REDUCING FLUORIDE EMISSIONS IN BRICK, TILE AND PIPE MANUFACTURE

GOOD PRACTICE: Proven technology and techniques for profitable environmental improvement
REDUCING FLUORIDE EMISSIONS IN BRICK, TILE AND PIPE MANUFACTURE

This Good Practice Guide was produced by the Environmental Technology Best Practice Programme

Prepared with assistance from:
CERAM Research
The technology for reducing pollutants in stack emissions can be very expensive. Making the wrong decision not only wastes money but also wastes management time and effort. This Guide is intended to inform managers in the brick, tile and pipe manufacturing industry of the options for reducing fluoride emissions from a firing process. It also provides a framework to help companies decide what equipment or process is best suited to their individual requirements for meeting new legislation.

The Guide covers the two main methods of reducing fluoride emissions - process optimisation and flue gas scrubbing. It explains how you can decide whether the lower-cost option of process optimisation is suitable for your company - and if so, it encourages you to follow this route. Savings of £100 000 in capital expenditure and £10 000 - £20 000 in annual running costs can be achieved through using process optimisation instead of flue gas scrubbing.

For companies selecting the process optimisation route, the Guide gives an outline of how the planning of a large-scale project can be tackled. It gives details of several options and shows how you can decide which to adopt. Advice is also provided on practical considerations of planning and implementation.

For those companies that are unable to take advantage of the process optimisation route, the Guide gives important information about selecting a scrubber and identifying a suitable supplier. It details what you should ask for in tenders and how to analyse them.

There are margin marks throughout the text to indicate sections dealing with process optimisation or scrubbers. These marks provide you with an easy route to information on your selected method of reducing fluoride emissions.
Since the introduction of the Environmental Protection Act 1990, industry has had to look again at the pollution it creates. For brick, tile and pipe manufacturers, this involves reducing fluoride emissions to comply with the Guidance Note for Heavy Clay and Refractories which is due to be implemented on 31 December 1999. By that date, processes rated above 2 MW will have a discharge limit of below 10 mg/m³ measured as hydrogen fluoride.

Many companies are only aware of the flue gas scrubbing method of achieving this level. However, there are lower cost options from which about half of the industry can benefit. As this Guide shows, companies with existing emissions of less than 35 mg/m³ of hydrogen fluoride should be able to reduce these emissions to below 10 mg/m³ by using process optimisation techniques. It is only those companies with higher emission levels that will need to install flue gas scrubbers.

Process optimisation costs considerably less than installing and running a scrubber. Typically, a company can expect to spend up to £100 000 less on capital equipment and £10 000 - £20 000 less on annual running costs. **For this level of savings, it is well worth while taking the time to check whether the lower cost option is suitable.** This Guide provides the information you need to help you make that decision.

Companies that choose to install scrubbers will know exactly what their future emission levels will be, although it is the more expensive option. This Guide provides advice on how to choose scrubbers and operate them efficiently.

Several types of scrubber are available. Some of these are innovative designs and may offer benefits over established technology. This Guide does not evaluate all the various types of flue gas scrubber, but the guidance it contains is relevant to all abatement technology. It provides a useful framework for evaluating new scrubber technology.

The Environment and Energy Helpline on 0800 585794 can provide a non-exhaustive list of suppliers of additives, scrubbers, kilns and process optimisation services.
Most clays contain fluorides of varying concentrations ranging from 0.03 - 0.06%. The fluorides are released during firing above 600°C and emitted into the atmosphere mainly as hydrogen fluoride (HF). The total fluoride emission depends on a number of factors and is illustrated in Fig 1.

2.1 THE INTERNAL FLUORIDE CYCLE

The emission/absorption process is as follows:

- The clay product enters the kiln. During the firing cycle, fluoride in the clay body reacts with moisture in the kiln atmosphere and forms hydrogen fluoride. A small proportion of this may react with airborne particles to produce other fluorides.
- The gaseous and other airborne fluorides are mixed with, and transported by, the counter-flowing kiln gases. They flow back towards the stack near the kiln entrance.
- The product is preheated by its interaction with the kiln gases and absorbs a proportion of the airborne hydrogen fluoride.
- The product now contains fluoride from two sources - that inherent in its composition and that absorbed from the kiln atmosphere.
- The fluoride trapped within the product leaves the kiln.

This process is known as the internal fluoride cycle. A simple equation governs how much hydrogen fluoride (HF) is discharged into the atmosphere:

\[ \text{HF evolved} - \text{HF absorbed} = \text{HF discharged} \]

Emission reduction methods aim to reduce HF in each of these three areas.
There are three main ways of reducing fluoride emissions:

- **Reduction-at-source.** This includes a range of process optimisation techniques that reduce the HF evolved or increase the HF absorbed (see Section 2), by optimising operation of the kiln, or incorporating a body additive, such as limestone.

- **End-of-pipe.** Stack gases from a kiln pass through a flue gas scrubber just before discharge into the atmosphere, reducing the HF discharged (see Section 2) in the stack gases. The gases react with a reactant in the scrubber which reduces the HF emissions to a harmless or less hazardous level.

- **Dispersion.** Raising the chimney height helps disperse emissions and reduces the ground level concentration, but it is not strictly an abatement measure. This Guide does not cover dispersion, but your local enforcing authority will provide guidance on the correct chimney height.

### 3.1 REDUCTION-AT-SOURCE (PROCESS OPTIMISATION)

Process optimisation is a relatively new and inexpensive way of reducing fluoride at source. It depends on organising the firing process in the kiln with the specific aim of reducing the amount of fluoride emitted. This can involve making modifications to the kiln, changing its operating parameters or adding materials to the body being fired. The techniques adopted depend on the manufacturing process, the characteristics of the raw materials and the firing process.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low implementation cost.</td>
<td>Not fully proven long term.</td>
</tr>
<tr>
<td>Low running costs.</td>
<td>May require change in production technique.</td>
</tr>
<tr>
<td>Allows capital to be spent on the manufacturing process.</td>
<td>May not achieve the target emission level.</td>
</tr>
<tr>
<td>No waste generated.</td>
<td></td>
</tr>
<tr>
<td>Low-cost trials can be carried out.</td>
<td></td>
</tr>
</tbody>
</table>

#### 3.1.1 Process modification techniques

The key to process modification is the internal fluoride cycle and how each part of it can be affected by altering the product characteristics or the design and operational parameters of the kiln.

Table 1 summarises the most successful low-cost process techniques and modifications developed to promote cleaner firing practices. Fig 2 provides a summary of a range of process optimisation techniques.
### Table 1 Successful abatement techniques

<table>
<thead>
<tr>
<th>Abatement technique</th>
<th>Method example</th>
<th>Reduction in HF concentration (%)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modifying the time-temperature profile</td>
<td>Reduce time at peak temperature</td>
<td>10</td>
</tr>
<tr>
<td>Reducing the airflow through the kiln</td>
<td>Decrease exhaust fan speed</td>
<td>63</td>
</tr>
<tr>
<td>Increasing the turbulence in the preheat zone</td>
<td>Add high-velocity burners to this section</td>
<td>86</td>
</tr>
<tr>
<td>Increasing the interaction between the product and the flue gas</td>
<td>Change setting pattern</td>
<td>53</td>
</tr>
<tr>
<td>Utilising the flue gas</td>
<td>Direct flue gas through preheater or drier</td>
<td>94</td>
</tr>
<tr>
<td>Adding a fluoride reactive compound</td>
<td>Add ~2% at the forming stage</td>
<td>75</td>
</tr>
</tbody>
</table>

* Maximum reduction obtained in industrial research carried out by: CERAM Research, UK; TNO, The Netherlands; and Forbairt, Ireland (1997).

