Contents lists available at ScienceDirect

Process Safety and Environmental Protection

journal homepage: www.elsevier.com/locate/psep

A study of maintenance-related major accident cases in the 21st century

*Peter Okoh**, *Stein Haugen*

Department of Production and Quality Engineering, Norwegian University of Science and Technology, NO 7491 Trondheim, Norway

ABSTRACT

This paper is based on a review of 183 detailed, major accident investigation and analysis reports related to the handling, processing and storage of hydrocarbons and hazardous chemicals over a decade from 2000 to 2011. The reports cover technical, human and organizational factors. In this paper, the Work and Accident Process (WAP) classification scheme is applied to the accident reports with the intention of investigating to what extent maintenance has been a cause of major accidents and what maintenance-related causes have been the most frequent.

The main objectives are: (1) to present more current overall statistics of maintenance-related major accidents, (2) to investigate the trend of maintenance-related major accidents over time, and (3) to investigate which maintenance-related major accident causes are the most frequent, requiring the most attention in the drive for improvement.

The paper presents statistical analysis and interpretation of maintenance-related major accidents' moving averages as well as data related to the types of facility, hazardous substances, major accidents and causes. This is based on a thorough review of accident investigation reports.

It is found that out of 183 major accidents in the US and Europe, maintenance was linked to 80 (44%) and that the accident trend is decreasing. The results also show that "lack of barrier maintenance" (50%), "deficient design, organization and resource management" (85%) and "deficient planning/scheduling/fault diagnosis" (69%) are the most frequent causes in terms of the active accident process, the latent accident process and the work process respectively.

Keywords: Maintenance; Major accident; Statistics; Hydrocarbon; Chemical; Process

1. Introduction

The handling, processing and storage of hydrocarbons and hazardous chemicals by industries whether small or large scale, inherently implies a potential for major accidents. Maintenance can keep the integrity of safety barriers and thus contribute to the prevention of major accidents. On the contrary, it can also be a cause of the major accidents themselves through insufficiency, incorrectness, new hazard inducement or being an initiating event for an accident scenario (Okoh and Haugen, 2013a, 2013).

Several investigations reveal that 30–40% of all accidents and precursor events in the chemical process industry are maintenance related. The UK's Health and Safety Executive linked maintenance to 30% of all accidents (a mixture of major accidents, occupational accidents and serious incidents) in the chemical process industry between 1982 and 1985 (HSE, 1987; Smith and Harris, 1992). As reported by Hale et al. (1998), out of 30–40% of serious accidents in the chemical process industry, 17% occurred during preparation for maintenance, 76% during maintenance itself and 7% during or soon after handback to production, whereas at least 8% of the chemical process accidents occurred in other phases (start-up, shutdown or normal operations) due to technical failures influenced by inadequate maintenance. In the same reference by Hale et al. (1998), Koehorst's report of 1989 based on the analysis of accidents

* *Corresponding author*. Tel.: +47 40309367.
E-mail addresses: peter.okoh@ntnu.no, okohpee@yahoo.com (P. Okoh).
Received 11 December 2013; Received in revised form 1 March 2014; Accepted 6 March 2014
http://dx.doi.org/10.1016/j.psep.2014.03.001

in FACTS database (formerly of TNO, The Netherlands) indicates that 38.5% of accidents involving chemical releases were linked to maintenance. Furthermore, as cited by Hale et al. (1998), the 1991 report of Hurst et al. links 38.7% of 900 accidents associated with piping failures in the chemical industry to maintenance. In the hydrocarbon industry reports, there are also some statistics showing maintenance contribution. A report from Australia indicates that 33% of hydrocarbon topside gas releases between 1985 and 1988 in Australia were linked to maintenance (NOPSA, 2008). A similar study of gas releases in the Norwegian offshore industry shows that over 65% of major hydrocarbon leaks on the Norwegian sector of the North Sea were linked to maintenance (Vinnem et al., 2007). Furthermore, a study of 242 accidents in relation to storage tanks in both industries between 1960 and 2003 reveals that about 30% of such accidents were caused by human errors including poor operation and maintenance (Chang and Lin, 2006).

