**Brief introduction of cement clinker production process**

The present cement clinker production process is derived from a real cement indutry in Shandong, China. For the convenience of description, a brief flowchart of cement clinker production that includes four main apparatuses (preheater, calciner, rotary kiln and grate cooler) is depicted in Fig. 1. The four apparatuses represent four stages of the process, i.e. preheating, calcination, sintering and cooling. At first, raw materials that contains CaCO3, SiO2, Al2O3 and Fe2O3 is fed to the multistage preheater (mostly five stages). During the vertical falling process, the material is preheated through countercurrent hot flue gas. After that, a calciner is utilized to precalcine the materials in the temperature of 800 ℃. According to the field process knowledge, the residence time of materials pass through preheater and stay in calciner are both about 2 min. Coming out the precalciner, materials then enter the rotary kiln for long-time sintering in temperature about 1300 ℃. The liquid phase of C2S, C3A, and C4AF in the material absorb f-CaO to form the major component (C3S) of cement clinker. The sintering process continues about 30 min. In the end, the hot clinker is discharged to a grate cooler and cooled by the air that comes from cooling fans. The residence time is about 30 min. In addition, the heat is recycled to the kiln and calciner, which forms a gas flow that runs across the process in the opposite direction. For the clinker quality indicator, cement clinker sample is collected every two hours from the discharge end of the grate cooler and the f-CaO content is confirmed offline in laboratory.

In practice, the f-CaO content in the clinker to a large extent affects the quality of the cement. However, the low sampling-rate of cement clinker for analysis fails to meet the requirement of quality monitoring and process control. Therefore, it is necessary to build a virtual sensor based on the historical process data and assay value for online f-CaO content prediction.



