PROCE$$ OPTIMI$ATION $AVING$*

Victor J. Turnell, P.E., Process/Environmental Engineer, Penta Engineering Corp., USA, explores methods of increasing the value of capital investments by optimising manufacturing processes, increasing production and reducing operating costs.

FOR THE SPANISH TRANSLATION, PLEASE REFER TO THE SPECIAL SECTION AT THE BACK OF THE ISSUE

Introduction

Cement plant owners, managers and technical personnel are constantly searching for ways to increase the value of capital investments by optimising manufacturing processes, increasing production and reducing operating costs. This article presents methods for achieving these objectives and includes several examples, including optimising clinker cooler operation, heat transfer, and combustion conditions; reducing air infiltration; adding alternate fuels; and improving cement bagging operations. The manufacturing process optimisation studies presented suggest methods of reducing production unit costs and increasing production capacity which are achievable through operational changes and small capital investments and which result in higher returns on investment (ROI). The operating plants reviewed have shown significant potential savings and production increases with minimum additional capital investment.

Potential savings from lowering specific fuel consumption and increasing clinker production are calculated using mathematical modelling results. The mass and energy balances are calculated on the kiln system using input variables based on actual operating conditions at existing plants, which emphasise the validity of the results. The heat capacities of elements and compounds were calculated using equations obtained from *Perry's Chemical Engineers' Handbook*[1].

Pyroprocessing system

The pyroprocessing system presents the opportunity for the most optimal amount of savings. The main operating costs are fuel and electrical power.

A comparison of the specific fuel consumption of one kiln system with other kiln systems of similar design provides an indication of how efficiently the system is operating. This also suggests what can be achieved by improvements and optimisations. However, other reasons for different specific fuel consumption must also be considered.

Following are examples of improvements and optimisations of various subsystems in a pyroprocessing system, and illustrations of how they are achieved, how they affect specific fuel consumption and clinker production, and the extent of potential savings and benefits associated with these optimisations.

The potential savings shown in these examples do not take into account any savings in electrical power, maintenance, or labour. Savings in electrical power will result whenever there is a reduction in specific fuel consumption because of a lower gas flow rate per ton of clinker produced. This lowers the power consumed in the kiln system induced draft (ID) fan.

In these examples, potential savings or income resulting from additional production are calculated based on an incremental savings or income of US$ 20/t of clinker.

Clinker cooler

Clinker coolers have two major functions in a pyroprocessing system: to supply hot combustion air to the kiln and to lower the clinker temperature for material handling after the kiln system. An ideal clinker cooler discharges clinker at a temperature close to ambient with all the heat recovered from the clinker used to raise combustion air temperature or for other purposes, such as drying coal or raw materials. Clinker cooler efficiency is measured by the percentage of useful heat recovered from clinker.

With grate coolers, kiln operators have significant control over combustion air temperature and hence, clinker cooler efficiency. Combustion air temperature from grate coolers is controlled by clinker bed depth and air flow rate. Typically, as bed depth increases, so does combustion air temperature. Maximum bed depth is limited by one of the following: undergrate fan capacities, the grate drive, or overheating in the kiln firing hood area.

In contrast, with planetary coolers, kiln operators do not have much control over the efficiency of the cooler. However, the operator can ensure all observation ports and doors are closed to minimise the infiltration of cooler ambient air.

The effects of increasing secondary air temperature on clinker production, specific fuel consumption, and clinker cooler efficiency for a preheater kiln equipped with a grate cooler are shown in

* Based on a paper presented at the APCAC Technical Meeting, Puerto la Cruz, Venezuela, October 1998.

Figure 1. In this example, the kiln exit gas flow rate was held at a constant level and the fuel firing rate, clinker production and clinker cooler efficiency were allowed to vary.

Kiln operators at a number of plants visited maintain shallower clinker bed depths than could be achievable with the existing undergrate fans. By increasing and optimising clinker bed depth, kiln operators can increase combustion air temperature and hence, clinker cooler efficiency. In some cases, it may be economically justifiable to modify or redesign the limiting factor to increase clinker cooler efficiency, for example, modifying the aeration system by replacing an undergrate fan or fans, or by installing static grates inlet section. Typical modification costs range from US$ 200 000 to US$ 600 000.

