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Improved research-scale foam generator design and performance characterization

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A B S T R A C T

The release of a cryogenic, flammable liquid, such as LNG, poses a threat to individuals in the area of the release as well as responders who attempt to limit the damage of the release. The most common mitigation technique is high-expansion foam which can be used to blanket the liquid, reducing the accumulation of flammable vapor above the pool through a number of different mechanisms. Despite the effectiveness of high-expansion foam blanketing, there are many aspects of the interaction between foam and LNG that are unknown. A lab-scale high-expansion foam generator has been developed to allow the study of those interactions. Additionally, the novel foam generator design addresses many of the drawbacks of industrial-scale foam generators and allows researchers better control of the foam, while producing foam at rates that are conducive to lab applications. Foam was produced using the generator and expansion ratio and foam stability were measured to determine the quality. The generator was able to produce foam with expansion ratio between 298 and 892 that collapsed at an average rate of 0.4 cm per minute. This quality of the foam is comparable to industrial-scale foam generators and the foam production rate is between 1.2 and 2.2 m^3/min, which fits lab-scale needs. The foam generator can also be used with other types of non-firefighting foam, such as decontamination foam for chemical, biological, or nuclear decontamination.

1. Introduction

1.1. Foam techniques and applications in the process industry

One of the original uses for foam in the process industry is in fire suppression. Depending on the fuel, the type of foam used can differ significantly (Martin, 2012; Sthamer, 2012), however the basics of the foam are the same, with the main components being a surfactant, water, and air. Foams can be used to fight class A and B fires (Martin, 2012), however the type of foam depends on the fuel source, and foams effective against one fire class may not be effective against the other (Martin, 2012).

A more recent application of foams is for decontamination. In this application, the foam has additional chemicals such as peroxides and chloride salts (Cronce, 2002), which can decontaminate dangerous substances, for example chemical and biological warfare agents (Cronce, 2002) and industrial contaminants.

Another application of expansion foam in the process industry is the hazards mitigation of LNG spills. Foam application for LNG spills can be used as either a preventative or protective measure. As a preventative measure, on one hand, the recent work reveals that the foam works by reducing the heat convection and radiation through the blanketing effect, thereby reducing the vaporization rate of the LNG pool(Zhang et al., 2015, 2014). On the other hand, as LNG vapors pass through the foam zone, they are heated by contact with the much warmer foam, reducing the density of LNG vapor and thus minimizing the size of the ignitable LNG vapor cloud (Hiltz, 1993).

When the LNG pool has already been ignited, the foam can be used as a protectant as well, which works to suppress a fire by four major mechanisms. The foam smothers the fire, physically separates the flames from the fuel source, cools the applied objects, and reduces the ability for flammable vapors to come in contact with oxygen from the air (Chemguard, 2014a). In high expansion foam applications on cryogenic liquid fuels, the foam performs three of these tasks, but does not work to cool the fuel surface, as the

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temperature of the foam is much higher than that of the fuel; however, it does work to reduce the heat input through convection and back radiation of the flames (Zhang et al., 2014). Although high expansion foam generally cannot extinguish an LNG fire on its own, it suppresses the fire, and allows the fire fighter to approach the fire and apply other firefighting methods, e.g., dry chemical. When the fire is ultimately extinguished by other means, any foam that is still present can take on a preventative role, serving to prevent reignition (Martin, 2012).

1.2. Gaps of industrial generators

As mentioned previously, foams have been used for many years, however there are still gaps in foam research in both the LNG field and decontamination field. One of the major gaps in LNG research is the understanding of the physical interaction between the foam and the LNG system in lab scale tests. In decontamination research, experimentation has been fairly minimal both due to the recency of the technology (Cronce, 2002; Tucker, 2008; Tucker et al., 2004) and the highly hazardous chemicals used as the contaminant in decontamination experiments (Love et al., 2011). In order to conduct these experiments, an improved foam generator, which will be explained in detail in this paper, was developed to meet the research demand.

In a fire scenario, the application rate of the firefighting agent (i.e., water, dry chemical, or foam) is a crucial factor in extinguishing an existing fire or preventing a fire from spreading. For this reason, industrial foam generators are constructed to apply foam at a very high rate. Industrial foam generators, such as Chemguard 1500 WP foam generator, often are able to create foam at flow rates above 38 m^3/min (Chemguard, 2014b), which is relatively low for an industrial foam generator (Angus Fire, 2014a, 2014b). Additionally, in order to increase the applicability of the foam generator, hydraulic power is typically used. Because fire codes require fire water to be pumped throughout the facility and accessible from fire hydrants at regular distance intervals (National Fire Protection Association [NFPA], 2012), the pressurized water is widely accessible in an industrial facility, which makes using hydraulic power an excellent approach.