### Modifying the time-temperature profile

More fluoride is emitted from the clay body as it gets hotter and the longer it stays at a high temperature. Fluoride emissions can be reduced by modifying the kiln time-temperature profile so the body remains at a high temperature for a shorter period.

### Reducing the airflow through the kiln

Reducing the airflow increases the concentration of airborne fluoride in the hottest part of the kiln. This suppresses the total amount of gaseous fluoride emitted into the kiln by altering the dynamic balance in the chemical processes involved in fluoride release.

### Increasing turbulence in the preheat zone

Flue gases are in contact with the ware longer when turbulence is increased, so improving the distribution of flue gases through the ware on each kiln car in the preheat zone. Both factors enhance re-absorption of airborne fluorides.
Abatement technique | Method example | Reduction in HF concentration (%)*
--- | --- | ---
Modifying the time-temperature profile | Reduce time at peak temperature | 10
Reducing the airflow through the kiln | Decrease exhaust fan speed | 63
Increasing the turbulence in the preheat zone | Add high-velocity burners to this section | 86
Increasing the interaction between the product and the flue gas | Change setting pattern | 53
Utilising the flue gas | Direct flue gas through preheater or drier | 94
Adding a fluoride reactive compound | Add ~2% at the forming stage | 75

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Increasing interaction between the product and the flue gas

Changing the setting pattern to improve flue gas dispersion means the flue gases are in better contact with the ware for a longer period. This enhances re-absorption of airborne fluorides.

Utilising the flue gas

Recirculating exhaust flue gases to the preheat section of the kiln, or to a drier, enhances the re-absorption of the highly reactive fluorides.

Adding a fluoride reactive compound

It has long been known that adding limestone to clay raw material can reduce fluoride emissions. However, limestone is just one of many additives that can produce this effect. Any material used as an additive should:

- not adversely affect the properties of the product;
- be easily incorporated into the manufacturing process;
- not entail excessive costs.

Fluoride reactive compounds react with the fluoride released by the clay mineral to form a more stable compound. This survives the high temperatures encountered during the firing process and effectively locks in the fluorides.

Limestone is the most economically viable example of this type of material and can reduce fluoride emissions substantially (see Table 1). The particle size distribution of the limestone is crucial for successful fluoride capture. Consult your limestone supplier for advice about the optimum grade for your process.

A new magnesium-based compound (a by-product of magnesium processing) is under trial and it is anticipated that it will work in the same way as limestone. Phone the Environment and Energy Helpline for more details.

Fluxes lower the vitrification temperature and increase the rate of vitrification of the body. This results in shorter firing schedules and lower fluoride emissions. A recent study (see footnote to Table 1) found that the abatement additives with the greatest potential for reducing fluoride emissions are:

- pulverised fuel ash;
- glass cullet;
- ceramic sludge;
- blast furnace slag.

Inert diluents contain little or no fluoride so they effectively reduce the fluoride content of the clay body. However, a current study indicates that it is the firing schedule of the clay and not its fluoride content that influences the amount of fluoride released to atmosphere. It is, therefore, questionable whether inert diluents used alone reduce fluoride emissions unless they form a high percentage of the body composition.

3.1.2 Efficiency and costs

The effectiveness of process optimisation depends on the process and the material to which it is applied. It is, therefore, a site-specific solution with each factory deciding, through laboratory or factory trials, which technique or combination of techniques is best for its process and products.

The following three case studies show the reduction in fluoride emissions achieved in major industrial projects.
Reduced airflow in a brick tunnel kiln

A tunnel kiln with a production of 500,000 bricks/week was the subject of a series of trials aimed at reducing the airflow from the firing zone to the stack. The result was a reduction in fluoride emissions.

The exhaust flow was reduced in steps from 14,000 m³/hour and fluoride emissions were measured at each step. The company reduced its fluoride emissions from 44 mg/m³ to 10 mg/m³ by cutting the exhaust flow by 33%.

| Capital cost: | zero |
| Running cost: | zero |

<table>
<thead>
<tr>
<th>Normal operation</th>
<th>Run 1</th>
<th>Run 2</th>
<th>Run 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust flow (m³/hour)</td>
<td>14 000</td>
<td>13 400</td>
<td>11 500</td>
</tr>
<tr>
<td>Fluoride emissions (mg/m³ at 18% O₂)</td>
<td>44</td>
<td>32</td>
<td>27</td>
</tr>
</tbody>
</table>

This solution has not yet been implemented in full. To do so, the company needs to make adjustments to the burner groups and, possibly, to add burners in the preheat section of the kiln to maintain the heat transfer characteristics of the kiln.

Using a recirculation system in a brick tunnel kiln

A recirculation system has been installed in the preheat section of a kiln where the temperature ranges between 150°C and 400°C. The system recirculates gases from one zone to an adjacent, higher-temperature zone. This increases the residence time of the flue gases in the fluoride absorption part of the kiln and increases turbulence within the zones. By recirculating 30% of the flue gases, fluoride emissions have been reduced from 25 mg/m³ to below 10 mg/m³. The recirculation system has also improved the top-to-bottom temperature distribution of the kiln.

| Capital cost: | £30 000 |
| Running cost (fan): | £1 500/year |
Addition of limestone in a brick tunnel kiln

Chelwood Brick added up to 5% limestone to its manufacturing process of etruria marl/shale bricks. The limestone was added as a slurry to ensure rapid and thorough mixing during processing. As a result, the Company cut its fluoride emissions in the tunnel kiln by 52%, reducing emission levels from 25 mg/m³ to 12 mg/m³.

Capital cost: £55 000 for slurry equipment and silo
Running cost: £2.60/1 000 bricks

Full details of this project are contained in New Practice Case Study 108, Reducing Fluoride Emissions Through Limestone Additions, published by the Energy Efficiency Best Practice Programme, and available free of charge through the Environment and Energy Helpline on 0800 585794.

In other companies, projects using a limestone addition have also shown promising results and are summarised below:

<table>
<thead>
<tr>
<th>Clay type</th>
<th>Original emission level (mg/m³)</th>
<th>Emission level after treatment (mg/m³)</th>
<th>Addition level (%)</th>
<th>Running cost (£/1 000 bricks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carboniferous shale</td>
<td>35</td>
<td>4</td>
<td>3</td>
<td>1.50</td>
</tr>
<tr>
<td>Keuper marl</td>
<td>25</td>
<td>10</td>
<td>4</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Table 2 summarises expected reductions in HF emissions from the various process optimisation techniques and the cost of implementing them. The techniques considered most applicable to existing kilns are shaded.

<table>
<thead>
<tr>
<th>Abatement technique</th>
<th>Estimated range of HF reduction (%)</th>
<th>Capital cost (£)</th>
<th>Running cost (£/1 000 bricks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reducing the airflow through the kiln</td>
<td>30 – 60</td>
<td>&lt;20 000</td>
<td>0</td>
</tr>
<tr>
<td>Utilising the flue gas</td>
<td>30 – 90</td>
<td>&gt;50 000</td>
<td>&lt;0.2</td>
</tr>
<tr>
<td>Increasing turbulence in the preheat zone</td>
<td>30 – 80</td>
<td>20 000 - 80 000</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Adding a fluoride reactive component</td>
<td>0 – 80</td>
<td>20 000 - 100 000</td>
<td>0.5 - 3.0</td>
</tr>
<tr>
<td>Modifying the time-temperature profile</td>
<td>10 – 30</td>
<td>&lt;20 000</td>
<td>0</td>
</tr>
<tr>
<td>Increasing interaction between the product and the flue gas</td>
<td>0 – 50</td>
<td>20 000 - 100 000</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2 Estimated reduction and cost ranges

3.2 END-OF-PIPE SOLUTION (FLUE GAS SCRUBBING)

Scrubbing is the most common method for removing pollutants from flue gas emissions and is used extensively throughout Europe.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proven and widely adopted technique.</td>
<td>Large capital expenditure.</td>
</tr>
<tr>
<td>Reactant is an abundant, inexpensive raw material.</td>
<td>Significant annual running costs.</td>
</tr>
<tr>
<td>Predictable running costs.</td>
<td>New process to manage.</td>
</tr>
<tr>
<td>Minimal risk of non-conformance.</td>
<td>Increased traffic movement.</td>
</tr>
<tr>
<td>Comparatively simple installation.</td>
<td>Waste product generated.</td>
</tr>
<tr>
<td>Increased energy consumption.</td>
<td></td>
</tr>
</tbody>
</table>
3.2.1 Types of scrubber

**Dry bed limestone scrubber (cascade scrubber)**

Dry bed limestone scrubbers consist of a silo containing a granular bed of limestone chips through which the flue gases pass. Contaminants within the gas react with the limestone and are removed. The limestone flows continuously from top to bottom through the silo (see Fig 3) and is usually recycled. Although the system is designed to reduce fluorides, it also removes low levels of chloride and sulphur oxides.