In addition, kiln operators must ensure that all observation ports and doors are closed to minimise infiltration of cooler ambient air.

Operational changes resulting from increasing secondary air temperature by 100 °C for a preheater kiln system with a grate cooler are summarised in Table 1.

Potential savings and benefits are as follows:

- US$ 64 000/yr is saved in fuel costs based on production of 320 000 tpa. This is a result of the lower specific fuel consumption achieved.
- US$ 200 000/yr in potential savings or income can be realised from the additional production achieved.
- Increasing and optimising clinker bed depth also has significant effects on the operation of a kiln system. The cooler will have better air distribution, reducing the chances of 'red rivers' occurring. The kiln system will become more stable, which in turn improves fuel efficiency, clinker production, refractory life and other maintenance items.

Air infiltration

Air infiltration into the kiln system occurs in many locations, including the seals between the kiln firing hood and kiln shell, the kiln feed end hood and kiln shell, observation ports, doors and other locations.

Air infiltration at the kiln firing hood displaces secondary air entering the kiln, thereby reducing clinker cooler efficiency. As clinker cooler efficiency is reduced, specific fuel consumption will increase and clinker production will decrease.

The effects of decreasing kiln firing hood air leakage on a preheater kiln system with a grate cooler are shown in Figure 2. In this example, preheater exit gas flow was maintained at a constant level and the fuel firing rate, clinker production and secondary air mass flow rate were allowed to vary.

In most plants, maintaining existing air seals and keeping observation ports and doors closed will result in significant improvements in the kiln system operations. In other plants, modifications of the kiln firing hood and kiln feed end hood seals systems may be necessary to prevent significant leakage. Typical modification costs range from US$ 20 000 to US$ 180 000.

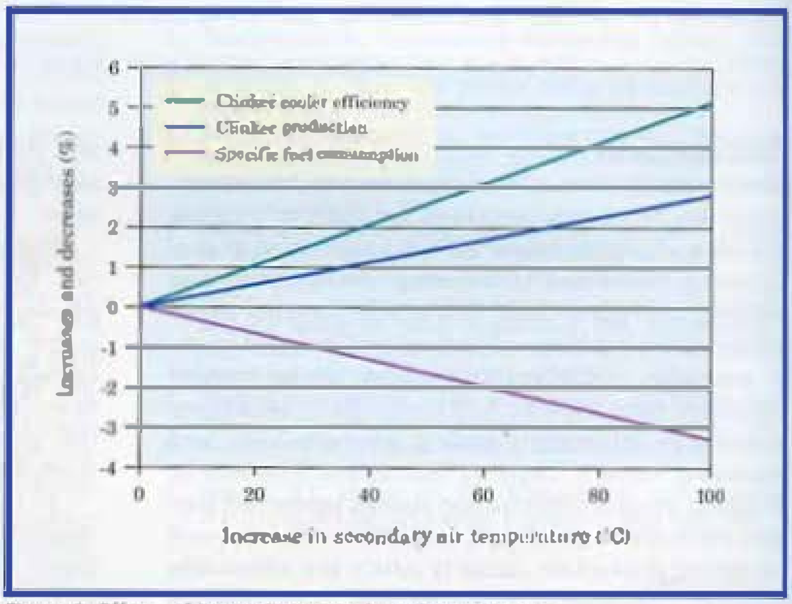

Figure 1. Effects of increasing secondary air temperature.

Table 1. Results of increasing secondary air temperature by 100 °C for preheater kiln system with grate cooler

	Before change	After change	Effect
Kiln secondary air temperature, °C	940	1040	+100 °C
Fuel consumption, net kcal/kg	775	750	-3.2%
Production capacity, tpd	970	1000	+3.1%
Potential annual production, tpa	320 000	330 000	+10 000 tpa
Fuel cost, US$/t at US$ 8/million kcal	6.20	6.00	-US$ 0.20

