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MITIGATION OF UNCONFINED RELEASES OF HAZARDOUS GASES VIA LIQUID SPRAYING

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SUMMARY

This paper focuses on the selection and evaluation of different types of liquid-spraying systems (i.e., water curtains and monitors). Case studies are presented as examples of how mathematical modeling can aid the design of water spray systems for mitigation of toxic gases and dilution/dispersion of flammable vapours.

I. INTRODUCTION

The capability of water sprays in mitigating clouds of hydrofluoric acid (HF) has been demonstrated in the large-scale field experiments of Goldfish and Hawk, which took place at the DOE Nevada Test Site.[1,2] The effectiveness of water sprays and fire water monitors to remove HF from a vapor plume, has also been studied theoretically using the model HGSPRAY5 with the near-field and far-field dispersion described by the HGSYSTEM models. This paper presents options to select and evaluate liquid spraying systems, based on the industry experience and mathematical modeling.

II. WATER CURTAINS VS WATER MONITORS

A spray curtain typically is designed as a sectional, peripheral curtain around the high-acid concentration part of the alkylation unit. Spray curtains are used when there is space for the curtain at the perimeter of the unit to be protected, and operator's interaction with an accidental HF release is to be kept to a minimum. The simplest way to deal with a gaseous leak is to turn on the entire peripheral water spray curtain surrounding the alkylation unit.

Thereafter it can be decided which sections of the spray can be turned off because they are upwind from the release. This approach, however, requires large amounts of water. Another way is to evaluate the wind direction first, and then turn on a U-shaped section downwind from the leak.

The Hawk tests indicated that water monitors, when properly located and operated, can achieve HF mitigation efficiencies almost as high as those obtained by water spray curtains at the same water rate. Monitors for HF mitigation have the advantage that they can alternatively be used as fire monitors. The reverse is true if the monitors are elevated to at least the level of an HF leak. Monitors are more flexible as to the size and location of an HF leak. In most cases an HF mitigation system using monitors is cheaper than a dedicated water spray curtain of the same capacity. A major drawback in the operation of monitor system is the complexity required for the manipulation of multiple, remotely controlled monitors. While curtains can be operated with a single on-off control, monitors must be individually controlled to achieve optimal mitigation efficiency. Changes in wind speed and direction, as well as increases or decreases in HF release rate, require readjustment of the system. Operation of a system of six to eight monitors can be a challenge, especially since little opportunity exists to gain experience with the system, unless a comprehensive training program with simulated releases is implemented.[3]

III. MODELING AS A PERFORMANCE EVALUATION TOOL

A complete computer simulation of a heavy gas (HG) release mitigation system entails the use of three models, each describing the plume behavior in a different region:[4]

A. The model HGPLUME for the initial release and near-field dispersion of the released jet.

B. HGSPRAY5, for liquid spray HG interactions.

C. HEGADAS5 for the subsequent dispersion of the remaining HG downwind of the sprays/monitors.

HGSPRAY5 is a two-dimensional spray model that describes absorption of gases by water sprays, air entrainment and heat transfer. It is a complete model of mass, momentum, and heat transfer between air/HF and drops injected by water sprays or monitors. It has been verified in the Hawk field tests performed at the DOE Nevada Test Site (as part of the ICHMAP) that the HFSPRAY model predictions are within ±6 percent of the experimental results obtained in the Hawk field tests.[5,6] In addition, the model replicated the dispersion patterns observed from boundary layer wind tunnel modeling of water spray mitigation systems from actual industrial installations.[4]

HGSPRAY can be linked with the HGSYSTEM models,[7] which describe the physical transformations and the dispersion of a jet or plume upstream and downstream of the water-spraying region. The HGSYSTEM models describe all the phases of an accidental gaseous release, including depressurization, phase-change, and atmospheric dispersion of buoyant or denser-than-air gases. The HGSPRAY5 model has been independently verified with experimental data involving releases of HF. The HGSYSTEM models have also been independently verified by comparisons with a wide range of experimental databases.

It is emphasized that the assessment of the performance of a mitigation system requires modeling of the strongly-coupled mass transfer and momentum effects; calculations based only on mass transfer may result in erroneous results.

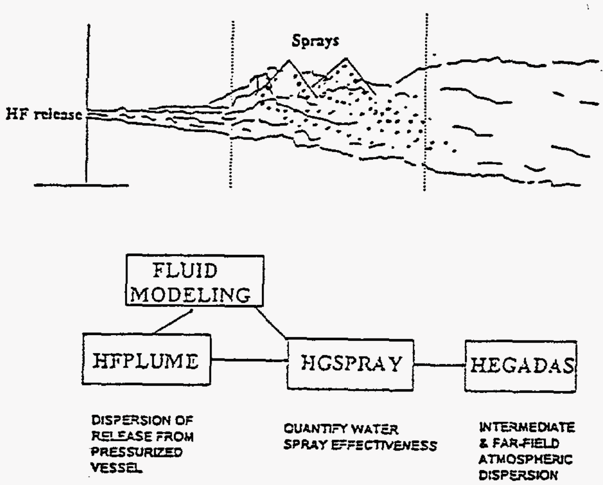

Figure 1. Mitigation Modeling Regimes

IV. CASE STUDIES

Two cases are considered, one involving sprays in a "curtain" setting and the other involving water monitors.

A. Case A -Water Curtain

This case involves modeling of an actual HF mitigation system based on sprays encircling an alkylation unit.[4] In the following we highlight elements of this study which illustrate the link between fluid and mathematical modeling.

