Understanding and control of fugitive emissions

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ABSTRACT

A fugitive emission is a spurious emission of the process fluid, usually a hydrocarbon in gaseous form, from any plant component which relies on a seal to separate the process fluid from the environment. The major sources of fugitive emissions are valve glands, pump seals and flanged joints, and although emissions from individual components can be small the cumulative effect can be very significant.

In recent years the general topic of fugitive emissions from chemical plant has received increased attention, driven by environmental and legislator pressure, by the desire to achieve cost savings and in particular by the introduction in the USA of specific legislation for the monitoring and control of these emissions.

In areas where prescriptive legislation exists, chemical plant operators have no alternative but to comply with the legislation, and efforts have focussed on cost effective ways of achieving compliance. However, many countries, including the UK, do not currently apply prescriptive legislation and instead use a “goal based” approach, requiring operating companies to apply “Best Available Technology” (BAT) to achieve low emission levels.

This paper is split into three parts. The first part describes the techniques available for estimating, measuring and controlling fugitive emissions, and concentrates in particular on emissions from valve glands, flanged joints and pump seals.

The second part of the paper addresses the techniques that can be used to minimise emissions from plant components. Making use of real plant data and practical operating and maintenance experience, the paper presents methods for minimising fugitive emissions directed individually at valve glands, flanged joints and pump seals.

The final part of the paper describes a process that chemical plant operators can use to decide how to focus their efforts so that maximum environmental benefits can be achieved from given resources / funds. The paper uses real data from an operating plant in the UK to illustrate the process, and the benefits obtained from the application of a focussed approach to emissions control.

1 INTRODUCTION

Emissions from chemical plants have two main impacts. Firstly, emissions of process chemicals can cause damage to the environment or harm to the health of plant workers or the general public. Secondly, emissions of process or service chemicals represent financial loss to the operating company, chemicals which are not retained within plant equipment cannot be sold to customers.

There are two types of emissions from chemical plants, often called “design emissions” and “fugitive emissions”. Design emissions are those that are known about at the design stage, and designed into the process. Analyser vents and purge streams are examples of design emissions. Fugitive emissions are unanticipated or spurious emissions from any part of the process plant. These can occur wherever there is a seal between the process fluid and the external environment, for instance at flanged joints, valve glands and pump seals. Fugitive emissions from individual sources can be very small, but on plants with many thousands of similar sources the aggregated impact of fugitive emissions can be extremely significant, in some cases sufficient to cause a noticeable impact on the overall mass balance for the plant. A characteristic feature of fugitive emissions is that they are often unnoticed, and until recently the measurement and control of these emissions has received little attention.

During the 1990s environmental concerns led to increased focus on fugitive emissions, eventually leading to direct legislative control of these emissions in the USA. American legislation requires routine monitoring of fugitive emissions, and required operating companies to take action to eliminate emissions above a prescribed level. Direct legislation of this type has not been introduced in the UK, but the approach is recognised by the UK legislator and chemical plant operators are increasingly being expected to have in place programmes for monitoring and control of fugitive emissions.

This paper discusses the topic of fugitive emissions. The various techniques that are used for estimating emissions are presented, and the paper also describes the approaches that may be used for controlling emissions from the main sources (flanged joints, valve glands and pump seals). The paper presents a process that can be used to ensure the establishment and implementation of a cost effective programme for controlling fugitive emissions, and illustrates this with experimental data from a UK petrochemical plant.

2 ESTIMATION OF FUGITIVE EMISSIONS

There are three main techniques available for the estimation of fugitive emissions from given individual sources, and a knowledge of the total number of sources of a specified type is then required to allow estimation of the total losses from a particular plant. The three main techniques are the use of emission factors, concentration monitoring (sniffing) and direct mass flow measurement (bagging). Details of these methods is given in the USA Environmental Protection Agency document “Protocol for Equipment Leak Emission Estimates” EPA-453/R-95-017, ref 1. This document provides a comprehensive analysis of the available techniques. The following sections provide a brief description of the techniques, and identify the main advantages and disadvantages of each.