**Dry cloth filter scrubber**

This type of scrubber injects a finely divided material - normally hydrated lime (Ca(OH)₂) - into the gas stream (see Fig 4). The pollutant reacts with the lime to produce a dry waste which is collected in bag filters. The system has multiple stages of contact between gas and reagent with a relatively long residence time. It is efficient in removing fluorides, chlorides, sulphur oxides and particulates.

![Dry bed limestone scrubber](image_url)
**Wet scrubber**

Wet scrubbing involves passing the kiln exhaust gases through an aqueous solution of chemicals which react with the pollutants. Although this procedure is one of the most effective methods of flue gas scrubbing, the cost involved in the treatment, handling and disposal of the resulting liquids is often high.

**Other scrubbers**

There are a number of other scrubber designs on the market, most of them based on the systems already described. However, some new ones are also being developed.

In one, there are trays of beads which have been treated with a highly reactive coating. The trays are removed periodically for reprocessing. The system has no moving parts. Maintenance is, therefore, low and the coating on the beads can be changed to deal with other types of pollutants.

In another, pure limestone modules act as the absorbent. The system consists of stacks of honeycomb blocks within a steel cabinet. The walled structure maximises the reaction surface and provides efficient scrubbing. Again, there are no moving parts, so maintenance is low.
3.2.2 Efficiency and costs

The capital and operating costs for a scrubber vary according to the type of scrubber installed. The size of scrubber required depends, primarily, on the airflow through the kiln. Typical costs are illustrated below for a modern tunnel kiln producing 1.5 million bricks a week.

Table 3 summarises the range of efficiencies and costs for different systems. Running costs include waste disposal and fuel consumption.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Dry bed limestone scrubber</th>
<th>Dry cloth filter scrubber</th>
<th>Wet scrubber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluoride reduction (%)</td>
<td>up to 95</td>
<td>&gt;95</td>
<td>&gt;95</td>
</tr>
<tr>
<td>SO(_x) reduction (%)</td>
<td>-20</td>
<td>&gt;50</td>
<td>&gt;90</td>
</tr>
<tr>
<td>HCl reduction (%)</td>
<td>-20</td>
<td>&gt;50</td>
<td>&gt;95</td>
</tr>
<tr>
<td>Costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Capital cost (£)</td>
<td>120 000 - 500 000</td>
<td>400 000 - 700 000</td>
<td>120 000 - 700 000</td>
</tr>
<tr>
<td>Running costs (£)</td>
<td>5 000 - 40 000</td>
<td>40 000 - 120 000</td>
<td>40 000 - 120 000</td>
</tr>
</tbody>
</table>

Table 3 Evaluating costs and efficiency for different scrubbers

Further information on evaluating efficiency and costs associated with adopting cleaner technologies is given in the Environmental Technology Best Practice Programme’s Good Practice Guide (GG82) *Investing to Increase Profits and Reduce Wastes*. 
3.3 DISCUSSION

The new emerging techniques of process optimisation have the environmental advantage of reducing pollution at source rather than removing it from the discharge stack. They also have the commercial advantage of costing less than scrubbers. Because the techniques are integrated into production, they focus on the manufacturing process instead of a new end-of-pipe process.

Where process optimisation is inadequate to ensure compliance, the most frequently applied end-of-pipe technique in industry is the dry bed limestone flue gas scrubber. It is likely to remain the most commonly applied end-of-pipe technology over the next five years. Dry cloth filter scrubbers may have limited application where other acid gas species need to be reduced, in particular sulphur oxides (SOx). Wet scrubbers have comparable costs to dry cloth filter scrubbers and extra requirements associated with liquid effluent treatment.

New scrubbing techniques are being developed as suppliers see the market develop. Some are current technologies offered by new companies, but there are also interesting new technologies with fewer or no moving parts and low start-up costs. Suppliers are likely to obtain a significant share of the market where these technologies offer greater operating flexibility at a lower capital cost. Before you choose such an option, make sure you research the suppliers of the reactant fully to ensure security of supply.
Choosing a new technology involves many technical, financial and psychological factors. This Section (along with Sections 5 and 6) considers these in turn to help you to select the technology best suited to your manufacturing process and business methods. Good Practice Guide (GG109) Choosing Cost-effective Pollution Control is also a valuable source of information about selecting the most suitable pollution control measures as part of an overall waste management strategy.

The first decision to make is whether you want to use a reduction-at-source or an end-of-pipe solution. In adopting new technology, you must make sure the existing process can accommodate it. The following review will help you match the appropriate technique to your process.

### 4.1 EMISSION FACTORS

This Section looks at the stack emissions and related factors you need to consider in making your decision.

#### 4.1.1 Fluorides

The best place to start the selection process is to determine the fluoride levels in the stack - very high levels make reduction-at-source options risky and therefore favour end-of-pipe solutions. Fig 5 illustrates how the level of fluoride emissions are likely to influence the decision.

#### 4.1.2 Chlorides

Gaseous chlorides in the flue gases react with the reactant in flue gas scrubbers. Dry bed limestone scrubbers may remove around 20% of the total chloride present, but the proportion may be higher if other scrubber reactants are used, eg lime. In most of the brick industry, this is not a significant factor in selecting the abatement technique. However, you may need to make an allowance for removing chlorides when calculating the running costs of a scrubber. The presence of chlorides can affect the operation of a scrubber (see Section 7.5).

Reduction-at-source methods also reduce chloride emissions. The presence of chlorides does not interfere with process optimisation techniques.
4.1.3 Sulphur oxides

Sulphur oxides, which may be present in the flue gases as SO$_2$ or SO$_3$, also react with the reactive material in flue gas scrubbers. A dry bed limestone scrubber removes approximately 20% of the SO$_x$, but this figure can be significantly higher if other reactants, such as lime, are used. Tell the supplier if you believe SO$_3$ is present in significant amounts. Its highly reactive nature may affect scrubber operation. In most kilns, SO$_2$ is the dominant type present and has a lower reactivity with limestone. As with chlorides, remember to make an allowance for reactant consumption and disposal.

A high level of SO$_x$ in the flue gases may restrict the options for reduction-at-source. In particular, directing the flue gases through a preheater may cause scumming of bricks. As with chloride and fluoride, process optimisation techniques also reduce SO$_x$ emissions.

4.1.4 Nitrogen oxides

At the levels generally emitted from ceramic kilns, these acid gas emissions are not a major factor in the decision-making process for selecting fluoride abatement technology.

4.1.5 Dust

Dust is produced at low levels by most modern kilns and is not a key factor in the decision-making process. However, if a kiln discharges high levels of dust, it may affect the operation of a flue gas scrubber by increasing the waste material or increasing the pressure drop across the scrubber.

4.1.6 Flow

Flow is a key factor in reduction-at-source (see Table 2). For scrubbers, the volume flow through a stack is the dominant factor in determining both the size and type required.

