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Maintenance of petroleum process plant systems as a source of major accidents?

Jan Erik Vinnem [a, *], Stein Haugen [a], Peter Okoh [b]

[a] Dept. of Marine Technology, NTNU, Trondheim, Norway
[b] NTNU, Trondheim, Norway

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ABSTRACT

The prevention of hydrocarbon leaks is of great importance as they are the most critical precursor events that may lead to major accidents on petroleum facilities. Maintenance of process components on offshore and onshore petroleum facilities is therefore crucial in order to avoid major accidents, such as Piper Alpha and Texas City. Maintenance of Pressure Safety Valves (PSVs) is a significant activity because they are usually in quite high number and are recertified regularly. The accident chain that led to Piper Alpha started with maintenance of a PSV. Studies of leak circumstances have shown that, on Norwegian offshore installations, there is approximately one hydrocarbon leak per year resulting from recertification of PSVs, due to errors made during isolation and blinding or reinstatement. The preventive maintenance of PSVs thus becomes a source of a leak (which indicates risk) as well as a safety barrier element to reduce risk. The paper discusses corrective as well as preventive maintenance of static (not rotating) process equipment in relation to experience with hydrocarbon leaks and makes a case for optimization of preventive maintenance scheduling for static process equipment.

1. Introduction

1.1. Background

Preventive maintenance is an important activity in all industrial applications where major accidents may occur. This is certainly the case in offshore and onshore petroleum facilities where fire and/or explosion may put many lives at risk.

Typical preventive maintenance tasks include inspections of components, such as those susceptible to corrosion or erosion, and replacing parts that wear out over time. Another preventive maintenance action is testing safety-critical valves with respect to their ability to isolate flow, including time to close. One such component subjected to preventive maintenance is the Pressure Safety Valve (PSV), which is recertified at regular intervals, usually once per year.

The recertification of PSVs is a case of special importance because the recertification is often done in a workshop, either on or off the plant, by a subcontractor. This implies that a section of the plant is isolated and depressurized prior to the PSV being removed for recertification. The pipe section may be left with temporary seals in some cases; in other cases, the removal of a valve may be followed by immediate installation of a substitute valve that has been recertified already, if there is a pool of identical valves available for rotation in the process plant.

In both cases, the work will involve isolation of the valve from the rest of the process plant, depressurization and gas-freeing of the isolated section, removal of valve, possible installation of temporary seals (while waiting for valve to be returned), installation of a new or a recertified valve, and reinstatement of the section of the plant. The duration of the work will depend on whether a new valve from a pool is installed or the same valve is returned after recertification in the workshop. The event chain that led to the loss of the Piper Alpha installation in 1988 started in a blind flange where a PSV had been removed for preventive maintenance and not returned the same day after recertification.

When a recertified valve is installed, it can be assumed to be ‘as good as new,’ i.e. with a low failure probability. According to prevailing models, assuming failures to be exponentially distributed, the probability of failure on demand (PFD) will increase over time, until the next recertification. Timing of such recertification is therefore an important parameter, since the PFD will increase with longer intervals between recertification.

* Corresponding author.
E-mail address: jev@preventor.no (J.E. Vinnem).

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The recertification interval has traditionally been determined by the maximum allowable failure probability, and this has meant that the interval is limited. No negative effects of the recertification have been considered.

Several studies (Vinnem and Røed, 2014) have shown that hydrocarbon (HC) leaks (i.e. loss of containment [LOC]) are caused in association with maintenance and modifications in the process plant, especially during the isolation and depressurization of the sections of the plant, as well as during reinstatement of the sections. It may be claimed that the most frequent process component to be involved in loss of containment incidents is actually the PSV, probably due to the high number of valves and thus the high number of valve removals and installations.

It is therefore a dilemma that actions aimed at reducing major accident risk are actually increasing risk due to the likelihood that the work itself causes loss of containment during execution of the preventive maintenance work. Okoh and Haugen (2014) have shown that 43% of 184 major accidents occurring in the process industry in the US and Europe during the period 2000–2011 could be related to maintenance causes.

Thomassen and Vinnem (1991) have considered installation of emergency shutdown (ESD), blowdown valve (BDV), and PSV from a fire safety engineering point of view. Hameed and Kahn (2014) have discussed an approach to planning shutdown periods for a processing plant and have also given an overview of different approaches to planning regimes for preventive maintenance of process plants. The main emphasis in this work is on rotating machinery and equipment.