2.1 Emission Factors

Emission factors are published estimates of emissions from given source components, based on data gathered from chemical plant assets. Two sources of emission factors are quoted in Ref 1, those from the Synthetic Organic Chemical Manufacturing Industry (SOCMI) and Refinery Average Emission Factors. Typical examples are given in Table 1.

Component	SOCMI emission factors Kg/year/source	Refinery Average emission factors Kg/year/source
Valves	52	234
Pumps	174	998
Flanges	16	2

Table 1 Emission Factors

As can be seen from Table 1, the two sets of factors give different estimates of emissions from specified sources, however both agree that at a component level pumps leak more than valves, and in turn valves leak more than flanges

The use of emission factors allows very rapid estimation of emissions from a particular plant, provided that the number of component items is known for each source. However, there are a number of significant disadvantages with the use of emissions factors to estimate emissions:

- The factors were developed from experimental data from a number of plants, and therefore do not take into account plant specific issues, for example type of gasket and standard of fitting, type of gland seal arrangement etc.

- As can be seen in Table 1, the calculated emissions depend on the set of factors that are used to make the estimation.

- For the above reasons the use of emissions factors can lead to very inaccurate / misleading estimates

- The use of emissions factors does not allow leaking components to be identified, and therefore cannot be used to target repair activity at component level. That is, the process might establish / indicate for a particular plant that the likely biggest cause of emissions is valve glands, but it does not help identify which valves are leaking more than the average.

2.2 Concentration Monitoring (Sniffing)

Concentration monitoring, often known as sniffing, forms the basis of most programmes aimed at reducing emissions. The basis of this approach is to measure the concentration of the process fluid in the atmosphere close to the component being monitored. There are two basic approaches: In the first of approach those components that show a concentration above a certain value (nominally 10,000ppm, but other values have been used) are classed as “leakers” and assigned a higher emission rate than the components classed as “non-leakers”. Total emission values can then be derived by counting the number of leakers.

A more refined approach is to use the concentration as an indication of the size of fugitive emission, either directly as a figure measured in parts per million, or through conversion by the use of correlations into an estimated leak mass flow rate. This technique offers a number of advantages, as follows:

- The technique is described in Ref 1 and is used as the basis for most Leak Detection and Repair (LDAR) programmes, and is therefore accepted as good practice.

- The technique is simple and fast, and typically it is possible to monitor up to 200 components per day.

- The technique provides plant specific data.

- The technique allows individual leaking components to be identified and repaired.

- The measurement can be repeated after repair work to check that this has been effective.

However, there are some drawbacks:

- The monitored emission concentrations are sensitive to weather conditions and the competence of the technician.

- The technique does not give a direct measurement of leak mass flow rate; if this is required then it has to be estimated by the use of published or developed correlations.

- The technique requires an instrument capable of identifying the process fluid. For most hydrocarbons this is achieved using an organic vapour analyser. These instruments are suitably sensitive, but can be unreliable and can saturate at high leak rates.

Ref 1 contains correlations relating leak mass flow rate to measured concentrations, as shown by example in Table 2.

Measured concentration ppm	Leak mass flowrate according to SOCMI correlation (ref 1) kg/year / component		
	Flanges	Valve glands	Pump seals
50	0.7	0.5	4
500	4.5	3.7	30
50000	30	30	200
500000	200	200	1200
100000	350	380	2200

Table 2 Correlation of concentration to mass flow rate

2.3 Mass Flow Measurement (Bagging)

This is the most sophisticated of the techniques available for measuring fugitive emissions, and it does provide a direct mass flow measurement of the leak rate. The technique requires that the leak source is contained or "bagged". A carrier gas, usually nitrogen, is then passed through the bag at a known flowrate. The concentration of the process fluid in the carrier gas leaving the bag is measured, allowing the leak mass flow rate to be calculated. The advantages of this technique are as follows:

- It allows direct calculation of the leak mass flow rate.