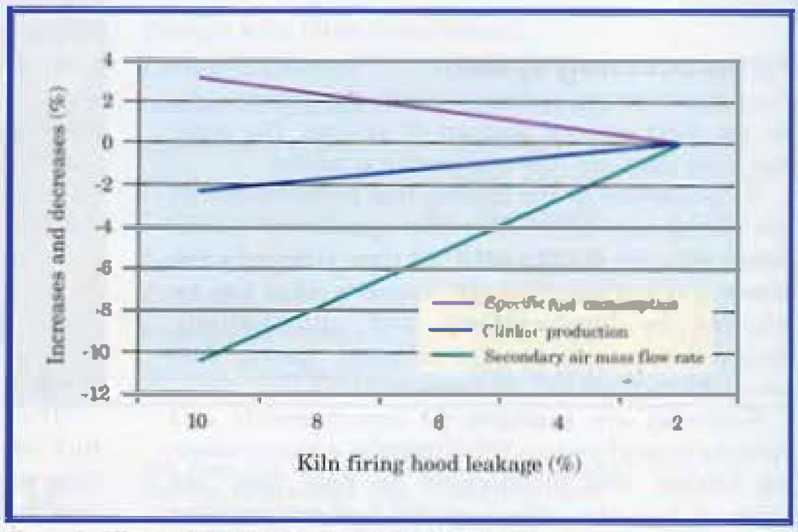

Figure 2. Effects of decreasing kiln firing hood leakage.

Operational changes resulting from decreasing kiln firing hood leakage from 10% of the total air entering the kiln to 2% on a preheater kiln system with a grate cooler are shown in Table 2.

Potential savings and benefits are as follows:

- US$ 64 000/yr is saved in fuel costs based on production of 322 000 tpa.
- US$ 160 000/yr in additional savings or income can be realised from additional production achieved.
- In the case of planetary coolers, reducing kiln firing hood leakage will increase air flow through the planetary cooler which reduces the clinker discharge temperature as it leaves the cooler and improves fuel efficiency.

Table 2. Results of decreasing kiln firing hood leakage from 10% of total air entering kiln to 2% on preheater kiln system with grate cooler

	Before change	After change	Effect
Kiln hood leakage, % of total kiln inlet air	10	2	-8%
Fuel consumption, net kcal/kg	775	750	-3.2%
Production capacity, tpd	975	1000	+2.5%
Annual production 330 days/yr, tpa	322 000	330 000	+8000
Fuel cost, US$/t	6.20	6.00	-US$ 0.20

The effects of decreasing kiln feed end hood leakage on clinker production, specific fuel consumption and preheater inlet gas temperature for a preheater kiln with a grate cooler are shown in Figure 3. In this example, preheater exit gas flow was maintained at a constant level and the fuel firing rate, clinker production and preheater inlet gas temperature were allowed to vary.

In a preheater kiln, reducing air infiltration at the kiln feed end reduces the amount that the kiln exit gases are cooled. Higher gas temperatures entering the preheater improves heat transfer efficiency between gases and material flowing in the preheater. In addition, lower air infiltration decreases the volume of air travelling through the preheater that results in lower velocity and, therefore, increases the retention time of the gases travelling through the preheater. An increase in retention time improves heat transfer in the preheater. This also applies to a calciner kiln system.

In a kiln system limited by the ID fan capacity, kiln capacity will increase significantly and specific fuel consumption will decrease as shown in the above example.

The potential savings achieved by decreasing kiln feed end preheater leakage from 10% of the total air entering the kiln to 2% are shown in Table 3.

Table 3. Potential savings of decreasing kiln feed end preheater leakage from 10% of total air entering kiln to 2%

	Before change	After change	Effect
Preheater leakage, % of total preheater inlet	10	2	-8%
Fuel consumption, net kcal/kg	65	750	-2.0%
Production capacity, tpd	910	1000	+9.9%
Annual production 330 days/yr, tpa	300 000	330 000	+30 000
Fuel cost, US$/t	6.12	6.00	-US$ 0.12

