Development of Computer Models
for the Discharge of Halon Alternatives

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Introduction

Halon alternatives are being considered for use as replacements to Halon 1301 in fire extinguishing systems designed to protect high risk and high value facilities where cleanup of other media following a fire presents a problem. To design effective systems, fire protection engineers carefully select bottle size, piping, and nozzles to adequately distribute the alternative agent within required concentration and discharge time limits. The designer must balance competing factors such as quantity of agent, pipe size, nozzle size, bottle fill density and storage pressure to obtain desired results.

MPR Associates has developed two computer programs designed to simplify the flow and pressure drop calculations needed to evaluate system design options. The first of these programs is called TFA (Transient Flow Analysis) and utilizes a rigorous transient flow solution approach which requires detailed information on piping geometry and initial bottle conditions. This program is suited for special detailed modeling of discharge systems which have non-standard initial conditions or piping geometry, and provides explicit results of pressures, temperatures, and flows throughout the discharge piping as a function of time for the discharge event. The second program is called FLONET and uses a simpler calcu-lational technique to allow discharge system models to be generated and modified more quickly but provides less detailed results. Use of the FLONET program therefore simplifies the design problem when a large number of calculations are required for a system with standard piping components as compared to the detailed analysis using TFA.

This paper describes both the TFA and FLONET programs, including the analytical method used by each. It also describes the approach used to validate the analytic models used and the status of the validation effort. Finally, the results of a typical design problem are presented to illustrate the potential applications of these programs as design tools for alternative agent firefighting systems.

TFA (Transient Flow Analysis)

As described above, TFA provides for the detailed analysis of the discharge of firefighting systems which utilize halon alternatives. TFA calculates fluid parameters throughout the system by solving the conservation of mass, momentum, and energy equations.

TFA permits a designer to enter detailed piping system geometry and initial conditions. Output options include plots of system geometry, calculated parameters versus time, in addition to a listing of calculated fluid parameters for each time step.

Analytical Method

The program uses a control volume and flow connector approach to solve the transient conservation equations. The conservation equations are integrated over each appro-

priate volume or connector. The resulting system of equations is solved to obtain the transient solution. The solution technique is summarized in the following five steps:

1. Division of the piping system into control volumes and flow connectors;

2. Integration of the mass and energy conservation equations over each control volume;

3. Integration of the momentum conservation equation over each flow connector to determine mass flow between control volumes;

4. Use of equations of state for agent and nitrogen to obtain pressure. temperature, and other thermodynamic properties in each control volume; and

5. Solution of the resulting transient equations using a partially implicit backward difference numerical technique.

The partially implicit backward difference technique utilized to integrate the conservation equations in time solves for the mass and energy of each constituent in each control volume and the total mass flow rate in each fluid connector. Thermodynamic properties such as pressures, temperatures, densities, and enthalpies are obtained from the masses and energies in each control volume and the volume of the control volume. These properties are used to define the conservation equations for the next time step.

The thermodynamic properties necessary for the solution include pressure as a function of the masses and energies of the components of the mixture in a control volume. In addition, choked flow correlations must be provided for the complex mixture of agent and nitrogen. To accomplish this, a separate set of computer programs were developed to generate the appropriate thermodynamic properties and critical flow rates from standard thermodynamic tables for use by the transient analysis package. This modular software format has simplified the process of incorporating new alternative agents into the transient analysis program. Incorporating a new agent into the program requires that a thermodynamic property module which provides the appropriate thermodynamic properties and critical flow rates for that alternative agent be incorporated.

Development of a Thermodynamic Property Module

The TFA thermodynamic property module includes equations of state which relate pressure, temperature, specific volume, enthalpy, and entropy for both liquid and vapor phases. Previous work to model Halon 1301 has demonstrated that the effects of dissolved nitrogen can have a significant impact on pressures and flow rates throughout the piping during a transient as nitrogen comes out of solution. Therefore, the parameters necessary to describe the effect of dissolved nitrogen, such as Henry's Constant in Henry's Law, must be included in the model.

In addition to the thermodynamic properties themselves, the development of the thermodynamic property module involves developing the appropriate correlation for critical flow of the alternative agent. The critical flow correlation sets an upper limit on the calculated flow rates determined by numerically solving the mass, momentum, and energy conservation equations. In cases where the calculated flow rate exceeds the critical flow correlation, the critical flow correlation is imposed on the fluid solution. The critical flow correlation for the HFC-227ea model uses a modified homogeneous equilibrium model and is based on thermodynamic properties obtained from the Carnahan-Starling-DeSantis equation of state. For large flow rates, as expected in fire-fighting discharge systems, the homogeneous equilibrium model is considered to provide acceptable results.