- It can be used to develop plant specific correlation between concentration and leak mass flow rate.

- It can be used to identify leaking items, and the test can be repeated to demonstrate the effectiveness of repair work

- Compared to other techniques, bagging is accurate and repeatable

However, this technique is expensive and time consuming. Typically, bagging provides up to 5 sets of data per day, and consequently is not in widespread use other than to support the development of correlations.

3 CONTROL OF FUGITIVE EMISSIONS

Fugitive emissions can occur wherever there is a requirement to provide a seal between the process fluid and the external requirement, and where this seal is assumed from a design perspective to lead to insignificant or trivial leakage of the process fluid. Typical sources of fugitive emissions are:

- Flanged joints in pipework

- Valve gland assemblies

- Atmospheric vents
- Relief valve seal systems
- Unburnt flare losses
- Pump seal systems
- Compression fittings on instrument piping

The significance in overall emissions of components is a function of the leak mass flow from a typical component and the number of leaking components on the plant. For example on most chemical plants there are many more valves than pumps, so in terms of overall impact pump seals may be less significant than valve glands even if the leak rate from a typical pump seal is greater than that from a typical valve gland. Section 4 of this paper illustrates this point with data from a real plant.

As mentioned in Section 2, the most common technique for the measurement of fugitive emissions is concentration monitoring or “sniffing”. Using this technique, accepted practice is to define a given component as “leaking” when the emission levels rise above 500ppm. This limit is applied for most hydrocarbon duties, although lower levels may be specified for particularly hazardous process fluids.

Experience shows that for most chemical plants the three main components that influence overall plant fugitive emissions are normally flanged joints, valve glands and pump seals. This paper gives no further consideration to other potential source of fugitive emissions; either those components listed above or other possible components. The following sub sections make specific comments about the control of fugitive emissions from flanged joints, valve glands and pump seals.

3.1 Control of Fugitive Emissions from Flanged Joints

A flanged joint is a compressed joint assembly in which two pressure components are connected together, with the compression usually achieved by loading applied by bolting and the seal achieved using a gasket made from a suitable material. The flanged joint is a static joint, that is once the seal is made there is no requirement for the components parts to be able to move relative to each other.

Historically, the requirements for design and assembly of flanged joints have focussed on the avoidance of leaks large enough to cause gross losses of process fluid at levels that would result in visible leakage or failure on pressure testing. For flanged joints that are to be subject to process duties it has become established practise to “leak test” finished assemblies prior to plant start up. Leak testing of this type is often undertaken using nitrogen and the test gas, with the presence of a leak indicated by bubbles forming at the joint when at the joint is at pressure and covered with a prescribed “soapy fluid”. The so called “soapy bubble test” produces an accepted pass / fail test for flanged joint assemblies.

A number of features have been identified as important in ensuring leak free flanged joints:

- Correct joint design and calculation of the load required to seal the joint.

- Correct gasket selection.

- Correct assembly of components, all of which are confirmed to be in good condition prior to assembly.

- Correct application of the design load to achieve the specified compression of the gasket.

A number of papers have been produced to describe in detail the processes that are commonly used to ensure the reliable assembly of leak free gasketted joints e.g. (Ref 2). The following additional comments are relevant here:

1 Testing shows that gasketted joints that are made in accordance with the above key features and that pass the “soap bubble” test will reliably produce emission levels well below the suggested leak threshold of 500ppm.

2 Testing shows that correct alignment of the flanges is important if reliably low emission performance is to be achieved.

3 Correct assembly of a properly designed gasketted joint can give low emission performance, but the ability of the joint to continue to provide an effective seal depends upon a number of time dependent factors, particularly:

a. Relaxation of the bolts and subsequent loss of load.
b. Process / ambient temperature fluctuations.
c. Degradation / relaxation of the gasket material.