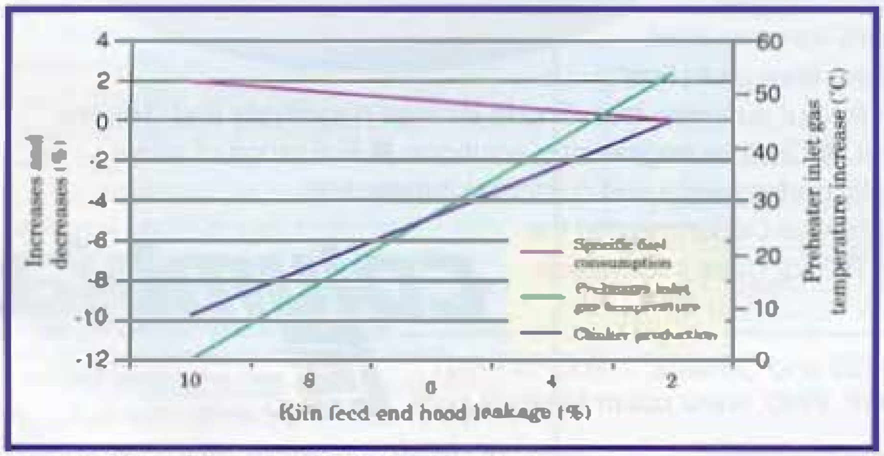

Figure 3. Effects of decreasing kiln feed end hood leakage.

Potential savings and benefits are as follows:

- US$ 36 000/yr is saved in fuel costs based on production of 300 000 tpa.
- US$ 600 000/yr in potential savings or income can be realised from the additional production achieved.

Heat transfer efficiency

Numerous indicators of heat transfer efficiency exist, such as kiln system exit gas temperature. A comparison of the kiln system exit gas temperature with other kiln systems of similar design will provide an indication of the efficiency of heat transfer in the kiln system. If the temperature is found to be higher than expected, heat transfer could be improved.

However, a relatively low exit gas temperature does not imply that good heat transfer is occurring. A low kiln system exit gas temperature can result from high air infiltration.

The effects of increasing heat transfer efficiency, as reflected by the reduction of kiln exit gas temperature, on kiln production capacity, specific fuel consumption and secondary air temperature for a wet process kiln with a planetary cooler, are shown in Figure 4. In this example, the kiln fuel firing rate was held at a constant level and kiln production capacity, specific fuel firing rate and secondary air temperature were allowed to vary.

In the kiln system described in this example, heat transfer could be improved by redesigning the chain system to ensure that more heat transfer occurs while maintaining minimum air resistance.

Other examples of improving heat transfer could be accomplished by maintaining and, in some cases, redesigning the following items may significantly improve heat transfer efficiency in the kiln system:

- Refractory system in the kiln, preheater and cooler.
- The chain system of kilns equipped with a chain system.
- Preheater vessel thimbles.
- Preheater meal distribution boxes discharging materials from one preheater vessel to other.
- Airlocks at the preheater vessels' discharge.
- Preheater cyclones including inlets and other areas.

Typical modification costs range up to US$ 500 000.

Potential savings achievable by increasing the heat transfer efficiency of a wet process kiln with a planetary cooler are shown in Table 4. The additional heat transfer efficiency is reflected in the temperature reduction of the kiln exit gases.

Potential savings and benefits are as follows:

- US$ 237 000/yr is saved in fuel costs based on production of 130 000 tpa.
- US$ 700 000/yr in additional savings or income can be realised from the additional production achieved.

Combustion conditions

Optimum combustion conditions in cement kiln systems occur when kiln exit gas oxygen and carbon monoxide emissions are as low as possible. Stated another way, optimum combustion conditions occur when excess air is as low as possible and complete combustion still occurs. A kiln operating with low excess air may cause partial combustion of fuel. A kiln system operating with high excess air increases the heat loss in the kiln system exit gases. In either case, the net effects are higher specific fuel consumption and lower clinker production.

The effects of reducing kiln exit gas oxygen percentage on kiln production capacity, specific fuel consumption and secondary air temperature for a wet process kiln with a planetary cooler are presented in Figure 5. In this example, kiln exit gas flow was constant and the kiln fuel firing rate, kiln production and secondary air were allowed to vary.

Effective control of excess air is accomplished when an optimal level of oxygen and carbon monoxide exist in the kiln system exit gas. Optimal combustion conditions can be maintained by various means; for example, measuring oxygen or carbon monoxide in the kiln system exit gases and adjusting kiln system gas flow rate accordingly. Typical installation costs range from US$ 75 000 to US$ 300 000.

The potential savings achievable by reducing the kiln exit gas oxygen percentage for a wet process kiln system with a planetary cooler are shown in Table 5.