Because a flue gas scrubber should present a constant and relatively low resistance to the flow of flue gases, a larger volume of scrubber is required for a greater airflow even when fluoride levels are lower. The scrubber must provide sufficient contact between the flue gases and the reactant for long enough to ensure efficient fluoride removal. It must also have a mechanism for removing the waste products without affecting the flow of flue gases.

It is essential that any scrubber has a by-pass feature to allow the kiln to operate while the scrubber is blocked or otherwise inoperable.

All end-of-pipe solutions work best with a constant flow of flue gas at a constant temperature. Where this is not possible (e.g. with an intermittent kiln), the scrubber must be large enough to accommodate the greatest flow of kiln gas emitted over the schedule. The scrubber must also be able to cope with warm moist gases while running cold without forming condensation. In these circumstances, simple low-mass modular scrubbers with no moving parts have advantages.

If a tunnel kiln is switched off every weekend, the scrubber must be able to accommodate a start-up cycle.

4.1.7 Summary

Fluoride concentration is the most important factor in deciding whether to use a process optimisation or end-of-pipe solution. It is, therefore, essential for you to obtain detailed information on fluoride emissions and their variability from the process requiring abatement.

4.2 BUSINESS AND MANAGEMENT FACTORS

Whichever solution you decide to adopt, it must be compatible with your management priorities. The following procedure aims to match business objectives and management priorities with the abatement technology selected. You will find it particularly useful if your fluoride emission analysis indicates that both reduction-at-source and end-of-pipe solutions are suitable.
Step 1
Determine the relative importance of the following factors. Omit those not relevant to your business and add others as appropriate. Decide how important the factor is to you by giving it a rating of 1 (least important) to 10 (most important).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Examples of rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guaranteed compliance</td>
<td>8</td>
</tr>
<tr>
<td>Capital cost</td>
<td>8</td>
</tr>
<tr>
<td>Running costs</td>
<td>8</td>
</tr>
<tr>
<td>Speed of implementation</td>
<td>1</td>
</tr>
<tr>
<td>Providing the best environmental option</td>
<td>4</td>
</tr>
<tr>
<td>Technical and management supervision</td>
<td>2</td>
</tr>
</tbody>
</table>

Step 2
After reading Sections 5 and 6, evaluate the two abatement alternatives - reduction-at-source process optimisation and end-of-pipe flue gas scrubbing. Assign each with a score from 1 (unlikely to meet this criterion) to 10 (highly likely to meet this criterion). Table 4 has assigned scores from 1 (worst) to 10 (best) based on the general characteristics of the technologies. You may wish to modify these based on your own experience.

Multiply the factor rating calculated in Step 1 with the technique score to give a weighted score. You will then be able to judge whether process optimisation or scrubbing matches your business needs most closely.

<table>
<thead>
<tr>
<th>Critical factor</th>
<th>Rating of importance to your company</th>
<th>Scrubbers</th>
<th>Process optimisation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Score</td>
<td>Weighted</td>
<td>Score</td>
</tr>
<tr>
<td>Guaranteed compliance</td>
<td>8</td>
<td>9</td>
<td>72</td>
</tr>
<tr>
<td>Capital cost</td>
<td>8</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>Running cost</td>
<td>8</td>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>Speed of implementation</td>
<td>1</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Best environmental option</td>
<td>4</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Ease of supervision</td>
<td>2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Total weighted score</td>
<td>166</td>
<td>188</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 Business factors evaluation table

In this example, process optimisation receives the higher score, suggesting it is more closely aligned with company priorities. A discussion of the various business factors is provided below.

4.2.1 Guaranteed compliance
Companies looking for a guarantee of compliance to a certain level of emission will tend to look towards scrubbing techniques because they are usually supplied with a performance guarantee.

Since process optimisation does not offer equivalent guarantees, the chance of success needs to be estimated so you can allocate it a score from 1 to 10 in Step 2. For the example in Table 4, odds of 3:1 have been assumed in favour of the planned process modifications reducing the stack fluoride emission level from 35 mg/m³ to below 10 mg/m³. A score of six was considered appropriate to this level of risk. A higher score would be appropriate if the starting point was lower than 35 mg/m³. Talking to the regulator may help in sharing concerns over any potential risk, although compliance with the 10 mg/m³ limit will be expected to be achieved.
It is important to make sure process optimisation will work for you before implementing it. The level of 35 mg/m³ used in this publication assumes that no process optimisation measures, as described in this Guide, have been applied. It incorporates a safety margin that ensures a good chance that emissions will reach the 10 mg/m³ limit once process optimisation is in place. For any company in doubt about its present levels of emission, or that may be above the 35 mg/m³ threshold, it is worth remembering the following.

4.2.2 Cost
This is always an important part of an initial evaluation of technology and some indications are given in subsequent sections. Contact suppliers, or people with first-hand experience, to obtain comparative data. Make sure all costs are included when you are assessing your options for pollution control. These include:

Capital cost:
- cost of equipment and associated items.

Running costs:
- raw material purchases;
- electricity for motors, fans and pumps;
- charges for disposal of waste by-product;
- fuel for heaters and burners;
- maintenance;
- increased labour for operation;
- increased energy consumption;
- wasted resources.

4.2.3 Speed of implementation
Trying to find a quick end-of-pipe solution to a pollution problem may mean you miss opportunities to minimise the problem at source. Talk to your regulatory authority and agree timescales for compliance within statutory limits. Even if you decide to adopt an end-of-pipe solution, you should not rush such an important decision.

4.2.4 Best environmental option
The best option depends very much on local circumstances. Although end-of-pipe solutions reduce acid gas emissions effectively, they also have several environmental disadvantages including generation of waste products, consumption of resources and higher energy usage. Many of these can be avoided by using process optimisation techniques. In general, preventing pollution at source is best for the environment.
4.3 OTHER FACTORS

Other factors that can influence your decision include:

**Future trends.** When you are choosing abatement techniques with a life expectancy of ten years or more, you should consider carefully future production trends (e.g., raw material supply, product type, new manufacturing technology) and future legislation on emissions and health and safety.

**Improved company image.** Company image is increasingly important to a company’s competitive position. Many retailers and product users now request information on a company’s environmental performance. The local community also expects a higher level of environmental performance from manufacturers. Justifying a technique as the best environmental option may increase in importance in the near future.

4.4 SELECTION

At this stage, you should be in a position to select the most appropriate type of abatement technology. It will be helpful if this is a clear decision for each site. Table 5 summarises the different positions you are likely to adopt.

<table>
<thead>
<tr>
<th>Options</th>
<th>Reasons</th>
<th>Next action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do nothing</td>
<td>Already complies with the authorised limit</td>
<td>Adopt appropriate best practice for minimising emissions</td>
</tr>
<tr>
<td>Definitely adopt process optimisation</td>
<td>Emissions below 35 mg/m³</td>
<td>Prepare process optimisation plan (see Section 5)</td>
</tr>
<tr>
<td></td>
<td>Willing to accept small risk, carried out successful trials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Convinced it is the BATNEEC* option</td>
<td></td>
</tr>
<tr>
<td>Probably adopt process optimisation but will</td>
<td>Process suitable for change</td>
<td>Return to the procedure described in Section 4</td>
</tr>
<tr>
<td>scrubbing as a back-up</td>
<td>Would like a back-up option</td>
<td>or Prepare process optimisation plan and carry out trials (see Section 5)</td>
</tr>
<tr>
<td>Probably install a scrubber but may look at</td>
<td>Not confident about process optimisation</td>
<td>Seek independent advice</td>
</tr>
<tr>
<td>process optimisation</td>
<td>Emissions above 60 mg/m³</td>
<td></td>
</tr>
<tr>
<td>Definitely install a scrubber</td>
<td>Unwilling to take any risk of non-compliance</td>
<td>Prepare tender specification (see Section 6)</td>
</tr>
<tr>
<td></td>
<td>Process unsuited to change</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Convinced it is the BATNEEC* option</td>
<td></td>
</tr>
</tbody>
</table>

* Best available techniques not entailing excessive costs

*Table 5 Process evaluation table*
Once you have decided to investigate process optimisation, you need to devise a strategic plan highlighting the actions and sequence to follow.

