# 4 Burning and Cooling

**The basic cement kiln system comprises a preheater in which feed material is prepared by heat exchange with hot exhaust gas, a fired rotary kiln in which the clinkering reactions occur, and a cooler in which the hot clinker exchanges heat with ambient combustion air.**

Kiln feed is subject to successive reactions as its temperature increases (Lea; The Chemistry of Cement and Concrete):

| | |
|---|---|
| 100°C | Evaporation of free water |
| > 500° | Evolution of combined water |
| > 900° | $CaCO_3 \rightarrow CaO + CO_2$ (this reaction is called calcination) |
| > 900° | Reactions between CaO and $Al_2O_3$, $Fe_2O_3$ and $SiO_2$ |
| > 1200° | Liquid formation |
| > 1280° | Formation of $C_3S$ and complete reaction of CaO |

Spahn (ZKG; 7/2004, pg 72) reviews the chemistry and mineralogy of clinker formation and concludes:

- The dimensions of alite ($C_3S$) crystals are largely determined by the particle size of limestone/marl in kiln feed.
- The size and distribution of $SiO_2$ particles in raw meal have a decisive influence on alite and belite ($C_2S$) formation.
- The Bogue calculations for cement compounds assume chemical equilibrium which, of course, is not realised under kiln conditions.

Cyclone preheater kilns have developed rapidly since the 1950s and have been virtually the only type of cement kiln installed over the past 30 years. The first units were 4-stage preheaters. Relative to the previous technology of long wet and dry kilns (Sec 11), air suspension in the cyclone system greatly increased the efficiency of heat exchange between hot gas and feed material over the temperature range of ambient to about 800°C and also allowed significant calcination to occur before the hot meal entered the rotary kiln. Kiln gas is cooled from, typically, 1100°C to 350°C. The feed material is preheated by what appears to be counter-current flow but is, in fact, a series of parallel flow processes in each successive duct and cyclone (see Figure 4.1). Heat transfer in each cyclone stage is completed in less than 1 second.

Unfortunately it is now almost universal to count cyclone stages in order of material flow with the first stage at the top. With the proliferation of preheaters having other than 4 stages, it is believed that counting in order of gas flow from the bottom would allow more meaningful correlation from kiln to kiln.

Precalcination is the addition of a second firing point and combustion chamber at the base of the preheater with separate ducting of hot air from the clinker cooler through a 'tertiary' air duct. This system allows an approximate doubling of production from a given rotary kiln size.

Single string (precalcining) preheaters are available up to about 6,000t/day (with up to 10Mϕ cyclones) and larger kilns now have two- and even three- strings allowing unit capacities in excess of 10,000t/day. Heat recovery has also been improved, where heat is not required for drying raw materials, by using 5-and 6-stages of cyclones, and redesign of cyclone vessels has allowed pressure drop to be reduced without loss of efficiency (Hose & Bauer; ICR; 9/1993, pg 55). Exit gas temperatures, static pressures, and specific fuel consumptions for modern precalciner kilns are typically:

| | | | |
|---|---|---|---|
| 6-stage | 260° | 550mm $H_2O$ | 750kcal/kg (NCV) |
| 5-stage | 300° | 450mm | 775 |
| 4-stage | 350° | 350mm | 800 |

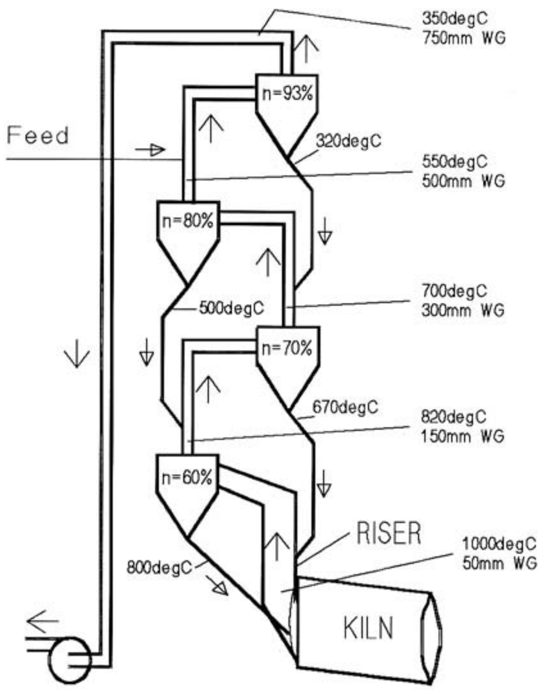
Temperatures are 20-30° lower without precalciners and older systems are usually 20-30° higher than the above. Early 4-stage cyclone preheater kilns commonly have pressure drops of 700-800mm (higher if ID fans have been upgraded without modifying cyclones and ducts) and specific fuel consumptions of 850-900kcal/kg (Figure 4.1). Large modern kilns are designed to 700kcal/kg and below.