Given the above comments, it can be seen that proper design and tight control of assembly standards can be relied upon to produce gasketted joints that result in low fugitive emissions. Therefore routine monitoring of gasketted joints should not be necessary unless time dependent deterioration of the seal is likely. Furthermore, for most normal petrochemical and chemical processes, time dependent deterioration should not be an issue provided that correct gasket selection is undertaken and on this basis gasketted joints should not contribute significantly to overall plant emissions.

3.2 Control of Fugitive Emissions from Valve Glands

A valve gland joint is a compressed joint assembly in which a seal is achieved between the static component of the valve, the valve “stuffing box”, and the shaft that connects the valve handwheel to the component that controls the flow of the process fluid. The sealing material is the gland packing, compression of which is achieved by loading applied by bolting to the gland follower assembly. A typical set up is shown in figure 1. The valve gland joint is a static joint, but there is a requirement for the components of the joint to be able to move relative to each other when the valve is operated. This can be an occasional requirement, for instance if the valve is only opened / closed at plant shutdown or start-up, or a routine / continuous requirement, for instance in an automatic valve used to control process fluid flow rates. In all cases the compression assembly must not be overloaded to a point where operation of the valve is not possible.

Historically, most valve gland packings in chemical plant operation were asbestos based. More recently, most packing materials for fire – safe duties are graphite based, either in “structured graphite” or “braided graphite” format. Structured graphite packings are made up of pre-formed graphite rings that are assembled in the stuffing box according to manufacturer’s instructions. These packings have established a track record of being able to maintain emissions performance at below 500ppm, both in new valves and when retro-fitted to valves originally fitted with asbestos packings. Braided graphite packings are not pre-formed for specific valves sizes and types, instead being cut to desired length from a spool of a specified thickness, and fitted into the valve stuffing box. Generally, braided packing are less expensive than structured packings, but their performance in controlling emissions is more varied. However, there are specially processed braided graphite products available which have been shown to offer similar emission performance to their structured counterparts.

Testing shows that for valves fitted with appropriate graphite based structured or braided packings, emissions performance at <500ppm is achievable provided that the packings are installed in accordance with manufacturer’s instructions and good practice. However, testing also shows that for a significant percentage of such valves, performance deteriorates with time. When performance does deteriorate to a point where the emission rate rises above 500ppm, the leak can often be reduced by retightening the valve gland assembly. This approach is successful for approximately 50% - 75% of leaking valves, with others having to be repacked to re-establish leak free performance at below the specified 500ppm.

Given the above comments, and additionally noting that from a population of initially leak free valves it is usually not possible to predict which individual valves will leak, it becomes necessary to establish a routine programme for monitoring the performance of valve seals. Such LDAR programmes for valves are common in the USA, often required by legislation, and are becoming more common at UK chemical sites. As will be shown in Section 4, the environmental and financial benefits of such programmes can be significant.

3.3 Control of Fugitive Emissions from Pump Seals

A pump seal is a loaded seal between a rotating pump shaft and a pump seal housing. The pump seal is a dynamic seal, that is the seal is between a static component and a pump shaft that is in continuous motion.

Pump seals are highly engineered assemblies, and range from single seals to double seal assemblies with pressurised barrier fluids. Most double seal assemblies either prevent emissions to atmosphere of process fluids, or allow for any process fluid losses to be vented to a flare system. However, single seal assemblies remain common on most chemical plants, and by design these seal assemblies involve emission to atmosphere of the process fluid (albeit in small quantities, movement of the process fluid across the seal faces is required to cool and lubricate the seal assembly).

Testing shows that emissions from single seals are often at levels higher than 500ppm. Overhauling pump seal systems and replacing the seal components sometimes results in improved performance, but not always. Fitting double seal systems is expensive, and can reduce the mechanical reliability of the pump, but in many cases this is the only approach that can be relied upon to produce emission free performance. As shown in Section 4, the decision as to whether to fit double seal systems to pumps needs to be taken with good understanding of overall plant emissions performance, and the percentage of this attributed to pump seals.