5.1 PROJECT PLANNING

Planning is crucial to the success of any project. It makes the project as straightforward and effective as possible and ensures smooth running of subsequent phases.

5.1.1 The team

It is very important to select the right team for the project. You may decide you can proceed without any external help, or you may find there are some parts that would benefit from the viewpoint of an external company with knowledge and experience in this field.

Devise a checklist of tasks and allocate them to the team accordingly. The checklist should include:
- project co-ordination;
- monitoring;
- equipment installation;
- laboratory trials.

5.1.2 Documentation and communication

Make sure all the project documentation is reported correctly and distributed to the relevant people. Projects normally fail when there is a breakdown of communication between parties. To avoid this at an early stage, plan regular review meetings and make your team aware of the importance of good documentation and communication.

5.1.3 Familiarisation and information exchange

During the planning stage, arrange for an initial transfer of knowledge to the team so they understand fully the key issues and all the decisions available to modify the process. Start by familiarising key staff with the basic theory and mechanisms controlling fluoride emission. During this introductory period, collect a basic description of the materials, the processing equipment and the manufacturing control parameters to form the foundation for the next stage.

5.2 DECIDING ON APPROPRIATE CHANGES

To determine which process optimisation options are suitable for your process, you need to have information on the specific characteristics of the raw materials, the product and the firing process. You may already have completed much of this work in the decision-making stage and this will be a good foundation for further analysis.

5.2.1 Fluoride profile

The map of fluoride movement within the kiln forms the basis for selecting the most appropriate abatement techniques. It identifies the key emission/absorption areas and allows you to focus attention on those areas where modification is most appropriate.

To carry out a fluoride profile, measure the fluoride concentrations at five or six points within the kiln from the stack to the firing zone. By correcting for airflow, you can determine the mass flow
of fluorides (travelling from the firing zone to the kiln stack). This information can then be used to identify opportunities for process optimisation.

5.2.2 Kiln review

This involves a detailed survey of the kiln, appraising its current capabilities and assessing the scope for modifications to its structure and operating conditions.

A kiln review should include:

- kiln construction, builder, date of construction, major modifications and dimensions;
- schematic drawings of the kiln;
- speed push of cars through the kiln;
- temperature control zones, identification of the temperature control zones;
- time-temperature profile (this can be measured using an under-car sensor);
- details of burners, self/part-igniting burners, fuel types, burner capacities;
- throughput information, production levels;
- quality assurance information on compressive strength, dimensions, efflorescence, water absorption and rejection levels;
- setting patterns sketch diagrams;
- exhaust conditions;
- firing schedule.

Table 6 provides an example of typical survey information.

<table>
<thead>
<tr>
<th>Tunnel kiln number 1</th>
<th>Survey information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kiln type</td>
<td>Tunnel</td>
</tr>
<tr>
<td>Date of construction</td>
<td>1993</td>
</tr>
<tr>
<td>Number of kilns</td>
<td>2</td>
</tr>
<tr>
<td>Length</td>
<td>123 m</td>
</tr>
<tr>
<td>Internal width</td>
<td>5.00 m</td>
</tr>
<tr>
<td>Internal height</td>
<td>2.15 m</td>
</tr>
<tr>
<td>Height above kiln car to the roof</td>
<td>0.95 m</td>
</tr>
<tr>
<td>Number of kiln cars</td>
<td>24</td>
</tr>
<tr>
<td>Setting</td>
<td>Number of bricks on car plus diagrams</td>
</tr>
<tr>
<td>Clay type</td>
<td>Alluvium</td>
</tr>
<tr>
<td>Weight of dry brick</td>
<td>3.85 kg</td>
</tr>
<tr>
<td>Weight of fired brick</td>
<td>3.42 kg</td>
</tr>
<tr>
<td>Push interval</td>
<td>14.4 minutes every 1/4 kiln car</td>
</tr>
<tr>
<td>Production rate</td>
<td>2 131 bricks/hour</td>
</tr>
<tr>
<td></td>
<td>18 667 560 bricks/year</td>
</tr>
<tr>
<td>Fuel</td>
<td>Natural gas</td>
</tr>
<tr>
<td>Number and rating of side burners in the heating zone</td>
<td>26 @ 200 kW</td>
</tr>
<tr>
<td>Number and rating of side burners in the firing zone</td>
<td>36 @ 160 kW</td>
</tr>
<tr>
<td>Number and rating of top burners in the firing zone</td>
<td>22 @ 30 kW</td>
</tr>
<tr>
<td>Airflow</td>
<td>See kiln airflow balance</td>
</tr>
<tr>
<td>Firing schedule</td>
<td>Predrying time</td>
</tr>
<tr>
<td></td>
<td>Preheating time</td>
</tr>
<tr>
<td></td>
<td>Heating rate to top temperature</td>
</tr>
<tr>
<td></td>
<td>Dwell at top temperature</td>
</tr>
<tr>
<td></td>
<td>Cooling</td>
</tr>
</tbody>
</table>

Table 6 Survey information
In addition to the survey information, planning should also assess the processes’ ability to adapt to process optimisation. This should include:

- assessing the space available for retrofitting a recirculation system;
- determining the availability of access points for sampling the kiln atmosphere;
- identifying possible sites for adding high-velocity burners or fans.

### 5.2.3 Fluoride mass balance

Obtain an analysis of the fluoride concentration (ppm) in the dry clay and fired ware. These data, combined with the production throughput, give a fluorine mass balance (note the values are expressed as fluoride (F)):

- Mass of fluoride into kiln (kgF/hour) = Mass of dry clay/hour (kg/hour) \times \text{fluoride content of dry clay (kgF/kg of dry clay)}
- Mass of fluoride out of kiln (kgF/hour) = Mass of fired clay per hour \times \text{fluoride content of fired clay}
- Fluoride discharged (kgF/hour) = Mass of fluoride into kiln - mass of fluoride out of kiln

This information provides the benchmark conditions for the process.

### 5.2.4 Current fluoride re-absorption level

Samples of the formed green product are fired in a laboratory intermittent kiln to the standard time-temperature profile used in production. If appropriate, a comparison can be made between different clay types. The fluoride emission profile obtained shows the temperatures at which the emission starts and the range where the rate of emission is greatest. The area under this curve represents the total amount of fluoride emitted and allows specific emission (kgF/kg of fired product) to be calculated. This figure can be related to the product throughput and the stack emission to give an indication of the fluoride re-absorption currently occurring in the system.

### 5.2.5 Absorption capacity

By exposing the green product to a fluoride-containing atmosphere (e.g., the stack), you can estimate the ability of the clay to absorb fluoride. This will give an indication of how much more fluoride the system can re-absorb during production, i.e., over and above the re-absorption presently occurring.

### 5.2.6 Additives

Investigate the effect of additives on both the emission and absorption behaviour of the product. Place particular emphasis on maintaining product quality and minimising the increase in manufacturing costs.
5.3 EVALUATING TECHNIQUES

Combining the process and material information builds a picture of the absorption and emission characteristics of manufacturing processes. From this, you can evaluate each technique.

Table 7 provides an appropriate template for summarising your conclusions. An outline of the function of each technique and its potential effectiveness is given in Section 3.1.1.