In cyclone preheater kilns without precalciners, the feed is 20-40% calcined at the kiln inlet. Riser firing increases this, and addition of a precalciner allows up to 90% calcination before the meal enters the kiln. Although calcination could be completed in air suspension, this must be avoided as the endothermic dissociation of $CaCO_3$, which buffers material temperature at 800-850°C, is followed by exothermic formation of cement compounds and an uncontrolled temperature rise in the preheater could lead to catastrophic plugging.

The major cyclone preheater configurations are shown in Figure 4.2. Other terms frequently encountered include:
**NSP (New Suspension Preheater)** – Precalciner technology which was developed in Japan in the early 1970s.
**AT (Air Through)** – Precalciner or riser firing using combustion air drawn through the kiln.
**AS (Air Separate)** – Precalciner using tertiary air.
**ILC (In-Line Calciner)** – AS precalciner in which kiln exhaust and tertiary air are premixed before entering the calciner vessel.
**SLC (Separate Line Calciner)** – AS precalciner vessel in parallel with the kiln riser and fed only with gas from the tertiary duct.
**SF (Suspension Preheater with Flash Furnace)** – IHI precalciner design which is an AS/ILC system.
**RSP (Reinforced Suspension Preheater)** – Onoda design of precalciner vessel which is an AS/SLC system.
**MFC (Mitsubishi Fluidised-Bed Calciner)**

Recent developments in burning technology are reviewed by Gasser & Hasler (CI; 3/2003, pg 34 & CI; 6/2003, pg 98).

*Figure 4.1: Cyclone Preheater Typical Temperature and Pressure Profile and Cyclone Efficiencies*




## 4.1 Kiln Burning

Kiln operation is monitored by:

- Production rate, tonnes/hour clinker
- Operating hours (feed-on)
- Involuntary downtime hours
- Total fuel rate, tonnes/hour
- Proportion of fuel to precalciner/riser, %
- Specific heat consumption, kcal/kg
- Secondary air temperature, °C
- Kiln feed-end temperature, °C
- Preheater exhaust gas temperature, °C
- ID fan draft, mm $H_2O$
- Kiln feed-end $O_2$, %
- Downcomer $O_2$, %
- Kiln feed-end material – LoI, %
  – $SO_3$, %
- Kiln drive power, kW

There are, of course, numerous other process parameters which should be logged, both to observe trends which may indicate problems, and to provide necessary mean data for process analyses such as heat balances.

Other kiln performance factors include:

Primary air flow and tip velocity, M/sec
Specific kiln volume loading, %
Specific heat loading of burning zone, kcal/H per $M^2$ of effective burning zone cross-section area.
Cooler air, $NM^3$/H per $M^2$ grate area
Cooler air, $NM^3$/kg clinker
Cooler t clinker/day/$M^2$ grate area
Temperature, pressure and oxygen profile of preheater

Modern kiln operation and maintenance should aim for at least 90% run factor (7884 hours/year), not more than 3% lost time per month (22 hours) between planned outages, and continuous operations exceeding 100days (Buzzi; WC; 11/2003, pg 92).

Note *primary air* is air entering through the main burner, *secondary air* is hot air recovered from the clinker cooler to the kiln, and *tertiary air* is cooler air ducted to the precalciner.