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Validation of Model

TFA analytical models are being validated by comparing model predictions with discharge test measurements. Two full-scale piping arrangements were designed to measure agent discharge characteristics. These systems were fabricated at the Naval Research Laboratory Chesapeake Bay Detachment and instrumented to measure pressures and temperatures throughout the piping system during agent discharge. A series of discharge tesrs without fires were performed using the following agents:

- HFC-227ea
- HFC-23
- FC-3-1-10

Current Status

A version of TFA for Halon 1301 systems (called TFHAL) has been validated and is currently in use. A preliminary version of TFA has been used to design a large-scale HFC-227ea distribution system for a test in a simulated shipboard machinery space. A comparison of the preliminary analysis results to test data indicates that TFA provides reasonably good predictions of discharge time and nozzle pressure for those tests which have cylinder storage pressures, fill densities, and discharge times that have traditionally been used for Halon 1301 in the Navy. The current model may not adequately model the rates at which nitrogen moves in and out of solution in HFC-227ea, and the choked flow correlation used in the program may require some adjustment as more test data is obtained and further comparisons are evaluated.

FLONET

FLONET is a simplified fluid flow and pressure drop analysis program which is currently used to analyze Halon 1301 fiied flooding systems. The development of FLONET for use with alternative agents is proceeding. This program calculates discharge time and the average pressure and mass flow rate at various locations in the system. including immediately upstream of each nozzle.

FLONET is designed to evaluate system designs or the effects of proposed system modifications with a minimal amount of input data to describe the discharge system. Discharge system models can be quickly generated using pull-down menus and libraries of typical piping components.

Analytical Method

The simplifying calculational technique used by FLONET makes use of the fact that during a typical transient discharge of agent, there exists a significant portion of the discharge time where a quasi-steady state condition exists. During this period, the rate at which the bottle pressure decreases while the agent is being discharged from the nozzles is relatively constant. FLONET estimates the averaged bottle conditions which would be present for a discharge transient based on geometry and initial conditions.

FLONET calculates the discharge conditions in the distribution system (average pressures and mass flow rates) by dividing the distribution piping into control volumes which are linked together with flow connectors. The mass flow rates in each connector and the pressure in each control volume are calculated by iteratively solving the steady state mass, momentum, and energy conservation equations using the averaged bottle conditions.

FLONET also includes correlations for choked flow of the agent, and the solution for the average conditions in the discharge piping considers the effect of choked flow as the solution is determined.

Validation of Model

The solution method used in FLONET was validated for Halon 1301 systems by comparing calculated results to results obtained from full scale discharge tests conducted by the U.S. Navy and NFPA criteria. During this process. calculations using the TFHAL program were instrumental in achieving a good understanding of the phenomena involved during a discharge. It is planned that a similar approach will be used to validate FLONET for halon alternative agents.

Current Status

FLONET has been in use for several years by the U.S. Navy to analyze shipboard Halon 1301 fixed flooding system designs. An effort is currently underway to develop FLONET for use with HFC-227ea. A preliminary version of this program is currently being tested.

Typical Design Problem

The halon alternative computer modeling programs developed by MPR can be used to investigate the feasibility of adapting current Halon 1301 systems for use with alternative firefighting agents. The computer programs can be used to perform comparative analyses of various design options in order to find a

design option which would minimize backfit costs while maintaining the same firefighting capability of the original system design.