Chien et al. (2009) have discussed a strategy for risk-based inspection of PSVs where the only consequences of failure are those that may occur if the PSV fails to open. Failures during the preventive maintenance activities are not mentioned. This may be reasonable if the fluid in the system is non-hazardous, but not in the case of flammable fluid in the system, which was not addressed by Chien et al. (2009).

Chang et al. (2005) have discussed preventive maintenance of piping systems in a refinery from the risk-based inspection point of view. The risk associated with the inspection work itself was not addressed.

Qingfeng et al. (2011) have discussed the general principles of equipment maintenance and safety integrity management, with the main emphasis on rotating equipment. Reciprocating compressors, screw compressors and centrifugal pumps are named as the highest ranked risk sources. This is not at all consistent with the experience in the Norwegian offshore sector, where PSV is the most frequent equipment involved in the LOC incidents, as will be discussed in Section 3.

Vinnem and Røed (2015) have analyzed loss of containment on offshore petroleum installations and have shown that the most frequent activity carried out at the time of the loss of containment is preventive maintenance of the process plant, followed by corrective maintenance and modification work. As James Reason said, “Maintenance can seriously damage your system” (Reason, 1997).

Barrier management has been discussed by some authors, such as Pitblado (2013), who focused on analysis of barriers without addressing the management aspect. Statoil's Technical Condition Safety (TTS) barrier approach was discussed by Ingvarson and Strøm (2009). Barrier management as such is not a topic of this paper.

The purpose of this paper is to illustrate one particular aspect of maintenance planning related to maintenance on HC containing systems. A substantial proportion of the HC leaks in process plants occur in association with preventive maintenance tasks. This does not appear to have been well known and thus not used in planning of such maintenance. The paper aims to discuss in some depth the dilemma between preventive maintenance of process components when such work at the same time is a source of increased risk during preparation, execution and reinstatement, and to propose some recommendations as to achieve an optimum balance between prevention and increase of risk.

The purpose of the paper is not to discuss planning of process plant maintenance in general, nor the planning of risk-based inspection or maintenance in general.

Section 2 summarizes the importance of preventive maintenance for the safety of process plants, and Section 3 follows with an overview of how preventive maintenance can be a risk increasing factor, based on available statistics. The challenges are discussed in Section 4, followed by conclusions in Section 5.

2. Risk reduction through preventive maintenance of process plant

Preventive maintenance of process plant components and systems is an essential element of safe operation, according to regulations and industry practice, as discussed by Qingfeng et al. (2011). This section discusses the importance of preventive maintenance and the potential for major accidents.

2.1. Preventive maintenance of PSVs

PSV preventive maintenance offers many challenges. PSVs are usually installed in order to protect a vessel from rupturing. For instance, a fire may heat the contents of a vessel and increase the pressure beyond the vessel's integrity. The PSV is installed in order to relieve pressure and thus protect against rupture due to overheating. It is therefore essential that the PSV opens at the prescribed overpressure. The periodic recertification of PSV is aimed at assurance that it will open at the right value. There could also be other causes of overpressure, but exposure to heat load is considered to be the most typical cause.

In Norwegian offshore oil and gas installations, the last time a HC leak was ignited was November 1992 (PSA, 2014). This implies that for a period of more than 20 years, there have been no cases where process fire on an installation could have exposed pressure vessels to overheating and put a demand for protection on the PSV. There have been some fires in utility areas on installations during this period, a couple of which have been extensive fires, but escalation to process areas did not occur.

Therefore, the average demand frequency for PSVs on Norwegian offshore installations is quite low based on occurrence of process fires. On the other hand, there have been seven HC leaks (above 0.1 kg/s leak rate) associated with preventive maintenance of PSVs during the period 2008–2014. This may suggest that the current preventive maintenance scheme is not optimal. An increase of the interval between recertification is likely to increase the unreliability of PSVs. But fewer PSV preventive maintenance tasks are also likely to cause fewer HC leaks.

2.2. Elements of major accident risk associated with maintenance

Maintenance of process systems consists of preventive and corrective maintenance. Preventive maintenance is planned in accordance with overall plans, in order to satisfy authority and other requirements, and shall reflect the requirements according to barrier management (Vinnem and Røed, 2015). Safety Integrity Level (SIL) requirements may also be part of the basis for the preventive maintenance plans.

Preventive maintenance is used extensively on offshore oil and gas installations for rotating equipment as well as critical barrier