The Split of Two-Phase-Flow at Horizontal Side-T-junctions in Unbalanced Pipe Systems for Clean Extinguishing Agents

by
Gudrun Fay
Minimax GmbH & CO. KG
Industriestraße 10-12, 23840 Bad Oldesloe, Germany
Tel.: +49-4531-803-597, Fax: +49-4531-803-500

Abstract

Phase separation tests for two-phase flow have been performed for a 90° Side-T with ½" diameter for the side branch and 1" diameter for the run and the feed pipe. The tests where conducted with the chemical extinguishing agent FK-5-1-12 superpressurized with Nitrogen (N_2) with constant filling pressure in the container. Measured parameters have been pressure at the nozzles and at some defined positions in the pipe as well as the amount of agent discharged by every nozzle.
By varying some parameters it could be proven that separation of the liquid and the vapor phase in the two branches of the T-junction depends nearly solely from the mass extraction rate to the side branch.

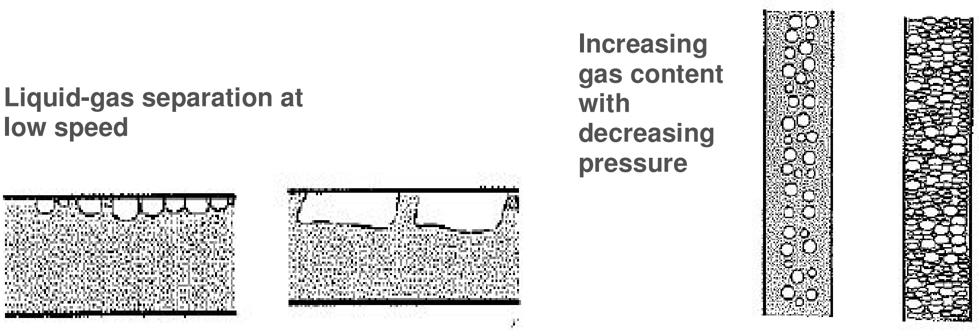
An empirical model has been developed to correct the mismatch between the calculated and the measured discharge of agent at nozzles which are connected to the pipes after a 90° T-junction. The model was validated with different pipe configurations between the limits of 10 % and 35 % mass extraction rate.
The data gained from calculation and experiment were satisfactory consistent. The deviance for pressure and discharge amount for each nozzle was less than 10 % for every investigated system.

The analytical model is now used in a design program to predict performance, nozzle pressures and amounts of nozzle discharge in unbalanced pipework for FK-5-1-12 fire extinguishing systems.

Introduction

Splitting two-phase mass flow is often necessary in pipework systems for industrial applications such as nuclear reactors, chemical process plants and clean agent fire extinguishing systems as well.
It is crucial for design calculations to predict the behaviour of the flow and the amounts of liquid and vapor after the split correctly. Especially for two-phase flow consisting of two different materials such as water/air or chemical liquid/nitrogen the prediction of their distribution after a T-junction is essential.
As this problem is evident for many years in the field of nuclear reactors and cooling in chemical processes most investigations have been done with water/air-flow.
Examples, investigations and some invented models can be found at the work of Hwang et. al.[1].

This physical process exists of course at each combination of liquid and gas. For the topic of fire protection every extinguishing system that consists of two-phase flow inside the pipe system is concerned.
These are extinguishing systems working with CO_2 (Carbondioxid) or clean agents as HFC227ea or FK-5-1-12 .
The chemical and physical characteristics of clean agents are similar to those of Halons. Their main advantage is that they have no ozone depleting potential and a much lower global heating potential [2].
Nonetheless there are some differences to Halons which affect the behaviour of the clean agents into a system. Clean agents have a higher boiling point at ambient pressure. FK-5-1-12 is even liquid at ambient values of 14.7 psi and 70°F.
To get the extinguishing agent into the hazard in a short time and to ensure spray at the nozzles, the storage is superpressurized with Nitrogen to a defined fill pressure. Usually this fill pressure is 25 bar (360 psi), 42 bar (610 psi) or, for large systems, 50 bar (725 psi).
Guidelines say that 95 % of the design concentration must be reached after 10 seconds [3], [4].
The superpressurization with nitrogen leads to two-phase flow into the pipe system: There is a liquid phase consisting of agent and diluted nitrogen and a vapor phase consisting mainly of nitrogen and a small amount of vaporized agent. Additionally the gas content varies along the pipes because nitrogen leaves the liquid while pressure is decreasing.
Typical effects of two-phase flow are phase separation due to low velocity as well as different flow pattern in horizontal and vertical flow. The gas content can change due to phase change of a component (see Picture 1).