Fig. Brief flowchart of cement clinker production process

Table 1 Descriptions of variables in the cement clinker production process

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| Tag | Description | Unit |
| FAR7310F01 | Feedback of pulverized coal feeding at kiln head | m3/min |
| PS5701P01 | Negative pressure of kiln head cover | MPa |
| P5703P01 | Outlet pressure of fan 1 | MPa |
| P5704P02 | Pressure in grate 1 | MPa |
| P5704P01 | Outlet pressure of fan 2 | MPa |
| P5705P01 | Outlet pressure of fan 3 | MPa |
| P5706P01 | Outlet pressure of fan 4 | MPa |
| P5707P01 | Outlet pressure of fan 5 | MPa |
| P5708P01 | Outlet pressure of fan 6 | MPa |
| P5709P01 | Outlet pressure of fan 7 | MPa |
| P5710P01 | Outlet pressure of fan 8 | MPa |
| T5702T01 | Grate1 temperature | ℃ |
| T5702T03 | Grate2 temperature | ℃ |
| T5702T05 | AR5710 current | A |
| T5702T07 | Grate4 temperature | ℃ |
| T57T01 | Smoke inlet temperature of kiln head | ℃ |
| AR5703\_CUN | Fan 1 current | A |
| AR5704\_CUN | Fan 2 current | A |
| AR5705\_CUN | Fan 3 current | A |
| AR5710\_CUN | Fan 9 current | A |
| B5750T2 | The outlet temperature of grate cooler T2 | ℃ |
| B5750T3 | The outlet temperature of grate cooler T3 | ℃ |
| BLJYYB1\_I | Grate cooler hydraulic pressure pump 1 current | A |
| BLJYYB2\_I | Grate cooler hydraulic pressure pump 2 current | A |
| BLJYYB3\_I | Grate cooler hydraulic pressure pump 3 current | A |
| BLJYYB4\_I | Grate cooler hydraulic pressure pump 4 current | A |
| STROKE2 | Feedback value of the second grate speed | m/s |
| F5203F01 | Quantity of raw material into kiln | m3/min |
| FAR7311F01 | Feedback of pulverized coal feeding at kiln tail | m3/min |
| M54015SI | High temperature fan frequency feedback | Hz |
| P5401P01 | Outlet pressure of high temperature fan | MPa |
| M5204F01 | Rotor weighing rate | m/s |
| M5204FH | Rotor weighing | kg |
| M5204I | Rotor current | A |
| M5204SI | Rotor speed feedback | m/s |
| M5601\_CUN | Kiln owner motor armature current | A |
| M5601\_ZS | Kiln owner motor speed | m/s |
| O5101P02 | Negative pressure at calciner outlet | MPa |
| Z5213Z01 | Electric distributing valve opening | % |
| O5101T02 | Calciner outlet temperature | ℃ |
| C1AP01 | C1A outlet pressure | MPa |
| C1AT01 | C1A outlet temperature | ℃ |
| C1BP01 | C1B outlet pressure | MPa |
| C1BT01 | C1B outlet temperature | ℃ |
| C2AP01 | C2A outlet pressure | MPa |
| C2AT01 | C2A outlet temperature | ℃ |
| C2BP01 | C2B outlet pressure | MPa |
| C2BT01 | C2B outlet temperature | ℃ |
| C3AP01 | C3A outlet pressure | MPa |
| C3AT01 | C3A outlet temperature | ℃ |
| C3BP01 | C3B outlet pressure | MPa |
| C3BT01 | C3B outlet temperature | ℃ |
| C4AP01 | C4A outlet pressure | MPa |
| C4AT01 | C4A outlet temperature | ℃ |
| C4BP01 | C4B outlet pressure | MPa |
| C4BT01 | C4B outlet temperature | ℃ |
| C5AP01 | C5A outlet pressure | MPa |
| C5AT01 | C5A outlet temperature | ℃ |
| C5BP01 | C5B outlet pressure | MPa |
| C5BT01 | C5B outlet temperature | ℃ |
| O5101T01 | Preheater outlet temperature | ℃ |
| OT5101T05 | Temperature of the preheater | ℃ |
| C5BT02 | Three time air temperature | ℃ |
| O5101P04 | Three times air pressure | MPa |
| M54015RI | High temperature fan frequency conversion current | ℃ |
| M5401\_CUN | High temperature fan current | ℃ |
| PDRIVER1 | Pushing pressure below the grate 1 | MPa |
| PDRIVER2 | Pushing pressure below the grate 2 | MPa |
| PDRIVER3 | Pushing pressure below the grate 3 | MPa |
| PDRIVER4 | Pushing pressure below the grate 4 | MPa |
| T5701T01 | Temperature of kiln head cover | ℃ |
| OP5101P05 | Preheater negative pressure | MPa |
| C5AP02 | Negative pressure in preheater C5A cone | MPa |
| C5BP02 | Negative pressure in preheater C5B cone | MPa |
| C4AP02 | Negative pressure in preheater C4A cone | MPa |
| C4BP02 | Negative pressure in preheater C4B cone | MPa |
| C11BP01 | Negative pressure in preheater C11B cone | MPa |
| C12BP01 | Negative pressure in preheater C12B cone | MPa |
| C11AP01 | Negative pressure in preheater C11A cone | MPa |
| C12AP01 | Negative pressure in preheater C11A cone | MPa |
| C5AT02 | C5A blanking tube temperature | ℃ |
| O5101T04 | C5B blanking tube temperature | ℃ |
| P7512P01 | Coal feed pressure at kiln head | MPa |
| P7513P01 | Coal feed pressure at kiln end | MPa |
| AR5760\_CU | AR5703 current | A |
| M5716\_CUN | M5716 current | A |
| M5713e1\_CU | Zipper electromechanical flow 2 | m3/min |
| M5713e2\_CU | Zipper electromechanical flow 1 | m3/min |
| M5702b14\_C | M5702b14 current | A |
| M5706\_CUN | Grate cooler fan 4 current | A |
| M5707\_CUN | Grate cooler fan 3 current | A |
| M5708\_CUN | Grate cooler fan 2 current | A |
| M5709\_CUN | Grate cooler fan 1 current | A |
| C1P01 | C1 outlet pressure | MPa |
| C1T01 | C1 outlet temperature | ℃ |
| C5P02 | Preheater C5 cone pressure | MPa |
| M5210\_CUN | Bucket lift current into kiln | A |
| T5101T05H | Infrared temperature of high temp. smoke chamber | ℃ |
| M5704\_SD | M5704 fan frequency conversion feedback | Hz |
| M5705\_SD | M5705 fan frequency conversion feedback | Hz |
| M5710\_SD | M5710 fan frequency conversion feedback | Hz |
| Z5706Z01 | 5706 Valve opening feedback | % |
| Z5707Z01 | 5707 Valve opening feedback | % |
| Z5708Z01 | 5708 Valve opening feedback | % |