Most of the aforementioned statistics are about 25 years old. In addition, the most recent statistics do not cover all equipment, being limited to storage tanks only. The data in this paper are recent and cover all types of equipment. The objectives of this paper are: (1) to present more current overall statistics of maintenance-related major accidents, (2) to investigate what the accident trend has been over the period 2000–2011, and (3) to determine which causes are the most frequent, requiring the most preventive efforts. To this end, the Work and Accident Process (WAP) classification scheme (Okoh and Haugen, 2013a) will be applied to 183 major accident cases consisting of 63 from the U.S. Chemical Safety Board (CSB) reports (Chemical Safety Board, 2013) and 120 from the BARPI's ARIA database (Bureau for Analysis of Industrial Risks and Pollution, 2013). The accident reports cover technical, human and organizational factors associated with the handling, processing and storage of hydrocarbons and hazardous chemicals in the process industries. Many of the accident reports also point to other causes than just maintenance. However, our intention in this paper is to focus on only the maintenance-related causes.

The rest of the paper is structured as follows. The paper will discuss the concept of major accident and present statistical analysis and interpretation of maintenance-related major accidents trend as well as data and interpretations related to the types of incident facility, hazardous substances, major accidents, causes and combination of causes. This will be followed by discussion and recommendations, and finally, concluding remarks will be presented.

The study is carried out by both authors independently and with iterative scrutiny. The Work and Accident Process (WAP) scheme is applied after having sorted the major accidents from the occupational accidents and identified the maintenance-related major accidents among the overall major accidents. The WAP scheme has defined accident causation categories. Each accident report has been revised and relevant causation categories were identified. Based on this, we could identify which causes and combination of causes occurred most. The study is also applied in relation to the chosen definition of a major accident. The usability and suitability of WAP had been verified in the previous paper (Okoh and Haugen, 2013a), being comprehensive, complete and finely categorized to address the peculiar challenges of industries (Okoh and Haugen, 2013a). Besides, the accident investigation reports which are the source of this study, are detailed and comprehensive.

Several significant contributions from researches related to major accidents have been recorded in the chemical process industry. These include the works of Kidam and Hurme (2013), Cheng et al. (2013) and Fabiano and Currò (2012).

2. Various views on major accident in relation to the process industry

There is no conventionally accepted definition of the term "major accident" across authorities linked to the process industry. The Norwegian Petroleum Safety Authority (PSA) (PSA, 2010), the European Commission (in relation to Seveso II directive) (EC, 2005) and the UK government (in relation to the Control of Major Accident Hazards regulations) (UK, 1999) have quite similar definitions for a major accident, which can be summarized as follows: an acute/adverse event such as emission/discharge/release, fire or explosion resulting in a serious loss with regards to human life/health, the environment and material assets.

The International Association of Oil and Gas Producers – OGP (OGP, 2008) and the Commonwealth of Australia (Commonwealth of Australia, 2009) also have similar definitions for a major accident, which can be summarized as follows: events connected with an installation having the potential to cause multiple fatality/serious damage inside or away from the facility.

The definitions of a major accident by the UK's Health and Safety Executive (HSE) (HSE, 1992) and the US Occupational Safety and Health Administration (OSHA)/US Environmental Protection Agency (USEPA) (USEPA-OSHA, 1996) also have expressions that imply the potential for serious loss and that the effects may be felt inside or outside the facility. Similarly, the US Department of Energy (DOE) [6] defines an incident as "an unplanned event that may or may not result in injuries and/or loss" and an accident/accident event sequence as "an unplanned event or sequence of events that has an undesirable consequence."

We have chosen to include also events with the potential to cause large consequences in our definition. The benefit is that the database is extended significantly. This introduces some uncertainty since there may be differences in causes of events involving losses and events that could have involved losses, but this is considered to be a limited problem. The consequences are usually defined by more or less arbitrary factors not connected to the causes at all, such as whether an ignition source is present at the time of a combustible gas release. Hence, a major accident as applied in this paper is "an unexpected event that causes or has the potential to cause serious consequences such as several serious casualties, extensive environmental or asset damage, with immediate or delayed effects experienced, within or outside the incident facility" (Okoh and Haugen, 2013a).

The term "process accident" is also often used with more or less the same meaning as the term "major accident" in the process industries. Accidents related to modification and maintenance are some of the types of process accidents that occur. Modification-related accidents are connected with the changing of the required function of an item to a new required function, whereas maintenance-related accidents are connected with an item being retained in or restored to a state in which it can perform it's original required function (EN 13306, 2010).