<table>
<thead>
<tr>
<th>Abatement technique</th>
<th>Method</th>
<th>Likely reduction</th>
<th>Ease of implementation</th>
<th>Cost</th>
<th>Other factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modifying the time-temperature profile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reducing the airflow through the kiln</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increasing the turbulence in the preheat zone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increasing the interaction between the product and the flue gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilising the flue gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adding a fluoride reactive component</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7 Template for assessing HF reduction options

All factors must be considered before implementation. When considering the practicalities, you should obtain as much information as possible about implementation. You may need to ask advice from key people, eg the kiln manager or the kiln builder, or a consultant.

5.4 IMPLEMENTATION PLAN

Having chosen your method of process optimisation, you must make sure it is installed properly and runs effectively. First, you should decide what has to be done for implementation and then devise a time plan. This is essential to minimise disruption to production and waste of ware.

Once you have carried out trials, you need to work out the fine details for full implementation. The factors for consideration could include the following:

- What equipment do we need?
- When will the trials finish?
- Who is going to carry out the work?
- What other measures are we employing?
- How many trials are we doing?
- How are we documenting them?
- What quality control requirements are we going to use?

Your overall project plan will probably look something like Table 8.
5.5 CHECKLIST

This checklist will help you prepare for the selection and implementation of process optimisation.

**Selection**
- Monitor all gaseous emissions - highest and typical range values.
- Measure all exhaust gas flows - highest and typical range values.
- Conduct a process survey and determine the extent to which your current process can be modified using process optimisation techniques.
- Carry out experiments to determine the reductions that can be achieved by process optimisation techniques (use consultants if necessary).
- Consult with suppliers, contractors and consultants to determine the costs of implementing process optimisation.
- Determine one, two or a maximum of three process optimisation techniques to implement and estimate the emission level you expect to achieve.

**Implementation**
- Select an appropriate measurement technique to monitor the fluoride emission reduction achieved, e.g., continuous analyser, bubbler method.
- Plan the implementation at the same time as you carry out a pilot-scale investigation (if appropriate).
- Make sure the plan is agreed jointly by the production, technical and environmental departments.
- Inform the local authority or regulator of the plan, take note of their comments and ask them to support your approach.
- Make process changes gradually to minimise the risk to production.
- Monitor fluoride emissions on a regular basis.
- Wait until all the planned process optimisation techniques have been implemented before making final emission measurements because fluoride reductions can take a long time to work through a process.
- Obtain independent verification of the reduced emission value.

### Table 8 Overall project plan for process optimisation

<table>
<thead>
<tr>
<th>Action</th>
<th>Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planning stage</td>
<td></td>
</tr>
<tr>
<td>Determination of material and process</td>
<td>1</td>
</tr>
<tr>
<td>characteristics</td>
<td>2</td>
</tr>
<tr>
<td>Assessment of abatement techniques</td>
<td>3</td>
</tr>
<tr>
<td>Implementation plan</td>
<td>4</td>
</tr>
</tbody>
</table>

**Table 8 Overall project plan for process optimisation**
If your company's preference is to purchase an end-of-pipe solution (which is most likely to be a flue gas scrubber), the next decision is which type of scrubber would best suit your process.

The different types of scrubber are outlined in Section 3.2.1. Even if you have a bias towards a particular type with which you are familiar, it is wise to keep an open mind and consider all options at this stage.

Before deciding which scrubber suppliers to approach, you need to define your operating requirements. Use these to select a short list of technologies that will best meet your operating criteria. Some important operating criteria are outlined below to help you. You may wish to add other criteria reflecting the particular requirements of your site.

6.1 WHAT TYPE?

Choosing the type of scrubber involves an in-depth evaluation of the technologies currently on offer and a risk analysis of their chances of achieving the required fluoride emission reduction. Some of the technologies are well established while others are new. Although the latter may offer advantages, they may not have a proven track record.

Scrubbers rely on the ability of a reactant, most commonly limestone (CaCO₃), to remove effectively 95% of the fluorides present in the flue gases. Problems that tend to arise over the medium-to-long term include:

- maintaining high reaction rates between the reactant and flue gas components;
- the scrubber becoming blocked with excess dust (from the firing and scrubbing processes);
- engineering problems affecting operation and/or maintenance requirements;
- corrosion.

Ask for evidence of the scrubbing efficiency of the technologies in a number of different flue gas conditions and over a time period of, say, three to six months. Also consider the following:

- Is the reactant widely available from more than one supplier?
- What is the cost of the reactant?
- Is the reactant safe and easy to handle?
- What other reactions will occur in the scrubber (eg with HCl and SOₓ) and how will these affect the operation?
- What is the nature of the waste product, how much is produced and what is the disposal route?
- What is the pressure drop across the unit; is it constant or does it vary with time?
- Is there a risk of blockage or condensation within the scrubber?

Also consider the following engineering issues:

- How complex is the plant? Is there a lot to go wrong and/or is it difficult to operate?
- Is it fail-safe, eg if it goes wrong, can the kiln still operate?
- How much supervision and maintenance does the plant need?
Is the materials handling of reactant and the waste product well engineered and reliable?

What is the size and weight of the unit?

What will be the cost of the civil engineering work?

6.2 RISK

No project is completely risk free, but if you decide you want minimal risk, you should choose your scrubber and scrubber manufacturer accordingly. Fig 6 should help with this decision.

![Fig 6 Risk analysis](image)

6.3 COSTS

Since the purchase of a scrubber represents a major capital cost, this factor should be taken into consideration at an early stage. Quoted prices for scrubbers can vary greatly and it is important when you are evaluating estimates to compare them on a like-for-like basis.

When you are reviewing costs as part of an initial evaluation, make sure you cover:

- the purchase price of a suitably-sized scrubber unit installed and commissioned;
- the purchase price of additional items such as new stack, new exhaust fan, new ductwork, preheat burner and monitoring access when installed and commissioned;
- the cost of purchasing the reactant plus the expected consumption rate and disposal cost of the waste product;
- running costs in terms of energy, supervision and maintenance;
- life expectancy and replacement cost.

The best investment is likely to arise from an appropriate balance between cost, expected performance and risk. Remember, a poor investment may require replacement or extensive modification and will deflect management time away from the main activities of the company.

6.4 IDENTIFYING SUPPLIERS

The Environment and Energy Helpline on 0800 585794 can provide a non-exhaustive list of suppliers of scrubbers. You may find other suppliers and it is worth reviewing trade literature regularly for new entrants to the UK market.
Suitable companies may be short-listed on the basis of criteria such as:

- their interest;
- their availability;
- their previous experience;
- their past performance;
- their financial position.

There are two kinds of scrubber supplier, as described below.

### 6.4.1 Turnkey supplier

A turnkey supplier provides the complete service from specification to installing the scrubber, ductwork and fans through to testing the outlet emission concentrations.

Most of the scrubbing systems installed in the heavy clay industry to date have used a turnkey contractor.

### 6.4.2 Vendor supplier

A vendor supplier provides part of the complete service, e.g., installation of the scrubber or installation of the ductwork and fans only.

If you are considering using vendors, you must have the knowledge, experience, time and confidence to organise such a large task. You may save money, but it could be at the expense of increasing the risk of failure due to poor performance of the scrubbing system.

### 6.5 PROVIDING INFORMATION TO SUPPLIERS

Suppliers need specific information to provide you with an estimate of the work. The job of evaluating the offers is much easier if the same information is given to each supplier. The following checklist represents the essential information your specification should contain. The information used for tendering does not need to contain every detail, but it must provide enough information to allow suppliers to price both the work and the risks. Provide each tenderer with the same information and the same timescale to submit a tender. A reasonable period for a final agreed cost is between six to eight weeks.

Table 9 gives an example of a specification for scrubber suppliers.

#### 6.5.1 Emission information

Provide as much detail as possible, i.e., both the average emission concentration value and the range over which the scrubber will be expected to operate. Decide on an average representative value that will enable accurate running costs to be calculated. Do not supply information on fluorides alone—also give data for HCl, SO\(_2\), NO\(_x\), and dust. Figures should be reported as measured at standard temperature and pressure (stp) so the supplier can calculate mass flows. Provide the oxygen content within the stack emissions so suppliers can make their own correction to 18% oxygen (specify either wet or dry basis).