Potential savings and benefits are as follows:

- US$ 75 000/yr is saved in fuel costs based on a production of 129 000 tpa.
- US$ 720 000/yr in additional savings or income can be realised from the additional production achieved.
- The secondary air flow rate decreases thereby resulting in increasing secondary air temperature.
- Lower oxygen levels reduce the oxidation rate of chains in the chain system of wet or long dry process kilns, thereby increasing the life of chains.
- Social benefits include reduced pollution emission levels for nitrogen oxides per ton of clinker produced.

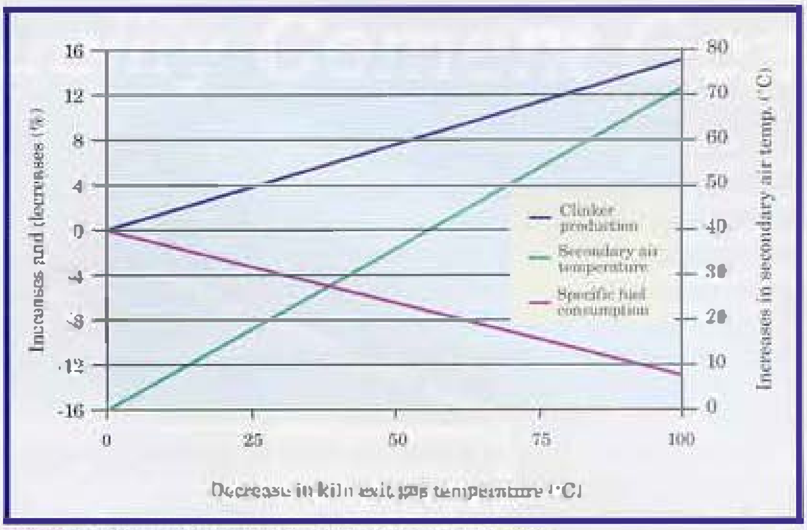

Figure 4. Effects of decreasing kiln exit gas temperature.

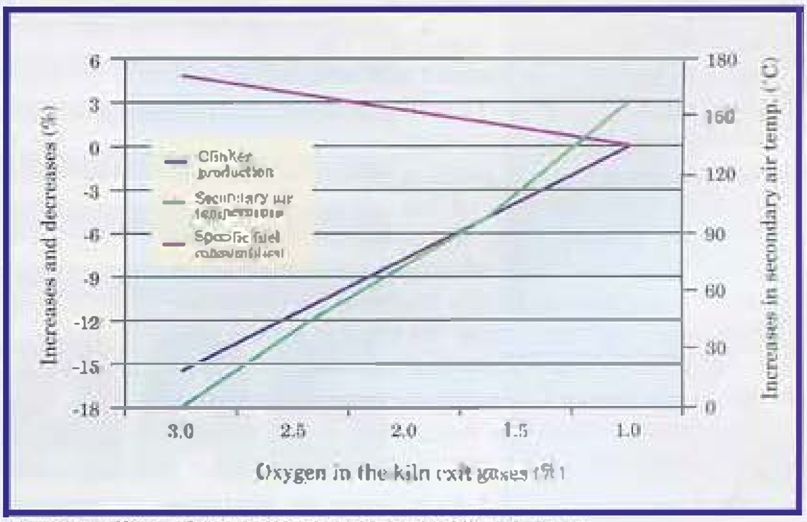

Figure 5. Effects of decreasing oxygen in the kiln exit gases.

Table 4. Potential savings of increasing heat transfer efficiency of wet process kiln with planetary cooler

	Before change	After change	Effect
Kiln exit gas temperature, °C	277	177	-100 °C
Fuel consumption, net kcal/kg	1725	1500	-225
Production capacity, tpd	395	500	+26%
Annual production 330 days/yr, tpa	130 000	165 000	+35 000
Fuel cost, US$/t at US$ 8/million kcal	13.82	12.00	-US$ 1.82

Alternative fuels

In all the examples illustrated above, the objective was to reduce specific fuel consumption and increase clinker production. This example presents alternative fuels that may be fully or partially substituted for existing fuels to reduce fuel costs. Fuels used in some cement plants as either the main fuel or as a supplement include natural gas, fuel oils, coal, petroleum coke, tyres, domestic refuse, rice husks, wood chips and a wide range of waste solvents and other organic liquids.