Excessive heat consumption should be investigated immediately and may be indicative of incorrect feed-rate measurement or feed chemistry, fuel or burner abnormality, insufficient or excess oxygen, air in-leakage at kiln seals or preheater ports, low temperature of secondary air, and distortion or collapse of preheater splash-plates.

Clinker free-lime should be as high as possible to avoid the inefficiency of hard burning, but safely below the onset of mortar expansion; typically between 0.5% and 2%. Having established the target, free-lime should, if possible, be maintained within a range of about 0.5%. Variation of kiln feed rate or composition makes this control more difficult. It should be appreciated that over-burning – a common solution to variable kiln feed chemistry or operator circumspection – wastes fuel, stresses refractories, increases the power required for cement milling, and reduces cement strength. Sasaki & Ueda (ICR; 8/1989, pg 55) found a 14kcal/kg heat penalty for each 0.1% reduction in free-lime though other references vary.

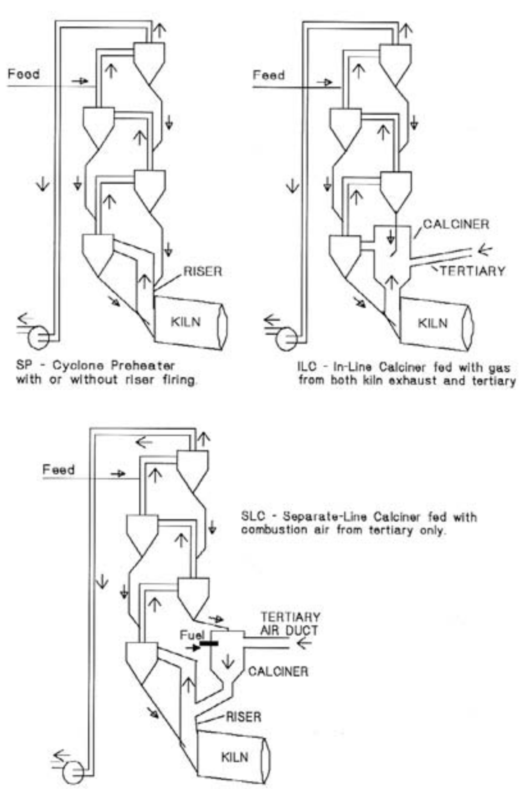
Obviously, if the clinker reactions can be achieved at reduced temperature there will be energy savings. Fluxes, which reduce melting point, and mineralizers, which increase reactivity by incorporation in a solid phase, are reviewed by Hills (ICR; 9/2002, pg 79) and by Kerton (ICR; 9/2003, pg 73). The addition of up to 0.5% $CaF_2$ in kiln feed has been found to reduce specific fuel consumption by 25-60kcal/kg clinker (Clark; ICR; 5/2001, pg 34) while higher levels can cause preheater build-ups and cement retardation.

A convenient supplement for free-lime measurement is the more rapid determination of litre-weight. This involves screening a sample of clinker from the cooler discharge to approximately +5/-12mm and weighing a standard 1 litre volume. Litre-weight is typically 1100-1300g/L (varying inversely with free-lime) but the target range should be determined with a minimum equivalent to the established free-lime upper limit. A surrogate for litre-weight can be obtained on-line by passing a small stream of screened clinker in front of a gamma radiation source and measuring its attenuation.

Secondary air temperature should be as high as possible in order to recover the maximum heat; usually 800-1000°C. Maximising secondary air temperature involves optimising clinker bed depth and cooling air distribution to the recouperating zone. A common misconception is that increasing the air flow to the hot end of the cooler will cool the clinker rapidly and recover more useful heat. In fact, contact time between cooling air and hot clinker is reduced with consequent lowering of secondary air temperature. Good clinker granulation is essential as fine, sandy clinker results in uneven air distribution and, commonly, a red river of hot clinker extending well down the cooler. Good granulation requires a sufficient liquid phase, typically 23-25%, with high surface tension (Timaschev; Proc International Congress on the Chemistry of Cement; Paris, 1980). High alumina ratio and low alkali increase surface tension of the melt while a low burning zone temperature will result in increased liquid viscosity and small crystal size (Sec 7.3). Secondary air temperature has been difficult to measure unless there is a hot-gas take off from the hood for tertiary or coal mill air. Recently, however, an acoustic pyrometer has been successfully introduced to the cement industry; this is a low cost and low maintenance instrument which integrates the temperature across the hood and is not affected by entrained dust concentration (ICR; 6/2002, pg 49). The availability of reliable secondary air temperature offers potential for cooler grate speed control to be, at least partly, directed to maintaining constant secondary air temperature rather than the less important function of maximising clinker cooling. Fluctuating secondary air temperature will inevitably cause cycling of kiln operation.

