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Fugitive emissions in chemical processes: The assessment and prevention based on inherent and add-on approaches

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ABSTRACT

Fugitive emissions are among the major concerns of industrial process releases. The emissions cause problem to various aspects including the environment, health, and economic. Early evaluation of process hazards is beneficial because process can be made inherently benign at lower cost. This paper discusses two important aspects of fugitive emissions assessment during process design – the quantification and the prevention strategies.

For the quantification part, three methods are presented for fugitive emissions estimation during the process design. They are tailored to data available in simple process flow diagram (PFD), detailed PFD, and piping & instrumentation diagram (PID). Such methods are needed as early emissions estimation allows production routes and process designs with lower emissions to be selected. The fugitive emissions estimation and methods to abatement are demonstrated on a benzene process case study. Valves are found to be the major emission source with 50% of fugitive emissions of process area in a base case of petrochemical process, in which no fugitive emission reductions are yet made. Pumps without mechanical seals come second with 30% and flanges with 8% of emissions. Inherently safer design keywords can be applied to prevent fugitive emissions in the process plants. Substitution is the most applicable keyword in fugitive emission reduction of existing plants.

The emission rate calculations together with estimation of health risk give a sound background for the decision making on elimination of emissions at source through equipment and piping changes. The case study presented reveals that by substituting emission prone components by inherently low-leaking ones, the plant emissions can be reduced over 90% in practice. This is created mainly by replacing rising stem valves with ball valves, installing double mechanical pump seals or hermetic pumps and making changes in sampling and relief systems. Ideally by also changing flanges to welded connections, which is not viable for various reasons, the emissions could be reduced nearly to zero.

1. Introduction

Safety and environmental issues started to get into public, regulatory, and industrial focus during the 1960s due to increasing production volumes and higher knowledge about the danger potentials of chemical substances and processes. Much effort has been put into developing end-of-pipe technologies for converting industrial controlled effluent into less dangerous substances. However, with these technologies, hazards are still remained in the process and unwanted events are bound to happen. The efforts of installing the so-called 'best technology' are also costly. Estimates show that in the oil and chemical industries, 15–30% of capital cost is now spent on safety and pollution prevention measures (Kletz, 1985).

Sustainability concept was introduced as an attempt to provide the best outcomes for the human and natural environments both now and into the indefinite future. It is the ideal end state that must be aspired. Nowadays, many companies have committed to sustainability by joining programs such as Responsible Care (Hook, 1996). EU directives, such as IPPC and REACH, have affected process

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development so that safety, health, and environmental (SHE) aspects have to be taken into consideration in earlier phases of process lifecycle.

The industrialized nations of the world are all placing increased emphasis on the control of volatile organic compounds (VOCs) and hazardous air pollutants (HAPs) being emitted to the atmosphere. Worldwide, fugitive emissions from industrial applications amount to over a million metric tons per year. It has been estimated that chemical process industries account for half of all the emissions (Drago, 2010). Fugitive emissions in the USA have been estimated to be in excess of 300,000 tons per year, accounting for about one third of the total organic chemical emissions from chemical plants (Lakhapate, 2006; Sikdar & Howell, 1998). This situation is mirrored in Europe and is probably much worse in other parts of the world where emission standards and regulatory levels are lower.

Increasingly challenging environmental, health, and economic are driving a need to reduce fugitive emissions that is perhaps greater today than ever before (Nicholls, 2005). From October 2007, all existing UK processing plants and power stations will have to comply with the EU's IPPC directive 96/61/EU, which aims to improve the management of industrial processes and ensure a higher level of protection for the environment. An important part of this legislation is fugitive emissions reduction, which will have significant consequences for processes in any factory. The new legislation is wide-ranging and a concept of Best Available Technique (BAT) is introduced, urging plants to find the best available solution for minimizing fugitive emissions right the way along the process, from areas such as design. Such effort does not take place in the UK only but almost everywhere worldwide.