One of the first steps in evaluating an alternate fuel is to determine whether or not it is economically feasible. If it is, the next step is to evaluate the effects of using the alternate fuel. Items to review before using an alternate fuel are as follows:

- How will the alternate fuel affect the operation of the kiln system? Will it reduce clinker production? Will it increase maintenance requirements?
- Will the alternate fuel produce ash? If so how will it affect the chemistry of the clinker produced? How will the ash affect the operation of the kiln system? In some cases, ash may contain high levels of silica, aluminium or iron that may be beneficial. It may, in some cases, allow the plant to reduce consumption of a more expensive raw material.
- Will the alternate fuel generate any additional pollutants? If so, what are the consequences of these pollutants? Are special permits required?

Potential savings resulting from using an alternate fuel are shown in Table 6. It is important to note that the cost of alternate fuels vary significantly. In some cases, the cement plant may be paid to use alternate fuels.

Potential savings and benefits are as follows:

- US$ 396 000/yr can be saved in fuel costs for a plant producing 330 000 tpa of clinker at 750 kcal/kg.
- There may be social benefits from using alternate fuels such as safe disposal of domestic and industrial wastes.

Table 5. Potential savings of reducing kiln exit gas oxygen percentage for wet process kiln system with planetary cooler

	Before change	After change	Effect
Kiln exit gas oxygen, % O_2	3	1	-2
Fuel consumption, net kcal/kg	1575	1500	-75
Production capacity, tpd	390	500	+28%
Annual production 330 days/yr, tpa	129 000	165 000	+36 000
Fuel cost, US$/t	12.58	12.00	-US$ 0.58

Table 6. Potential savings resulting from using an alternate fuel

	Before change	After change	Effect
Primary fuel cost, US$/million kcal	8.00	8.00	—
Alternative fuel cost, US$/million kcal	4.00	4.00	—
Fuel substitution, alt. fuel kcal/total kcal	0%	40%	—
Fuel cost, US$/million kcal	8.00	6.40	-1.60

Cement distribution

About 80-85% of all cement distributed in Latin America is done so in bags[2]. For this reason, much attention should be paid to the efficiencies of the packing system.

Numerous older technology packing machines, which use mechanical weights on a balance, are currently in operation. In some cases, these packing machines cause bag weights to vary by as much as 3%. Therefore, to ensure the minimum weight in each bag, the plant will typically put an additional 2-3% of cement in each bag.

In recent years, improvements made to packing machines have yielded machines with significantly more control of the weight of each bag. Weight tolerances in the range of 0.5% are now achievable.

These weight tolerances are achieved by the following:

- Placing a weighing device after the bag packer that feeds back the weight of each bag to the packing machine.
- Installing a bag filling system that constantly adjusts the amount of cement based on the feedback obtained from the weighing device.
- Installing hardware and software to accomplish the control described above.

Some plants may obtain significant savings by reducing the weight variation from bag to bag. For example, in a plant selling 500 000 tpa of cement in bags at a production cost of US$40/t, a 1% reduction of cement per bag could potentially save the plant approximately US$ 200 000/yr.

Conclusion

This article has presented a number of examples of potential savings achievable by operational changes and small capital investments, including: optimising clinker cooler operation, reducing air infiltration, optimising heat transfer, optimising combustion conditions, using alternate fuels and controlling cement bag weight variations. These potential savings provide an order of magnitude saving, which may vary according to existing plant operating conditions and production.

It is important to stress that these are only a selection of examples on relatively small kiln systems, and that many more areas of potential savings and benefits exist that are applicable to the kiln syste and other sections of the production process. It also important that larger equipment capacities will show larger returns on investment for similar operational changes and modifications. Plants are recommended to undergo an audit by technical experts to evaluate existing systems in order to optimise and maintain low operating costs using proven theoretical and practical tools.

References

1. PERRY, Robert H., *Perry's Chemical Engineers' Handbook*. Sixth Edition, Table 3-181.
2. GONZÁLEZ, José R., 'The South American Cement Industry: An Overview', *Presented at the 38th IEEE Cement Industry Technical Conference*.

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