1. Eight scenarios of release were identified after reviewing system, site and meteorological characteristics.

2. Fluid modeling experiments were conducted to generate concentration, velocity and turbulence data.[8]

3. The air entrainment relationships of HGSPRAY were compared with the data obtained from the fluid modeling tests.

4. Simulations using HGSPRAY, produced estimates of the mitigation effectiveness of the system.

The spray configurations considered are: a) two headers at about 30 ft off the ground, one equipped with spray nozzles pointing upwards and the other with the same nozzles pointing downwards, and b) two headers at different elevations (e.g., 30 ft and 60 ft) with nozzles pointing horizontally toward the release. Two different types of spray nozzles producing drops of different size were tested. HF releases at two elevations and flow rates were considered to bracket the range of potential releases. At grade (i.e., 1 m above the ground) the release rate was 43 kg/s and at a 15-m elevation the release flow rate was 37 kg/s. The water flow rate in the entire water curtain system was 33,000 gpm. The lateral spread and the concentration of the plume as it intersects the spray were determined from fluid modeling tests. According to the HGSPRAY simulations, the two-tier horizontal configuration removed HF somewhat more effectively than the up-and-down configuration for the specific release heights. Effectiveness of HF removal ranged from 70 percent for high wind speeds (e.g., 17 m/s) to 96 percent for light wind speeds (e.g., 5 m/s). The corresponding effectiveness of the up-and-down system ranged from 53 percent to 97 percent. The main reason for the advantage of the horizontal sprays, is that these sprays reached higher and covered elevated releases, whereas in the up-and-down configuration, a part of the plume escaped at the top.

B. Case B- Fire water-monitors

HGSPRAY5 is capable of modeling a release of HF anywhere between fire water monitors. A release can be introduced within the computational space either as a point release of a specified flow rate, or as a line release of a specified concentration profile. However, two-dimensional approximations of the monitor configuration need be developed. Therefore, the application of this model to describing the flow fields induced by fire water monitors spraying from various positions, requires considerable simplification of complex three-dimensional fields, and poses significant constraints in its application. In this section, we describe the model application to aid the design of mitigation systems comprising monitors placed around a potential release point for two sample simulations: i) a release of 3.4 kg/s of HF, with a 3-m/s wind, sprayed by two monitors in wide setting; and ii) a 14-kg/s HF release with 10-m/s winds, sprayed by three monitors in narrow setting.

In the first example, the removal effectiveness is a relatively low 60 percent due to the low initial concentration of the HF plume, but the dilution effectiveness is predicted to be about 92 percent. In the second example, both removal and dilution effectiveness are high, 81 percent and 93 percent, correspondingly. It is noted that the high water momentum produced by the monitors, makes spraying highly effective even at relatively strong wind conditions. Subsequent dilution is described by introducing the characteristics of the HF cloud downwind of the spray region, into the HEGADAS model. Thus, the downwind concentration reduction benefits of mitigation compared to an unmitigated release are estimated. Figure 2 shows an example of such modeling; the maximum predicted concentration (60-minute average) is a function of downwind distance for three cases: 1) unmitigated release; 2) mitigated continuous release and 3) mitigated 10-minute release (assuming that the release was shut off after 10 minutes).

Without mitigation, the hazard zone to the ERPG-3[1] level (50 ppm) extended to 2000 m downwind,

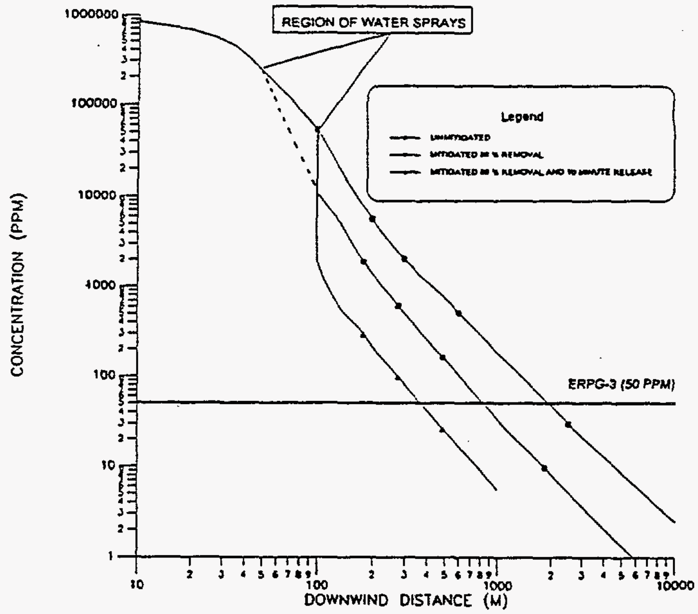

Figure 2. Predicted Downwind Concentration Reductions Caused by Water Spray Mitigation of a Hypothetical 14-kg/s HF Release.

whereas mitigation by water monitors reduced it to 800 m in the continuous release case and to 400 m in the 10-minute release case. In these simulations we assumed instantaneous detection and spray activation. The response time was not taken into account because the ERPG-3 level corresponds to 60-minute average concentration, a time interval significantly longer than anticipated detection and response times.

V. CONCLUSIONS

The capability of water sprays in mitigating clouds of hydrofluoric acid has been demonstrated in large-scale field experiments. The performance of these systems in the field can be evaluated using the model HGSPRAY5. The model is capable of predicting the performance of water-spray systems (both water curtain or monitor configurations), in mitigating water-soluble gases via absorption and dilution, and in reducing the concentration of flammable vapors via dilution.

[1] ERPG-3 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life threatening health effects.

ACKNOWLEDGMENTS

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