Precalciner kilns are designed to maximize the heat input to the calciner and, typically, 60% of fuel is fed to the calciner while 40% is burned in the kiln. This serves to minimize the size of the rotary kiln and its heat loading; it does not reduce specific fuel consumption. It has been widely found that preheater kilns without precalciner vessels can also benefit from feeding 10-20% of total fuel to the kiln riser. Kiln operation is noticeably more stable and brick life is extended. This is also a useful means of consuming low grade fuels or waste

*Figure 4.2: Major Configurations of Cyclone Preheater Kilns*



materials. The limit to fuel injection at the riser depends upon its size and consequent gas retention time, and upon fuel-air mixing characteristics; over-fuelling results in preheater operating problems, an increase in exit gas temperature, and CO in the exhaust.

All kilns, by definition, have a capacity limitation or ‘bottleneck’ (Sec 14.4) which is, most commonly, the ID fan. Increasing fan capacity is always possible but may lead to excessive pressure drop or inadequate dust collection. An alternative which may well be cost effective, especially for short-term production increase to meet peak market demand, is oxygen enrichment.

Traditionally this involved oxygen enrichment to the kiln burner but the difficulty of maintaining the lance and the danger of overheating refractory largely outweighed any benefits. More recently, injection of oxygen to the tertiary duct of precalciner kilns has been proposed (Tseng & Lohr; ICR; 5/2001, pg 41). This involves a maintenance-free injection port and does not cause refractory stress. A typical addition rate is 2% of total combustion air or 10% of available oxygen, and some 3.5tonnes incremental clinker are obtained per tonne of oxygen. The economics will depend on the cost of cryogenic oxygen or, for more permanent systems, the installation of an on-site Vacuum Swing Adsorption unit which can greatly reduce oxygen cost.

The vortex finders (dip tubes) of lower stage cyclones were for many years prone to collapse and, usually, were not replaced. During the 1990s, a new segmented design in high-temperature alloy became standard (WC; 10/1994, pg 39) and, more recently, a fibre-reinforced monolithic refractory construction is being tested (Gasser & Hasler; CI; 3/2003, pg 34). However, these are still subject to failure and the effectiveness of vortex finders in lower cyclones should be carefully assessed by review of preheater temperature and pressure profile and of specific fuel efficiency both before and after the tubes are removed or fall out; in many cases there is scant justification for reinstallation and the penalties of either distortion or failure far outweigh any trivial margin of efficiency.

For kilns with grate coolers, the burner tip should be in the plane of the kiln nose (hot) or slightly inside the kiln providing it does not suffer damage from falling clinker. The burner should normally be concentric with, and on the axis of, the kiln. Some operators prefer to hold the burner horizontal and even tilted into the load. Such orientation may result in reducing conditions and should be avoided. Clinker produced under reducing conditions causes reduced cement strength and abnormal setting. It should be appreciated that both burner position and tip velocity are intimately related to hood aerodynamics and can not be considered in isolation (see Section 9.3).

Kiln rings are sections of heavy coating, usually in the burning zone, though sometimes also near the back of the kiln, which can grow to restrict both gas and material flow and eventually force shut-down. Conversely, ring collapse causes a flush of unburned material. Ring formation in the burning zone is commonly attributed to operational fluctuations though a low coal ash-fusion temperature or high mix liquid phase will increase the risk (Bhatty; Proc ICS; 1981, pg 110). Early detection is possible with a shell scanner and rapid reaction is essential. Such ring growth may be countered by varying kiln speed or by small movements (10cm) of the burner in and out. Rings at the back of the kiln are usually associated with volatiles cycles, particularly excessive sulphur at the kiln inlet. It is evident, though of little help, that rings are structurally more stable in small diameter kilns. Recurrence merits an investigation of cause(s) (Hamilton; ICR; 12/1997, pg 53).

