation test is to research difficult characteristics unknown in TSSC. The other is to predict the possibility of industrial scale through data gotten by the pilot plant experiments. The results of the pilot plant experiments and the simulation test are shown in Table 8 and Fig. 10. According to Table 8, the TSSC performance was good because coal combustion rate and

Table 8. Compare Pilot Plant Experiment with Simulation Test of TSSC

Items	Simulation Results	Pilot Plant Results
Feeding Rate of Raw Mix (t/hr)	10.0	10.0
Input Heat (kacl/kg-cli)	950	950
Decarbonation rate Raw Mix (%)	83.2	86.3
Combustion rate of Coal (%)	95.2	-
Calciner Outlet Temperature (℃)	885	867
Gas Velocity in Calciner (ms)	6.3	6.1
Retention time of Raw Mix (sec)	2.4	-

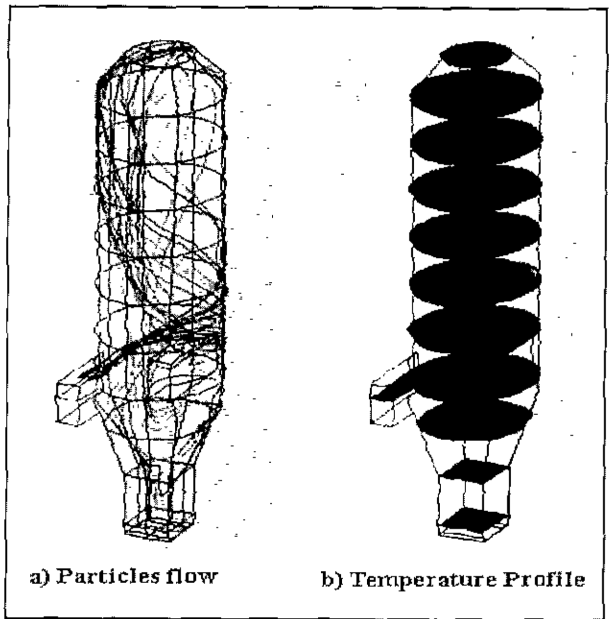


Fig. 11. The results of raw mix flow and its simulation test.

retention time were 95%, 3~4 sec respectively. These are almost same performance industrial scale plants. The particles of raw mix had two sage swirl flow of low part in calciner as shown in Fig. 10. Therefore, the particles of raw mix had long retention time by two sage swirl flow in the TSSC, resulting in excellent mixing effect between raw mix and hot gas. Also claciner outlet temperature was low with an excellent mixing effect. The pilot plant had no problems with coating because of uniform gas temperature like simulation test in Fig. 11.

V. Conclusions

The optimal type of TSSC was selected by the cold model test and the pilot plant experiments improved defects on heat losses. Pilot plant was suitably improved in order to operate with keeping an excellent performance. The performance of pilot plant was 88.5% decabonation rate and 950 kcal/kg-cli when the feeding rate was 10 t/hr. The pilot plant helped to succeed scale up over 3000 t-cli/d.

References

1. H. M. Garett, "Precalciners Today-A Review," *J. Rock Prod.*, **1985**(7), 39-61 (1985).
2. L. Kwech, "Precalcining in the Cement Industry-the state of the art," *J. Z. K. G.*, **39**(7), 351-366 (1986).
3. K.E.Peray, The Rotary Cement Kiln, pp.6-16. Chemical Publishing Co. Inc., 2nd Ed., (1986).
4. S. Chritiansen and G. M. Madsen, "Precalciners for Cement Kiln: Development and Application," *10th International Cement Industry Seminar*, 100-111 (1974).
5. J. Warshawsky, T. R. Lawall, and A. J. Kreisberg, "Enhancement of Flash Calcination through Recirculation," *J. Z. K. G.*, **39**(3), 119-121 (1986).
6. H. Hatano, Y. Hirota and A. Sasaki, "Mitsubishi Cement Introduces Energy-Saving Clinker System," *J. Rock Prod.*, **1983**(6), 48-C 48-H (1983)
7. M. Champonnois, "Increased Production and Energy Savings with Precalcination," *J. World Cement*, **1984**(Jan./Feb.) 8-12 (1984).
8. T. Nishida, J. Takabayashi and S. Nakano, "Suspension Preheater with KSV Calcinator," Kawasaki Research Report, **50**, 45-51 (1980).
9. Ch. Mostofizadeh, E. Kriegel and W. Kreft, "Method of Visible Revealing Three-Dimensional Flow Phenomena in a Precalcining model," *J. Z. K. G.*, **33**(3), 112-115 (1980).
10. S. Hundelbol, "Retention Time of Particles in Calciners of Cement Industry," *J. ZKG*, **40**(8), 422-425 (1987).
11. K. E. Peray, Cement Manufacturers Handbook, pp. 270-272, Chemical Publishing Co. Inc., 2nd Ed, 1979.
12. H. Ito, T. Maruyama and M. Morita, "New Cement Calcining Method DD Process," Kobe Steel Industrial Research Report, **28**(3), 18-23 (1978)