Picture 1: Typical flow pattern of Two-phase flow

Another serious problem is unequal split of liquid and gas at flow splits with a straight and a side run (Picture 2).
This unequal split of liquid and gas will be considered in the investigations presented in this article.
When a mixture of heavier liquid and lighter gas moves into a flow split with a run and a 90° side branch a significant phase separation occurs. This seems reasonable since the vapor phase normally has far less inertia than the liquid phase. Thus the heavier particles can be expected because of their greater inertia to move sluggishly into the run. The vapor phase is more agile and turns easily the corner into the side branch.
So the result is a shift in the ratio of liquid and gas in the two outgoing branches of the flow split in respect to the ratio of liquid and gas in the feeding branch.

Phase separation in branches can have a profound effect on system performance.
Relating to fire extinguishing systems that work with two-phase flow in their piping system like CO_2-, Halon-, HFC227ea- and FK-5-1-12 –systems, the unequal splitting of the phases can cause inadequate supplement of some nozzles with extinguishing agent.

A typical example is a room with a false floor: The pipe that supplies the false floor branches off from the main piping for the room with a 90° Side-T. At this branch phase separation occurs and less than the predicted liquid – extinguishing agent in this case – is transported to the nozzles in the false floor. The room gets more than the predicted amount of agent. When dynamics and mixture between room and false floor are low, the false floor will not be adequately supplied by agent. The necessary concentration of extinguishing agent will not be reached and the system can fail.

Williamson and Wysocki [5] documented this separation effect for Halon 1301 and developed empirical corrections to upgrade the quality of calculation results of Hesson's "two phase flow" equation for several agents: carbon dioxide, HFC227ea, and HFC23.
Enhancements for calculations based on the pressure drop model of Chisholm [6] for HFC227ea and FK-5-1-12 are investigated here.

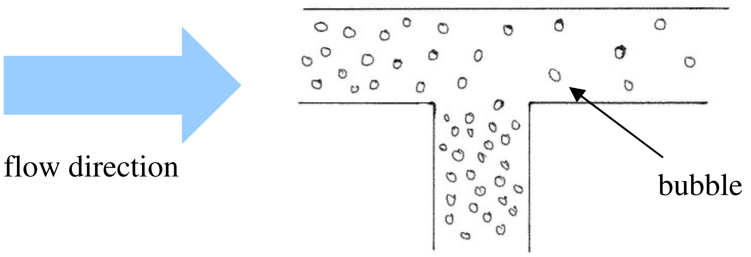
Modeling

In single phase flows classical conservation equations with empirical data for losses at the T-Branches can be used to carry out calculations and to design systems.
In the case of two-phase-flow however the number of influencing variables is much larger. The well known equations do not work. Separation and mixing of the phases complicate the process at flow splits. The unequal splitting of the phases at T-pieces can be observed to create problems in fire extinguishing systems which contain liquid agent and superpressurizing gas.
As the liquid phase of the flow consists of extinguishing agent (mostly) and the vapor phase of N_2, phase separation leads to a disproportionate shift of agent into the straight branch.
Neglecting this unequal split of mass flow causes inadequate supplement of some nozzles with extinguishing agent.
The physical reason is comprehensible: When a mixture of heavier liquid and lighter gas moves into a flow split, the heavier particles because of their greater inertia tend to move sluggishly. The

gaseous part is more agile. More heavy particles move straight through the flow split than into the 90°-branch. A significant part of the gas moves around the corner into the 90°-branch, (see Picture 2).
The result is the above described shift in the ratio x of liquid and gas in the two outgoing branches in respect to the ratio of liquid and gas in the feeding branch.

$$x = \frac{\dot{m}_{gas}}{\dot{m}_{gas} + \dot{m}_{liquid}}$$

Former investigations [7], [8], [9] show that this effect depends mainly on the portion of mass flow into the side branch.



Picture 2: Mechanical effect on two-phase-flow at a side-T-junction

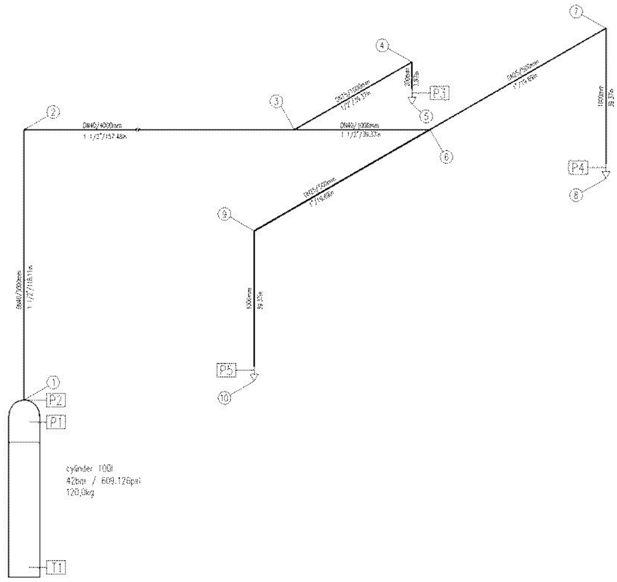
Experiments
A test range has been set up to investigate mass split from 10% to 35% side flow. The side branch has a 90°-angle to the straight pipe. This is usual for industrial applications.
A row of tests has been performed with the same system just changing the mass flow at the side-T. This was realised by varying nozzle orifices of the nozzles following the side branch and the straight branch.