Certain plants have raw materials which contain significant proportions of hydrocarbons (kerogens), typically up to 3%, or may wish to dispose of oil contaminated soils. If fed conventionally to the top of the preheater, the hydrocarbons will tend to distil at intermediate temperatures and exit with the flue gas – if they do not explode in the EP (Ryzhik; WC; 11/1992, pg 22). To prevent the resulting pollution, which is frequently in the form of a detached plume or blue haze, and to make use of the heat potential, kerogen-containing materials should be injected at above 800°C; usually to a 1-stage preheater with a short kiln if the hydrocarbons are present in the limestone. The high temperature exhaust may then be used for drying or for power cogeneration (Onissi & Munakata; ZKG; 1/1993, pg E7). If the hydrocarbons occur in a minor constituent, this component may be ground separately and fed to the kiln riser. Petroleum coke, or the residual carbon in fly ash used as raw material, being involatile, can be added conventionally with kiln feed and yield useful heat without a polluted exhaust (Borgholm; ZKG; 6/1992, pg 141). Note, however, that some fly ash contains high and variable carbon (1-30%) and, unless pre-blended, can seriously destabilize kiln operation.

## 4.2 Control Systems

Hard wired controls have largely given way to computerized systems. Relay logic for discrete (on/off) control tasks has for many years been handled by programmable logic controllers (PLCs) which also now have capability for analogue control. Distributed control systems (DCSs) have likewise replaced control systems once made up of numerous electronic or pneumatic analogue loop controllers. Recently, personal computers (PCs) have become available as man-machine-interfaces (MMIs or, of course, WMIs) working on both PLC and DCS platforms. The differences between systems lie mainly in their architecture.

**Distributed Control Systems** comprise a proprietary computer and software that performs supervisory control and data acquisition (SCADA), proprietary multi-loop controllers for running the analogue and discrete control alogarithms, proprietary input/output (i/o) modules that interface loop controllers with field devices (eg pressure transmitters, damper operators), and proprietary software running on standard PCs for the MMI.

Almost all DCS vendors (eg Honeywell, Rosemount, Bailey) design redundancy into the SCADA system and the multi-loop controllers which yields very high reliability. DCSs also come with high level programming software which automatically takes care of common programming tasks and greatly facilitates system configuration and maintenance. All major PLC suppliers (AllenBradley, Siemens, GE/Fanuc) offer controllers which interface with DCSs and a common form of DCS employed in cement plants uses integrated multi-loop controllers for analog control with PLCs for discrete control; with some 80% of cement plant control loops being digital. This uses DCS controllers only for the few analog loops which require them while using the less expensive PLCs for discrete control. Such interfaced PLCs continue to be favoured for discrete control due to speed, ease of programming, and reliability.

**Open Distributed Control Systems** comprise SCADA software running on standard PCs, proprietary software running on proprietary PLCs for running analogue or discrete control alogarithms, proprietary i/o modules interfacing PLCs with field devices, and proprietary software running on standard PCs for the MMI.

While a standard PC is used for both MMI and SCADA tasks, compatible software from a single vendor is used. The primary advantage of the PC system is the ease and economy of upgrading speed and memory. PLC hardware costs have halved over the past 10 years and their programming and maintenance have become standardised.

DCS and PC systems have continued to converge and hybrid systems are available which can be easily adapted as plant requirements change (Schenk; WC; 1/2003, pg 31). The trend is to more open systems which facilitate integration of process control into plant and company information systems (Garza et al; CI; 1/2003, pg 51 & 5/2003, pg 38).