4 PLANT DATA

This section uses data from a UK Petrochemical plant to illustrate the potential environmental and financial benefits that can be delivered through the adoption of a carefully designed and focused approach to the management and control of fugitive emissions.

The plant used in the example was built in the late 1970's and commissioned in 1979. Initial sealing technology for flanges and valves was based on the use of asbestos in gaskets and valve packings, with a change to graphite based sealing technology in the mid 1990's. Data for the plant concerned is as follows:

Number of flanged joints	10,000
Number of valves	9,600
Number of single seal pumps	45

A Novus Sealing LDAR program was introduced in 2002, involving sample monitoring of flanged joints and routine monitoring of all valve and pump seals. Initial testing revealed:

- Very few flanged joints leaking above 500ppm
- Approximately 10% of valves leaking at 500 – 60,000ppm
- Some large leaks from pump seals, but some pumps with low emissions. Overhauling leaking pumps was not found to be a reliable method for reducing emissions.

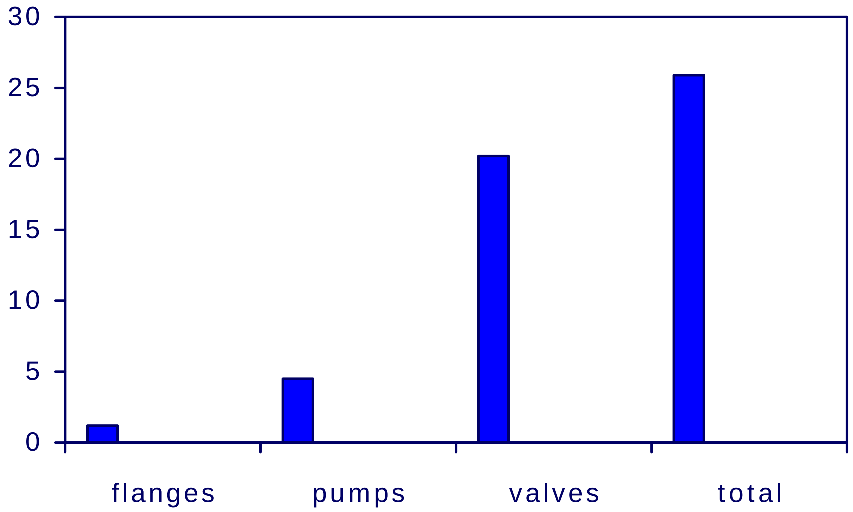

Figure 2 Baseline Plant Fugitive Emissions

Figure 2 shows estimated emissions from flanged joints, pump seals and valve glands. Flanged joints can be seen to have little overall impact despite the high number of components, whereas emissions from valve glands and pump seals are significant. During 2003 attention was focussed on reducing emissions from valve glands. A plant shutdown provided the opportunity to replace the gland packing in a number of valves, and for other leaking valves it was found to be possible to achieve a significant reduction in emission levels by tightening the gland nuts and increasing the compression of the packing. The results of this activity are shown in figures 3 and 4.