Although commercially available foam generators are suitable for foam application in industry, there are drawbacks of using them in a research setting. The most obvious problem is the foam application rate. During foam application on an industrial spill, high foam application rate is beneficial to cover the spill quickly; however, the same application rate is far too high for lab scale research. In an LNG spill scenario, characteristic foam depth for an LNG spill is anywhere from 0.45 m to 0.91 m (NFPA, 2013). Assuming a floor area of 55 m^2, which is typical for a research lab, even at the minimum setting the foam from these commercially available foam generators would fill the lab to a depth of 0.5 m in 43 s. Additionally, industrial scale foam generators are powered by pressurized water, which causes two operational problems, the requirement for a large volume of pressurized water, and excessive water discharge that accompanies the introduction of water during startup. The dependence on pressurized water also poses the safety issue created by having a pressurized system. The pressurized water requirement limits the availability of such equipment only to areas where pressurized water is accessible. In certain applications water discharge during startup is tolerable; however, when applying the foam to cryogenic liquids, the excessive water discharge causes rapid vaporization of the liquid, which compromises the objective of foam application. Moreover, commercial foam generators provide little working flexibility aside from changing hydraulic pressure (Angus Fire, 2014a, 2014b, 2014c; Chemguard, 2014b). Some dependent variables such as foam application rate, foam expansion ratio, and foam bubble size are important in research on foam functionality. The fact that these variables are inextricably related with others requires independent control of each parameter to study the effect of individual variable on foam functionality. Therefore, it is desired to manipulate those variables in an organized manner from the standpoint of experimental design. The ultimate purpose of this work is to provide a feasible design for a research scale foam generator and discuss several key parameters of foam functionality such as foam expansion ratio, time to half-height, and foam application rate associated with such design. Utilizing the design proposed in this work will help disclose the effect of individual variables on foam performance for different applications in the future including LNG spill control, decontamination, and fire suppression.

2. Foam generator design and construction

2.1. Foam generator design

The research scale foam generator was designed according to "NFPA 11 Standard for Low-, Medium-, and High-Expansion Foam" (NFPA, 2012). A picture of the conceptual device in NFPA 11 is shown in Fig. 1. The design also shares some similarities with aspects of previous foam generator patents, such as the position of the nozzle and screen and the use of a fan to generate airflow (Jamison and Barnes, 1965; Jamison, 1966; O'Regan et al., 1970; Williams, 1953). As mentioned previously, the main downsides of the industrial scale foam generator are: high foam application rate, dependence on hydraulic power, and lack of customizability.

In order to address high foam application rate, the device was built on a much smaller scale with the goal of foam application rate being less than 2.8 m^3/min (compared to the 38 m^3/min minimum of industrial scale generators). Additionally, the device was constructed with an effort to minimize dependence on utilities, such as pressurized air and water. In the current setup, the only required

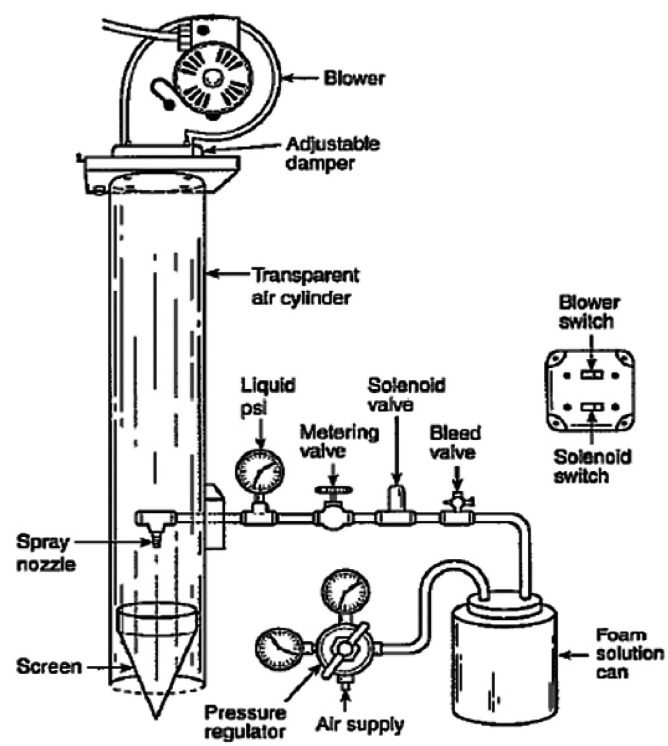

Fig. 1. High expansion foam quality test generator (NFPA, 2012).