**Process Optimisation**
Various expert systems, now usually called 'optimising' systems, are available. More than 75% of the market, however, is held by Linkman (Expert Optimiser Version 4.0) and FLSA's Fuzzy Logic (ECS ProcessExpert Version 4.0) both of which now use neural networks, soft sensors, and model-based control (MPC) technologies. There have been a plethora of one-off, PC-based MPC systems in recent years. Recent developments in process optimisation are reviewed by Haspel (ICR; 3/2003, pg 51). MPC is well established for mill control and gaining credibility for kilns. Overall use, however, is still limited. In 2001, Haspel estimated that only about 15% of worldwide clinker production was subject to expert control (Haspel; ICR; 8/2001, pg 45).

Ultimately, however, these systems require that adequate and reliable instrumentation is in place and that kiln operation is basically stable. Process alarms should be carefully designed and maintained. Critical alarms (eg excess CO in exhaust) should be designed so that cancellation is impossible until the problem is corrected. Interlocks are not uncommonly jumpered (either by hard wiring or by programming) to allow maintenance to cope with a temporary abnormality or for operator convenience; such jumpering must be strictly controlled and frequently reviewed.

## 4.3 Kiln Control

Kiln operation is a complex art of which the principal control variables are:

| | | *Typical Aim* |
|---|---|---|
| 1 | Burning zone temperature (pyrometer or indirectly from kiln drive power or NOx) | 1500°C |
| 2 | Feed-end gas temperature | 1000°C |
| 3 | Feed-end oxygen | 2.0% |

Control is effected by adjustments to kiln feed, fuel rate, and ID fan speed. Whether normal operation is manual or automated, most kilns are still liable to upset periods due to ring building, coating loss, etc and, while every effort should in any case be made to minimize such instability, effective computer control must be able to cope with the situation.

Kiln feed and speed are usually controlled with a fixed linear relationship and unilateral variation of kiln speed should be avoided. However, a given correlation set up at commissioning may no longer be optimum and it is an important process engineering task periodically to validate the operating graph (Clark; WC; 3/1994, pg 43).

Kiln speed should be such that volumetric loading is within the range 7-12% (Section B5.10). Typically cyclone preheater kilns rotate at 2-2.5rpm (50-70cm/sec circumpherential speed) and have material retention times of 20-40mins. Precalciner kilns rotate at 3.5-4.5rpm (80-100cm/sec). Material retention in the preheater is 20-40secs. It has been asserted by Scheubel (ZKG; 12/1989, pg E314) that CaO, upon calcination, is highly reactive but that this reactivity decreases rapidly so that slow heating between 900-1300°C can result in increased heat of formation of cement compounds. Keeping the same kiln retention time with increasing degree of calcination of the material entering the kiln resulted in extending this transition and there is evidence that the introduction since 1998 of short, two-pier, kilns has led to the reduction of material residence time before entering the burning zone from some 15 minutes to 6 minutes with resulting improvement in clinker mineralogy and grindability. Two-pier kilns have length:diameter ratios of 11-12 vs 14-16 for three-pier kilns.

Kilns are frequently operated to the limit of the ID fan. In this case, low oxygen must be corrected by reducing both fuel and feed.

Precalciner kilns burn fuel at the kiln hood using combustion air mainly drawn from the hot end of the (grate) cooler, and in the calciner using combustion air drawn from either the hood or the mid-section of the clinker cooler via a tertiary duct. Most precalciner kilns have dampers in the tertiary duct, and some have fixed or adjustable orifices in the riser, to control relative air flows to the two burners in order to maintain the desired fuel split. Frequently these dampers fail and it is then essential to adjust the fuel flows to the resultant air flows. This is effected by maintaining oxygen at the kiln feed-end at, say, 2%. The gas probe at the kiln feed-end should project inside the kiln to avoid the effect of false air in-leakage at the kiln seal; this is a difficult location for gas sampling and an adequate probe is essential (Gumprecht et al; WC; 10/2003; pg 103). CO should, and NOx may, also be measured at the kiln inlet.