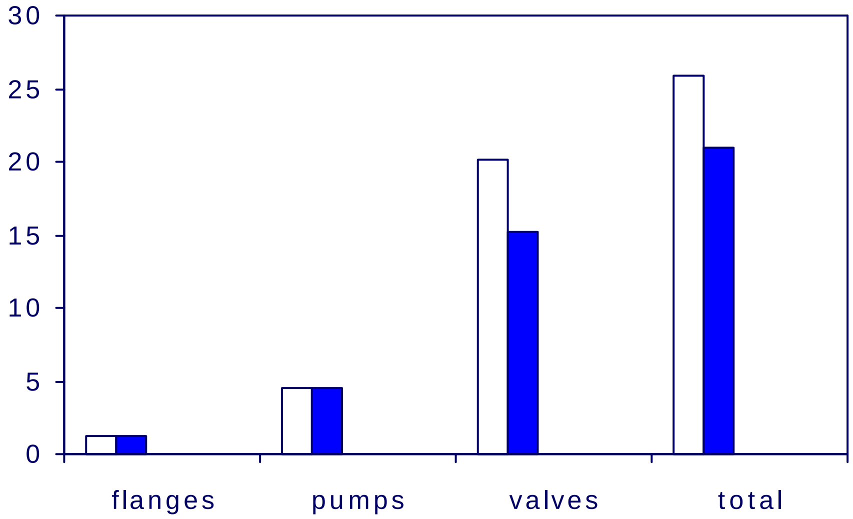

Figure 3 Plant Fugitive Emissions After Repacking Valves

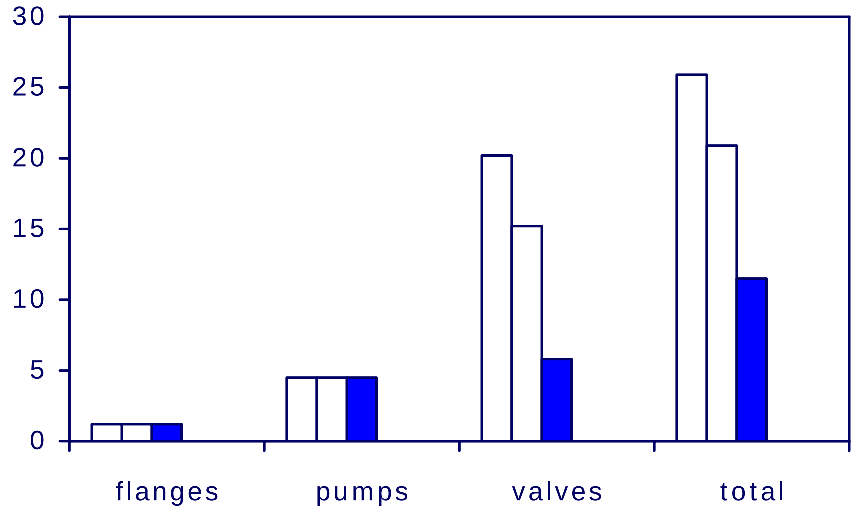

Figure 4 Plant Fugitive Emissions After Tightening Valve Glands

Figures 3 and 4 illustrate a significant reduction in overall fugitive emissions as a result of the application of a Novus Sealing LDAR programme for valve glands. To achieve further reductions it would be necessary to repack the valves that could not be prevented from leaking by increasing the packing compression, or to tackle the problem of emissions from pump seals. Figure 5 shows the extent to which emissions could be reduced without work to improve the performance of pump seals.

