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ScienceDirect

Energy Procedia 120 (2017) 2–19

Energy Procedia

www.elsevier.com/locate/procedia

INFUB - 11th European Conference on Industrial Furnaces and Boilers, INFUB-11

Fired equipment safety in the oil & gas industry

A review of changes in practices over the last 50 years

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Abstract

This paper reviews how the requirements of safety, availability, energy efficiency and environmental compliance have influenced the design and operation of fired equipment over the last 50 years. It presents the various norms and standards relevant to the classes of fired equipment used in the Oil & Gas industry and highlights the differences between prescriptive norms and performance based standards. The main hazards and common causes of accidents of process heaters, petrochemical furnaces and boilers are described. Finally, this paper reviews the evolution of the risk mitigations and design best practices over the last decades. It discusses in particular the particular challenges of improving the safety performance of existing equipment.

Before the first oil crisis of 1973, the price of refinery fuels was very low and it was common practice to run heaters inefficiently with high excess air (e.g. 5 to 8 % O2 in the flue gas) and high draft to reduce the probability of sub-stoichiometric combustion and positive pressure in the combustion chamber. Since the safety margin was provided by operating with high excess air and high draft, control improvements were considered unnecessary. Fired equipment safety was essentially distributed between operator response to alarms (e.g. process upset conditions), instrumented protective functions programmed in the safety instrumented system and solutions such as explosion doors and snuffing steam to mitigate the consequence of explosions.

In the last 25 years, the drive for safer operation with higher energy efficiency, lower NOx emissions and fewer nuisance trips has led operating companies to adapt their approach to fired equipment safety. The modern approach to fired equipment safety is to distribute the risk across independent protection layers. These safety barriers rely on a comprehensive control system with constraints and a safety instrumented system, but also on operational excellence with well-trained operators, good operating procedures and reliability-centered maintenance and risk-based inspection. As an important benefit, constraint controls with automated fuel cutbacks have proven effective at minimizing nuisance trips by keeping the heater within operational limits.

Peer-review under responsibility of the organizing committee of INFUB-11

Keywords: Fired equipment safety, risk analysis, HAZOP, LOPA

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Peer-review under responsibility of the organizing committee of INFUB-11
10.1016/j.egypro.2017.07.151

1. Introduction

The spectacular accidents that accompanied the industrial revolution caused many governments and industry representatives to take action to minimize loss of life and to protect the environment. Process Safety emerged as a key engineering field with techniques to assess process hazards, initiating event frequencies, consequence severity levels and safeguards to achieve an acceptable level of risk reduction. Since the turn of the 20^{th} century, each decade brought continuous improvements in terms of regulations and techniques as well as a reduction in the public perception of acceptable risk. What-ifs, checklist, HAZOP, Fault- and Event-Tree analyses were some of the essential techniques developed in the early 1960s [Lees, 2012]. Their use as safety systems and reliability techniques quickly gained widespread interest and represent some of the commonly used process safety techniques used today. The late 1990s saw the development of the layer of protection analysis (LOPA) method [Bridges, 2014]. The first international standards were published soon after [EN 746-2, 1996; ISA S84.01, 1996; IEC 61508, 1998 and IEC 61511, 2003], setting new industry practices and standards for the design of safety instrumented systems (SIS) in the process industries.

This paper reviews how the design and operation of fired equipment has evolved over the last 50 years to address growing requirements on safety, availability, energy efficiency and environmental performance at a reasonable cost. Process heaters, furnaces and boilers built in the 1950s and 1960s were considered modern designs and represented a significant progress compared to inefficient designs seen before 1940. Many of the heaters, furnaces and boilers built before the first oil crisis of 1973 are still in operation today. During the period from 1950 to 1975, the energy consumption of fired equipment was mostly ignored because refinery fuel oil and fuel gas were a byproduct of refining operations and had no commercial value. This period was characterized by manual mode operation, limited automation and protective functions and a preference for operator initiated emergency shutdown (ESD). As operator procedures were in their infancy, operator experience was the prime protection from the risk of explosion at startup. The risk of sub-stoichiometric firing and subsequent explosion was mitigated by operating with high excess air and high draft. In this period of limited instrumentation and controls, the frequency of combustion upsets and emergency shutdowns was fairly high.

The codes, standards and safety requirements introduced since the late 1990s have brought greater emphasis on safety and increased compliance with codes and practices on all new projects. These requirements, combined with industry objectives to achieve not only a high level of safety but also a high level of availability, energy efficiency and environmental performance have led to changes in fired equipment design and operation. A specific objective of this paper is to address the specific challenge of achieving today's safety and availability requirements on the fired equipment built before 1975.

Based on the author's experience, the fired equipment referred to in this paper includes mostly refinery process heaters, petrochemical cracking furnaces, steam-methane reformers and industrial boilers. However, some analogy may be inferred for other combustion equipment such as the furnaces, ovens and kilns used in the glass, mineral and iron & steel industries. In the terminology of this paper, fired heaters refer to process heaters used to heat a hydrocarbon feed in coils. Furnaces refer mostly to petrochemical cracking furnaces used for ethylene production and steam methane reformer (SMR) furnaces used for syngas production.

Nomenclature

API	American Petroleum Institute
DCS	Distributed Control System
ESD	Emergency Shutdown
HAZOP	Hazard and Operability
LEL	Lower Explosive Limit
LOPA	Layer of Protection Analysis
SIL	Safety Integrity Level
SIS	Safety Instrumented Systems
SCR	Selective Catalytic Reduction
SMR	Steam Methane Reformer