The oxygen level required at the kiln inlet will depend upon kiln stability and combustion efficiency. With a good flame, 1-2% $O_2$ should result in less than 200ppm CO while an unstable flame may yield in excess of 1000ppm CO with 3% $O_2$. In a cyclone preheater kiln without riser firing, the downcomer oxygen analyser serves both as backup to the kiln inlet unit and to monitor air in-leakage across the tower; an increase in $O_2$ of more than 2-3% suggests excessive in-leakage. In a precalciner kiln, an additional gas analyser is required in the outlet duct from the bottom cyclone and, again, this should be operated at as low an oxygen level as is consistent with less than 100ppm of CO.

Note that traditional $O_2$ operating levels must be modified if staged combustion (Sec 9.6) is employed to reduce NOx emission.

Useful information on kiln operation can be obtained from frequent (2-hourly) analysis of clinker for $SO_3$, and periodic (8-hourly) sampling of the underflow from the bottom cyclone stage(s) for LoI, $SO_3$, Cl, and alkali determination. Normal $SO_3$ levels (typically 0.6% in clinker and 2-3% in underflow) should be determined and maintained. In precalciner kilns, retention time and heat loading are particularly low and alkalis (K,Na) tend to pass through to clinker while sulphur is volatilised and builds a cycle at the back of the kiln exacerbated by the deficiency of alkalis. If the kiln is burned too hot or if the flame impinges on the load, this cycle increases excessively until build-up or cyclone plugging occurs. This is matched by an abnormally low $SO_3$ and free-lime contents in the clinker which should be taken as a warning. Eventually, if the kiln is allowed to cool, this sulphur is released and transient high clinker $SO_3$ results. Such variation in clinker $SO_3$ will also give rise to varying grindability in the finish mill.

In order to minimize volatile cycles, hard burning mixes should be avoided, the sulphur:alkali ratio should be maintained between 0.8 – 1.2, and Cl should be limited to not more than 1% and $SO_3$ to 3% in hot meal entering the kiln.

It cannot be over-emphasized that kiln stability, fuel efficiency, finish grinding power consumption, and cement quality all depend greatly upon the provision of kiln feed and fuel with minimal variation both of chemistry and feed rate. Healthy scepticism should be nurtured towards both instrument signals and manually reported data. Particular areas for mistrust are:

- False instrument signals of which pressure sensors and gas sampling probes are particularly liable to failure.
- Short term variations masked by electronically damped signals.
- Feeder variations especially when the material is either sticky or fine and dry.
- Chemical variations hidden by faulty analytical methods, statistical mistreatment, or outright fraud.

Variations in kiln behaviour always have a cause; any variations which cannot be explained by observed feed deviation or known operational disturbance should alert to the possibility of faulty data.

Automated kiln control seems, unfortunately, to have reduced operators' habits of looking in the kiln and inspecting the clinker produced. Modern kiln and cooler camera systems, however, are excellent tools (Prokopy; RP-C; 5/1996, pg 38) for observing flame shape and position of the load in the kiln (dark interface of unburned material), 'snowmen' (build-up on grates below the hood), 'red rivers' and excessive blow-through in the cooler. The appearance of clinker can also be instructive; preferably black with surface glitter, dense but not dead burned, dark grey cores, and absence of excessive fines. Brown cores are usually due to reducing conditions in the kiln but can also be due to the decreased permeability of clinker resulting from high belite and sulphate concentrations which inhibit oxidation of ferrous ($Fe^{2+}$) iron to ferric ($Fe^{3+}$) during cooling. This in turn is due to chemical variation of kiln feed and to low volatilisation of sulphur in the kiln (Scrivener & Taylor; ZKG; 1/1995, pg 34). Other causes have also been proposed (Jakobsen; WC; 8/1993, pg 32). Brown clinker is associated with increased heat consumption, reduced grindability, cement strength loss, and rapid setting.

Certain alarms on the kiln control system are critical. Apart from normal mechanical alarms and the routine monitoring of kiln shell for refractory failure, the potential for explosion requires particular care. Gas analysis is conventional at the feed end of the kiln, at the down-comer, and at the dust collector entrance. CO above 1% should cause alarm, and above 2% should cause fuel, and EP if so equipped, to shut off. Flame detection is particularly vital during warm up of the kiln and fuel should be shut off by interlock if the flame is lost. When the kiln is up to temperature it is common to deactivate the flame detector but it should be impossible to start a kiln without this protection.