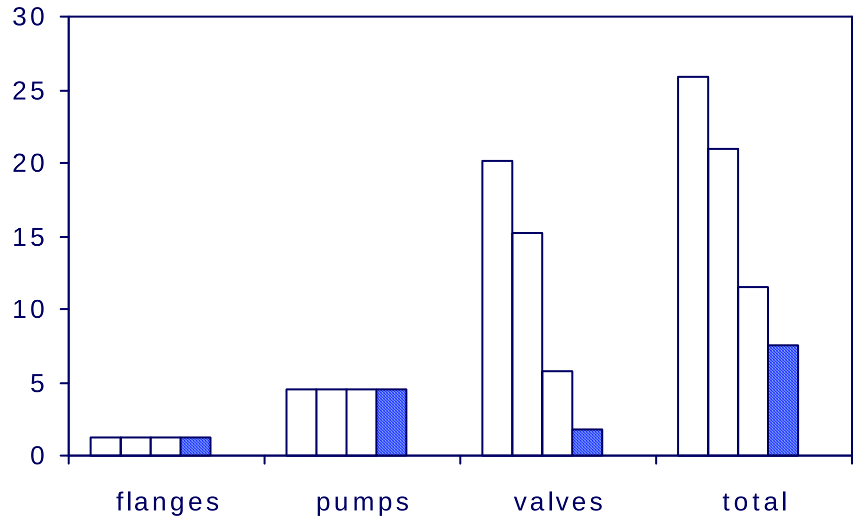

Figure 5 Possible Emission Levels With All Leaking Valves Repaired

Plant trials were undertaken in 2003 to investigate fugitive emissions from pump seals. An LDAR program was undertaken, which demonstrated that some pump seals had low emissions whilst other pumps on similar duties showed significant emission levels. It was thought that replacing seal assemblies and careful control of overhaul standards might result in reliable performance at low emission levels, but in practice this was found not to be the case, with variable emissions performance persisting even after seal replacement.

Given this, it seems likely that reduction in emissions from pump seals will require replacement of the seal with either a high performance / low leak single seal or alternatively a double seal arrangement. This, if undertaken for all pumps on the plant, would allow emissions to be reduced to background levels from flanges and valves as shown in figure 6.

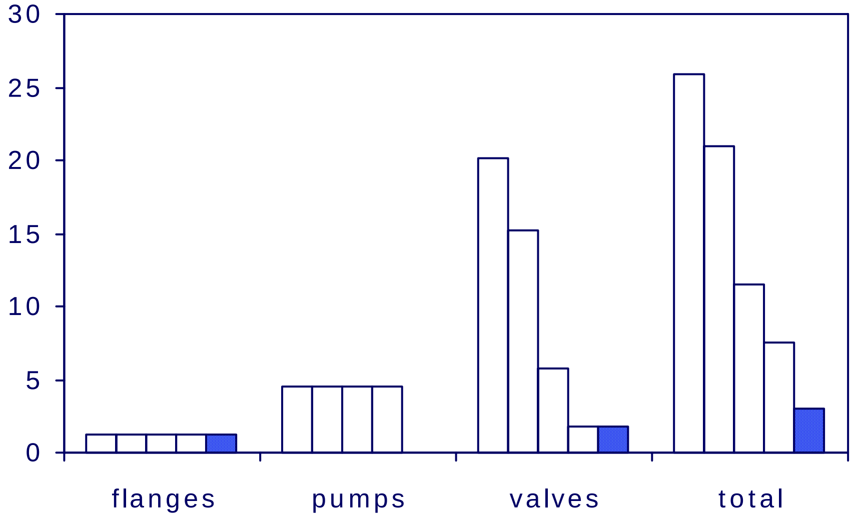

Figure 6 Possible Emission Levels With All Pump Seal Emissions Removed

At this point it is instructive to consider the cost of achieving reduction in fugitive emissions. Table 3 illustrates this, and it can be seen that the cost of removing a Tonne of emissions varies very significantly depending on the source of the emissions.

Action	Cost per Te (£)
Tighten valve glands	520
Repack leaking valves	5,100
Replace pump seals	100,000

Table 3 The Cost of Reducing Emissions

Table 3 was produced from cost and emissions data taken from the plant, and therefore although the actual costs must be regarded as variable from plant to plant, it is clear that care is needed to ensure that work to reduce emissions is focussed initially at the areas where the benefit to cost ratio is the most beneficial.

5 CONCLUSIONS

This paper has defined and explained fugitive emissions, and described the techniques that are available for their estimation and control. Key source of fugitive emissions have been described, and real plant data has been used to illustrate the potential benefits of the careful and focussed application of Leak Detections and Repair (LDAR) programmes.

6 REFERENCES

Ref 1 USA Environmental Protection Agency document "Protocol for Equipment Leak Emission Estimates" EPA-453/R-95-017.

Ref 2 "Achieving a Leak Free Start Up – Impossible Dream Or Achievable Project?" BHRG 16th International Conference on Fluid Sealing, Brugge, Belgium, 2000