Figure 1 shows an example of a comparative analyses performed to investigate the effect of varying two system design parameters (bottle fill density and nitrogen superpressure) in order to achieve faster discharge times in a two-nozzle discharge system using HFC-227ea. The discharge system (shown in Figure 2) includes a single 60-pound cylinder, a cylinder discharge valve, a flexible hose, socket welded schedule EO steel piping, and two 3/16 inch nozzles.
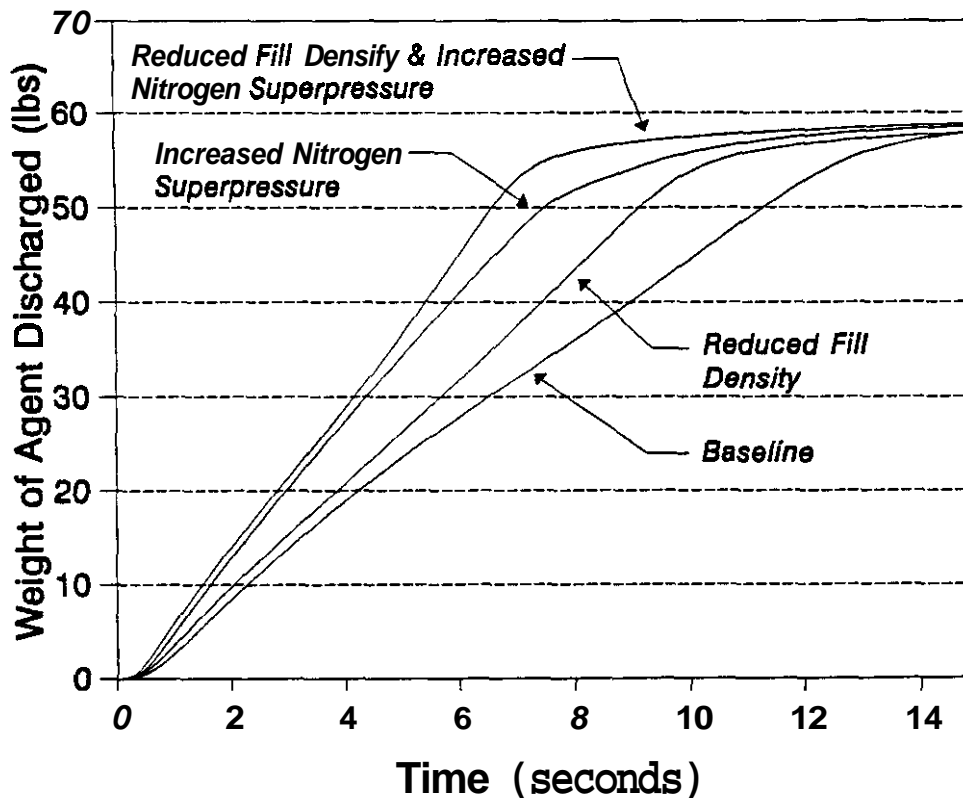
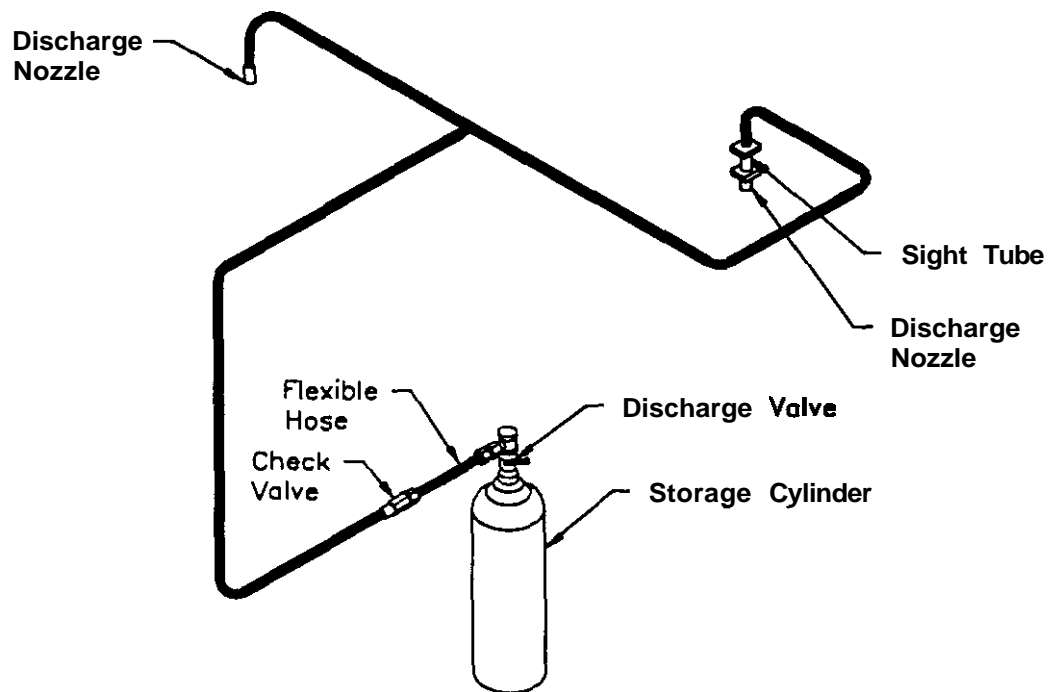Figure 1: Comparative Analyses of a HFC-227ea Fire Extinguishing System

Figure 2: Double **Nozzle Discharge System**