The light-up of kilns is potentially dangerous as there is insufficient temperature in the system to ensure continuous ignition. Unburned gas, either natural or volatile hydrocarbons from solid fuels, accumulates rapidly in the kiln and, if then re-ignited, will probably explode. It is important that ignition be achieved as soon as the fuel is injected and, if the flame fails during warm-up, the kiln should be purged with 5 times the volume of kiln, pre-heater, ducting, and dust collector (probably some 3-5 minutes) before re-ignition is attempted. A simple and reliable ignition system has been described by Davies (ICR; 9/1996, pg 77).

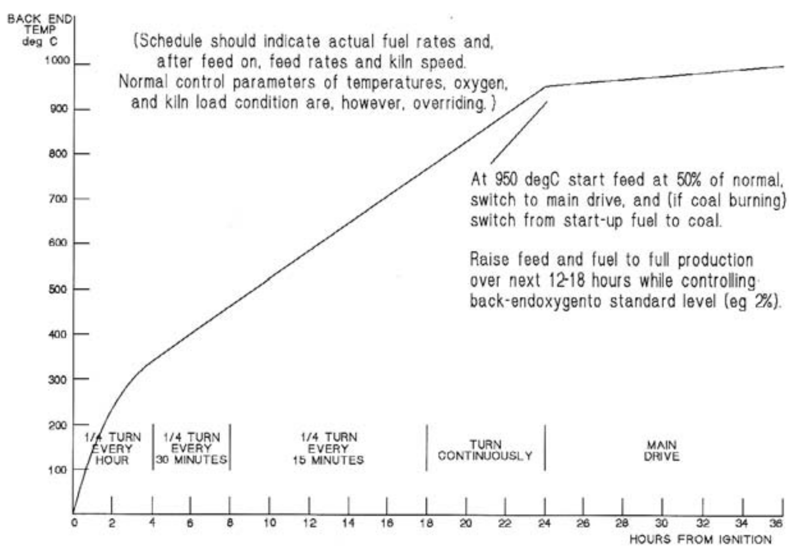
## 4.4 Kiln Start-up and Shut-down

Detailed schedules should be provided to operators to ensure that what, one hopes, are infrequent occurrences do not result in undue stress to kiln components.

**Warm-up** follows agreement by production and maintenance management that all work is completed, that all tools and materials have been removed, and that all doors are closed. Work may, with discretion, continue in the cooler during warm-up but no workers should remain in the cooler at the time of ignition. Commonly, warm-up from cold takes 24 hours from ignition to feed-on, but may be increased if extensive refractory work requires curing. A typical chart is shown (Figure 4.3) indicating the desired rate of increase in back-end temperature (this may also be set out in terms of fuel rate), the kiln turning program, the introduction of feed (usually 50% of full rate), and the increase of fuel, speed and feed to normal operation which should take another 8 hours from feed-on. For PC kilns, fuel is supplied to the calciner at the same time as, or soon after, feed-on. ID fan should be operated to approximately 10% $O_2$ at the back of the kiln to feed-on whereupon the normal $O_2$ target is adopted.

For coal fired kilns, warm-up almost invariably employs gas or oil with switch-over to coal at the time of feed-on. If the coal mill uses hot gas from the cooler, there may be a delay before heat is available from the clinker.

*Figure 4.3: Typical Kiln Warm-up Schedule*




Before and during warm-up, equipment checks should be performed to ensure that each unit is ready to operate when required.

Warm-up from shorter stops where the kiln is still hot, say stops of less than 24 hours, are conventionally accelerated to half the shut-down time.

**Shut-down** may be either:

- Emergency, in which case all equipment upstream of the failure must be stopped immediately, or
- Controlled, in which case feed bin and coal system should be emptied, the kiln load run out as far as possible, and the cooler emptied. The burner pipe is withdrawn, or cooling air is continued through the burner, and the kiln is rotated on a standard schedule for about 12 hours with the ID fan running at reducing speed.