Safety and Reliability Assessment of a Miniature Steam Generator

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1. Introduction

The safety and reliability of pressure vessels is of a major concern because human health and environment are exposed to high risk with such equipment. The risk of potential injuries due to explosion and the contamination by spill and fugitive emissions must be reduced to a minimum. Reliability, safety, ergonomics technical aesthetics and ecological aspects must be part of a reinforced pressure vessels sustainability program [1]. Pressure vessels must are designed and fabricated according to sophisticated codes and strict standards such as those of ASME (American Society of Mechanical Engineers) [2] in order to ensure very high levels of structural integrity. Failure to comply with standards can cause catastrophic structural failures resulting in injuries and fatalities to workers and the public. The present study is related to a study of a catastrophic failure of a jewellery steamer machine and the resulting actions taken by the Quebec health occupational safety.

The reliability assessment of this miniature steam generator is evaluated by conducting a series of tests and analysis on its different components. The study focused on the probabilities of its failure and quantified the consequences. The root cause of its failure were then determined. It was demonstrated that the pressure vessel equipment does not comply with the safety and regulations that are applicable in Canada and in particular in the province of Quebec. Some recommendations were given to improve and maintain the reliability of this pressurized equipment.

2. Context: Miniature boilers and regulation requirements

A steamer machine designed in the 30's and shown in Fig. 1 exploded at few occasions in jewellery and textile industries. The Quebec occupational health and safety agency known as CSST has launched an investigation. The first step was to demonstrate that such a machine is under the Quebec regulation respecting pressure vessels [3] which refers to the Canadian boiler, pressure vessel, and pressure piping code CSA-B51-F03 and the code for construction and test of industrial heating equipment, C22.2 NO. 88-1958 (R2013) [4]. The latter gives only the general requirements for the design and construction of such a vessel. Nonetheless, it refers to the ASME Boiller and Pressure Vessel Code Section I part PMB Miniature Boillers [2] which actually details the design calculation procedure that design engineers must follow. Although at first it was not obvious that this kind of machine was a pressure vessel a demonstration shown in Fig. 2 was required to lift any ambiguity.

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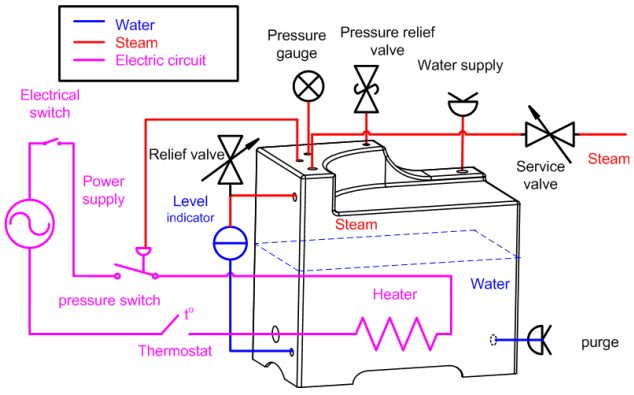


Figure 1. Steamer Machine (Minuature Boiler)

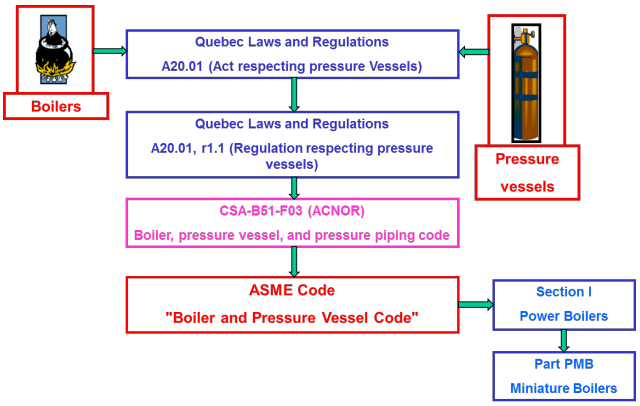
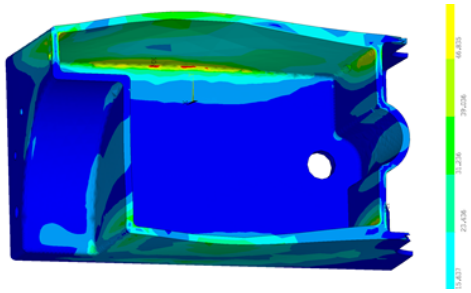


Figure 2. Applicable standards of minuature boilers



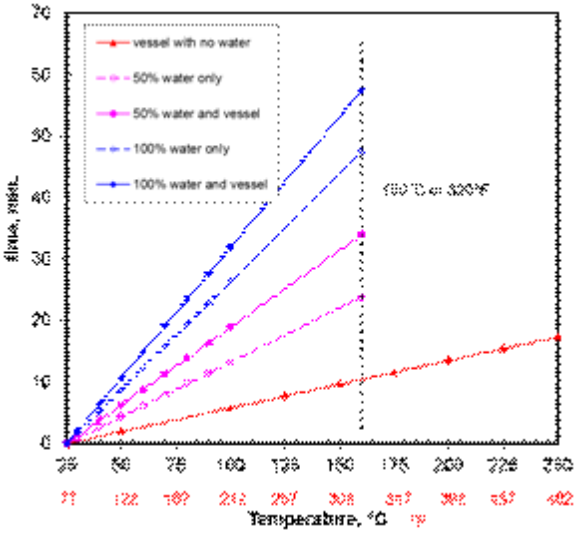


Figure 4. Time required to produce a temperature increase

3. Results of the investigation

The investigation involved technical aspects including analytical numerical simulations and experimental testing. The structural integrity was verified using Finite Element method and validated analytically using the code calculation procedure. The thermal analysis was conducted to evaluate the time required to reach a critical temperature based on different water level conditions in order to validate the time specified by the witness in the inspector investigation report. The experimental tests showed that the vessel was overheated after most of it water content disappeared because it was not perfectly closed (leak or one of the valve was open). The low grade aluminium used to construct the vessel with is not covered by the code material allowed list. In addition its strength is drastically reduced with temperature. The presence of a low liquid level sensor would have detected the lack of water and avoid the explosion.

The regulations that govern the operation of commercial miniature boilers require conservative margins of structural integrity during the normal operation and upset conditions. In the latter, they must have sufficient structural integrity such that failure is implausible under any postulated condition, including pressurized thermal upsets. In the extreme thermal transients, the structural integrity of miniature boilers may be severely degraded, with the degree of strength loss dependent on temperature resistance of the materials. After full investigation, the final report included nine recommendations some of which are clearly specified by the code requirements. A notice of danger was issued by the Quebec health and occupational safety to alert users of this particular steamer machine against the risk of explosion [5].

Acknowledgements

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