#### 6.5.2 Exhaust gas flow rate

This is a vital piece of information as it will determine the size and maximum capacity of the scrubber. Look closely at the exhaust flows for all production conditions and for the maximum capacity of the kiln. If you are planning to increase kiln capacity within five years, ask yourself if the scrubber will be able to cope with the additional exhaust flow. Specify a flow rate that will at least cope with the maximum current flow rate. Allow a reasonable contingency provision of, say, 10 - 20% to accommodate any production increases.
<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Lowest level</th>
<th>Highest level</th>
<th>Average at stp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluorides (as HF, mg/m³)</td>
<td>26.4</td>
<td>30.7</td>
<td>28.6</td>
</tr>
<tr>
<td>Chlorides (as HCl, mg/m³)</td>
<td>30.2</td>
<td>43.8</td>
<td>37.0</td>
</tr>
<tr>
<td>Oxides of sulphur (as SO₂, mg/m³)</td>
<td>105.6</td>
<td>120.9</td>
<td>113.3</td>
</tr>
<tr>
<td>Oxides of nitrogen (as NO, mg/m³)</td>
<td>10.2</td>
<td>40.1</td>
<td>25.2</td>
</tr>
<tr>
<td>Particulates (total, mg/m³)</td>
<td>3.2</td>
<td>4.5</td>
<td>3.9</td>
</tr>
<tr>
<td>Oxygen (%)</td>
<td>15.2</td>
<td>19.6</td>
<td>17.4</td>
</tr>
<tr>
<td>Stack temperature (°C)</td>
<td>132.9</td>
<td>133.4</td>
<td>133.15</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>3.9</td>
<td>4.0</td>
<td>3.95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (m³/hour) at STP</td>
<td>36 255</td>
</tr>
<tr>
<td>Provision in stack flow for production rate (m³/hour) at STP</td>
<td>43 506</td>
</tr>
<tr>
<td>Contingency (%)</td>
<td>20</td>
</tr>
<tr>
<td>Maximum flow rating for scrubber (m³/hour) at STP</td>
<td>43 506</td>
</tr>
<tr>
<td>Stack diameter (m)</td>
<td>1.3</td>
</tr>
</tbody>
</table>

* As defined by the Secretary of State's Process Guidance Note PG3/2(95)

** Dependent on the sulphur content of the clay

<table>
<thead>
<tr>
<th>Sulphur content</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.12%</td>
<td>500 mg/m³</td>
</tr>
<tr>
<td>&gt; 0.12%</td>
<td>2 000 mg/m³</td>
</tr>
</tbody>
</table>

Table 9 Example specification for scrubber suppliers

### 6.5.3 Site and services

The scrubber should be sited as close as possible to the kiln flue and the exhaust stack. State what services are currently provided to the site and their capabilities.

### 6.5.4 Performance specification

For the non-fletton brick industry, the fluoride limit specified within the Secretary of State’s Process Guidance Note PG3/2(95) is 10 mg/m³. This should be the minimum specification. Many companies may look for a 5 mg/m³ guarantee which is the limit specified by many of our European Union partners.

### 6.5.5 Kiln type and manufacturer

Provide appropriate information about the kiln, its date of manufacture, details and dates of any modifications carried out, fan details, capacity, etc.

### 6.6 EVALUATING TENDERS

The object of tendering is to secure the best value for money for the type and design of scrubber required. Most companies are experienced in evaluating offers from a number of suppliers. A scrubber is a specialist piece of equipment with which many companies will have little or no experience. Therefore, it is very important to organise an internal team to evaluate the tenders. Use consultants if time or expertise is in short supply within your organisation.

When you receive a quotation, you should check that the supplier has understood your specifications and they have quoted for all the items requested. Tenders should be examined for both content and any major inconsistencies. Obvious errors should be presented to the tenderer so that they can be amended.
It is advisable to have at least three to six tenders for evaluation as there can be considerable cost differences. The tenders should be evaluated in a systematic manner against your criteria. Information on how to evaluate tenders for pollution control technology is contained in Good Practice Guide (GG109) Choosing Cost-effective Pollution Control which is available free of charge through the Environment and Energy Helpline on 0800 585794.

A selection matrix similar to that described in Section 4.2 may help you evaluate scrubber tenders. This should list your criteria for making the decision and allow you to apply quantitative judgements to the decision-making process. Table 10 is an example of an evaluation table.

The weighting factor expresses the importance of each criterion on a scale of 1 (not important) to 10 (essential). The score expresses your impression of the tenderer’s performance for each criterion on a scale of 1 (very poor) to 10 (excellent). A high total final mark indicates a good tender. Evaluating tenders in this way will help you eliminate most suppliers so you can focus on the one or two front runners.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weighting factor, (W) 1 to 10</th>
<th>Score, (S) 1 to 10</th>
<th>Final mark W x S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost over five years*</td>
<td>8</td>
<td>6</td>
<td>48</td>
</tr>
<tr>
<td>Performance</td>
<td>5</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Simplicity</td>
<td>3</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Guarantees offered</td>
<td>8</td>
<td>8</td>
<td>64</td>
</tr>
<tr>
<td>After-sales service</td>
<td>4</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Risk and costs of failure</td>
<td>4</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Supplier rating</td>
<td>5</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>220</td>
</tr>
</tbody>
</table>

* Indicating capital depreciation over five years, interest on the loan and all running costs.

Table 10  Evaluating scrubber tenders

6.7 PRE-CONTRACT ARRANGEMENTS

Once you have chosen your technology and supplier, and agreed the specification, scope of supply and the price, you are in a position to make the pre-contract arrangements. However, the following issues need to be considered before placing an order.

6.7.1 Planning permission

You must get planning permission for a scrubber and approval for the chimney height before installation. If you are in doubt whether planning permission is required, contact the planning department of your local authority.

6.7.2 Structural assessment

You may need to make an assessment of the ground conditions for foundation works for some scrubbers. Make sure that the responsibility for ensuring adequate foundations is agreed before placing any contracts.

6.7.3 Contract conditions

The contract conditions require considerable input to determine the proposed contract, its period, any warranty arrangements and the amount and type of insurance you will receive.

6.7.4 Working conditions

Site access and working arrangements for development work must be made clear. You also need to appraise special requirements, the health and safety plan and supervision of the work.
6.7.5 Installation timetable

The planned time of installation is as important for the client as it is for the supplier. At an early stage, you should specify to the supplier when you require the work to be finished. This could be a major stumbling block if it is not planned correctly. There may be problems if you want the work to be completed during a major factory shutdown common to the industry sector. This can obviously cause problems for scrubber manufacturers who may be able to complete only a few scrubber installations each year. Obtain a bar chart showing the expected duration of the main activities. An example is shown in Table 11.

<table>
<thead>
<tr>
<th>Action</th>
<th>Week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site clearance</td>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18</td>
</tr>
<tr>
<td>Lead time for manufacture</td>
<td></td>
</tr>
<tr>
<td>Site preparation</td>
<td></td>
</tr>
<tr>
<td>Installation</td>
<td></td>
</tr>
<tr>
<td>Commissioning</td>
<td></td>
</tr>
</tbody>
</table>

*Table 11 Example of a project schedule*

6.8 CHECKLIST

This checklist will help you prepare for the task of planning and selecting a scrubber.

**Planning**

- Rule out process optimisation.
- Monitor all gaseous emissions - highest and typical range values.
- Measure all exhaust gas flows - highest and typical range values.
- Consult on expected increases in stack gas flow.
- Survey site for suitable space and availability of services.
- Produce tender specification.