The concept of inherent safety professes that process hazards should be identified as early as possible, starting from the process development and design phase (Kletz, 1984). Before a hazard can be managed, it is necessary to first identify and evaluate it. Various methods have been developed to assess inherent safety of chemical processes during design stage (Edwards & Lawrence, 1993; Heikkilä, Hurme, & Järveläinen, 1996; Khan & Abbasi, 1998; Khan & Amyotte, 2004; Koller, Fischer, & Hungerbühler, 2000; Shah, Fischer, & Hungerbühler, 2003). The rationale of the concept makes it interesting for application in the environmental aspect for pollution prevention (Kletz, 1984). Basically the adoption of inherent safety principles for pollution prevention has long been recognized before as clean technology, aiming to minimize or eliminate emissions and wastes through renewable materials and energy sources instead of end-of-the pipe treatment (El-Halwagi, 1997). Later the idea was properly researched for application during process development and termed as inherent environmental friendliness. Among the related works are presented in Cave and Edwards (1997), Gunasekera and Edwards (2006, 2003). Upon successful integration between inherent safety and pollution prevention, the concept was later extended to occupational health. Inherently occupational healthier design is a new concept focussing on developing a process which is fundamentally healthier through the selection of less toxic and volatile chemicals, milder operating conditions, simpler process with less sources for uncontrolled emissions, and better work procedures that may reduce workplace exposures. Among the notable works on inherent occupational health are published in Hassim (2003), Hassim and Edwards (2006), Hassim and Hurme (2008, 2010b, 2010a), Hassim, Pérez, and Hurme (2010) and Hassim, Edwards, Hurme (2006) .

Kletz (1984) highlighted that for inherent safety adoption to industrial hygiene (occupational health), focus should be given to the avoidance of small continuous leaks into the atmosphere of the workplace. This undoubtedly is referring to fugitive emissions. Early consideration of fugitive emissions in process development will not only benefit workers' health and the environment, but also can yield significant operational and economic benefits as well as avoid punitive penalties for non-compliance with regulatory standards (Drago, 2010). Like any other hazard management program, the problem related to fugitive emissions can be tackled earlier by first, assessing the amount of emissions before implementing appropriate counter-measures to prevent or minimize the emissions. However study on fugitive emissions in chemical process design has been poorly researched due to the lack of process related data in design stage, hence complicating early assessment of process emissions. This is witnessed in the existing fugitive emissions estimation methods, in which even though they claim to be applicable for process design, actual process data is still required. More details on the methods are discussed in Section 2.1.

Therefore in the first part of this paper, methods for estimating the amount of fugitive emissions during chemical process design are presented. The study focuses on fugitive emissions from large-scale continuous industrial processes rather than the highly variable smaller scale batch production operations. Because of the magnitude of production volumes, continuous processes were often presumed as single sources of the large emitters of air pollutants (Shine, 1996). Fugitive emissions estimation should already be considered earlier during conceptual process design. This allows process with lower amount of fugitive emissions, besides other criteria, to be selected and progressing through the subsequent project stages. Early consideration of fugitive emissions in process development may reduce the emissions up to 50% as demonstrated by methyl methacrylate production plant using the method proposed in this paper.

All the existing methods on fugitive emissions only discuss on the quantification or estimation part, without recommending strategies for abatement. Therefore, the second part of the paper discusses inherent safety approaches for preventing the generation of fugitive emissions, which are of assistance towards achieving sustainable process. Strategies for reducing the severity and the likelihood of exposure to the emissions are also described, particularly from occupational health perspective. In process plants, fugitive emissions are the main sources of origin of the continuous background exposure to workers (Lipton & Lynch, 1994). Even though the quantity of fugitive emissions is very small, prolonged exposure may be threatening to health especially if carcinogens are involved. Consideration of fugitive emissions from occupational health standpoint is essential because each year more people die from work-related diseases than are killed in industrial accidents. The International Labour Office reported that in the EU27 alone, each year around 74,000 work-related facilities may be linked to workplace exposure to hazardous substances (ILO, 2005). Around 22% of all workers in the EU self-report breathing fumes and vapours for at least one-quarter of their working time (Levy, 1994). The number might be much higher for exposure to fugitive emissions, which are more difficult to assess since the emissions are very small and almost invisible. Therefore it is very important to reduce fugitive emissions as low as reasonably practicable to create a healthier, safer, more productive workplace besides improve operating efficiency.

2. Fugitive emissions

Fugitive emissions can be defined as a chemical, or a mixture of chemicals, in any physical form, which represents an unanticipated or spurious leak in an industrial site (Ellis, 1997; ESA, 2005; ESA/FSA, 1998). The leaks occur wherever there are discontinuities in the solid barrier that maintains containment. In chemical processes, fugitive emissions result from 1) equipment leaks, 2) solvent transfer, 3) filter changes, and 4) spills (Keoleian, Blackler, Denbow, & Polk, 1997). Causes 2) to 4) most likely occur in batch process. This study however focuses mainly on leaking piping equipment and