**Selection**

- Investigate and select scrubber types.
- Investigate and select potential suppliers.
- Investigate supply and disposal of reactants.
- Collect process information.
- Circulate tender documents.
- Discuss requirements with each supplier.
- Evaluate tenders.
- Review entire procedure; consult and confirm selection.
- Agree final arrangements and conditions.
This Section provides advice on the efficient operation of a scrubber.

7.1 LIMESTONE (CaCO₃)

There are many limestone suppliers, so finding a suitable one should not be difficult. However, it is vital to the efficient operation of your scrubber that the limestone is of suitable grade and purity. It is advisable to investigate this before using a particular limestone in your scrubber.

7.1.1 Limestone grades

Your scrubber supplier should be able to advise you which grades of material to use with your scrubber. Most limestone suppliers have a wide variety of grades and can offer chippings for dry bed scrubbers and powders both for dry bed filter scrubbers and for incorporating within the brick product. Most can also provide limestone grades specific to customer requirements.

7.1.2 Limestone purity

An investigation into the efficiency of limestone types used in dry bed scrubbers indicates that limestones of similar purity can often differ in their absorption of fluorides. It is worth finding the most suitable type of limestone to use within your scrubber. Some limestone suppliers offer a technical support service that you can use to decide which of the products are best suited to your scrubber. In general, efficient scrubbing calls for a limestone that can withstand crushing, has a high purity and a large surface area.

7.1.3 Transportation

Transportation costs vary from supplier to supplier. The costs depend mainly on the quantity of material ordered and distance to your site. Most companies deliver by bulk pressure tanker, but some also deliver by rail.

7.2 WASTE

Make sure you choose the correct method of disposal for the waste by-product produced by the scrubber. The two main methods of disposal are incorporation into the brick product and landfilling.

7.2.1 Incorporation into the brick product

For most brick-making processes, it is possible to incorporate the scrubber waste material into the clay mix.

Before mixing, the waste must be milled into a fine powder to avoid lime blowing. This can be done using a milling device fitted to the discharge point of the scrubber. Your supplier may have a milling device which can be added to the scrubber or may be able to advise you which technologies can be fitted.

The main advantages of incorporation into the brick product are:

- no landfilling costs;
- no transportation costs;
- ability to mill scrubbing waste from more than one factory.
The degree of feedstock mixing varies from plant to plant and depends on factors such as the plant layout. The milled waste should be incorporated into the clay mix as a slurry. This ensures that the waste is well distributed throughout the clay body and it avoids agglomeration and potential lime blowing problems. In most cases, the waste constitutes less than 0.5% of the body mix.

7.2.2 Landfilling

Although limestone scrubber waste is often classed as ‘special’, the cost of landfilling ranges from £20 to £50/tonne. This is likely to rise as landfill space becomes scarce and the landfill tax increases.

7.3 MONITORING

The plant should already be monitored at regular set intervals according to Government guidelines. Take the opportunity during monitoring to analyse fully the scrubber’s performance and, if necessary, look at ways in which it can be optimised.

The highly reactive nature of airborne fluoride makes it an extremely difficult gas to sample and measure. Values at low concentrations are normally determined by extractive or continuous sampling.

7.3.1 Extractive sampling

This method is the industry standard for sampling fluoride in flue gases. It gives an accurate concentration of the fluoride content in the flue gases at the time of monitoring. The method involves pumping the flue gases through a caustic scrubbing solution to remove the gaseous fluorides. The solution is analysed for its fluoride content by weight (mg). Combining this information with the volume of the gas sampled gives the fluoride concentration in mg/m³.

7.3.2 Continuous sampling

A continuous analyser allows a company to obtain a complete emission profile for its process. It identifies emission peaks, trends and the effect of process changes. Continuous analysers can be either optical instruments based on infrared lasers, or a direct measurement using wet chemical methods to measure continuously the fluoride content.

It is often difficult to determine accurately the concentration of fluoride in flue gases. It is essential to identify the correct value so you will have confidence in your choice of abatement technology. Specialist contractors with experience in this area and the correct monitoring equipment are available to carry out this task.

7.4 OPTIMISING OPERATION

The operation of a flue gas scrubber depends on a chemical reaction between the pollutant (here, HF and other acid gases) and the reactant (usually lime or limestone). Efficient operation of the process requires a balance of the following factors:

- final gaseous fluoride discharge must be below the permitted limit;
- waste generated from the system needs to be minimised;
- a constant pressure drop must be maintained across the scrubber.

Optimising a scrubber is a long-term process not normally carried out by suppliers. The supplier commissions the scrubber using settings based on experience to ensure compliance to a discharge limit. It is quite likely that the commissioning engineers will err on the side of caution and commission the scrubber to produce more waste than necessary. Optimising the scrubber over six to eight months takes little effort and could reduce running costs considerably.
To optimise your scrubber, you need to measure:

- fluoride concentration before and after the scrubber;
- amount of waste produced/day;
- chemical composition of the waste product in terms of:
  - Ca(OH)$_2$ or CaCO$_3$
  - CaF$_2$
  - CaSO$_4$
  - CaCl

The aim is to minimise the percentage of unreacted material in the waste (ie Ca(OH)$_2$ or CaCO$_3$) without:

- reducing the scrubber efficiency so the discharge exceeds permitted levels;
- creating a build-up of dust which may cause an unacceptable increase in pressure drop across the scrubber and so disrupt the kiln.

Although it is not possible to specify accurately how much unreacted material will be left at the optimum refresh time, a level of 50% indicates an efficient process.

For dry bed scrubbers with a recirculation system including a peeling drum, you can adjust the rate at which the reactant is removed from the scrubber and recycled. Where the discharge concentration is consistently low and there are no pressure drop problems, reducing the rate of recycling reduces the amount of waste product.

For scrubbers without a recycling system, optimisation only involves selecting the appropriate time to change all of the reactant for a new batch.

### 7.5 HYDROGEN CHLORIDE (HCl)

**Warning**

It has been noticed that, under some circumstances, HCl emissions can increase after scrubbing. This is due to the release of previously reacted chlorides within the scrubber which are displaced by the more reactive fluoride compounds. In these circumstances, it may be necessary to replenish the reactant more frequently.

### 7.6 MAINTENANCE

The maintenance of a scrubbing system can either be included with the kiln maintenance routine or have its own maintenance plan. Make sure that at least one person takes on this responsibility. Remember, as with all processes, preventive maintenance reduces unplanned stoppages as well as saving materials and improving productive running time. Your supplier will help you devise a routine maintenance plan and may also provide you with a servicing package.

### 7.7 EMERGENCY PROCEDURES

As with any other process, the scrubber system should have an emergency procedure to cope with unusual events, eg breakdowns. This should include problem indicators that act as a warning sign of imminent problems. Because scrubbers usually operate continuously, devising a shut-down/start-up checklist can prevent problems from incorrect procedures. This should also contain maintenance checks that can be carried out only when the plant is shut down, eg during company holidays. The scrubber’s by-pass system should be tested regularly.
7.8 TRAINING

Make sure that operators and kiln managers are trained properly in the operation of the scrubber and that a training procedure is documented for new operators. The scrubber supplier normally carries out training. Some suppliers include this in the scrubber purchase price; others provide it at an additional cost.

7.9 HEALTH AND SAFETY

The health and safety of operators is paramount. The health and safety officer should ensure that operators are aware of health and safety procedures and that they are obeyed. As most types of scrubber are likely to be classed as an enclosed space, these procedures should be incorporated into the design of the scrubber.
The Environmental Technology Best Practice Programme is a joint Department of Trade and Industry and Department of the Environment, Transport and the Regions programme. It is managed by AEA Technology plc through ETSU and the National Environmental Technology Centre.

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FOR FURTHER INFORMATION, PLEASE CONTACT THE ENVIRONMENT AND ENERGY HELPLINE

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