Experimental Setup
The tests to develop the analytical model have been performed with a 40 l – container filled with 48 kg FK-5-1-12 and a pipe system of screwed pipes with a side-T and three nozzles. To have good performing mass flow, dimensions of pipes are 1” for straight branch and ½” for the side branch. A sketch of the test system is shown in Picture 3.
To regulate the mass flow, different nozzle orifices have been used. The nozzle orifices have been dimensioned with a classical flow model for two-phase flow using the conservation laws of mass and energy without any correction at the mass splits. The two nozzles at the arms of the bullhead-T are symmetric.

Mass split was adjusted with changing nozzle orifices:

10%: 4.1 mm	15%: 5.1 mm	20%: 6.1 mm	25%: 7.0 mm	30%: 7.8 mm	35%: 8.7 mm

Constant parameters were:
- Ambient temperature between 18°C and 24°C.
- Temperature of agent in the container 21°C
- Designed discharge time 10 s



Picture 3: Experimental Setting for side-T Tests

Results

The first step was to design the test system without mass flow correction with a model using conservation laws of mass and energy. Mass flow and mass split are given parameters for the design program.

The results of this designing process are defined nozzle orifices for each given mass split. These combinations of nozzles have been built into the test system.

The comparison between the results shows a significant difference between the given mass split and the measured values. Much less extinguishing agent is discharged at the nozzle following a side-T, see Chart 1. The deviation of the 10% mass split is -37.4% from the designed discharge value. Even the mass split of 35% mass flow to the side differs -23.7% from the designed value.

A model for the shift in the gas content *x* has been developed that depends only on the portion of mass split at the side-T.

The calculation for system design was then again performed with the new correction model.

Given parameters for the calculation are now the nozzle orifices from the previous tests and the overall mass flow. The results of the new calculation match excellent with the measured data. Although depending only on one parameter, the model is able to give sufficient result for the design of unbalanced systems.

The highest deviation between calculation and measurement at this test system is to be found at the mass split of 10%. The deviation is even below 5% from the measured value.

The comparison of the deviation values with and without correction model are shown in Chart 2.

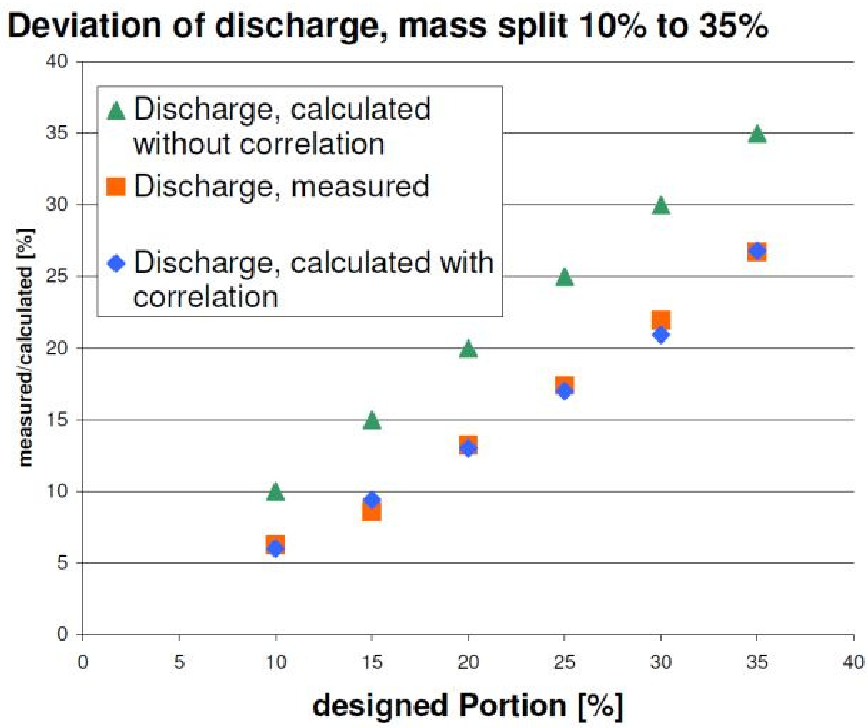


Chart 1: Deviation of nozzle discharge from the designed portion of measured mass split without and with correction model

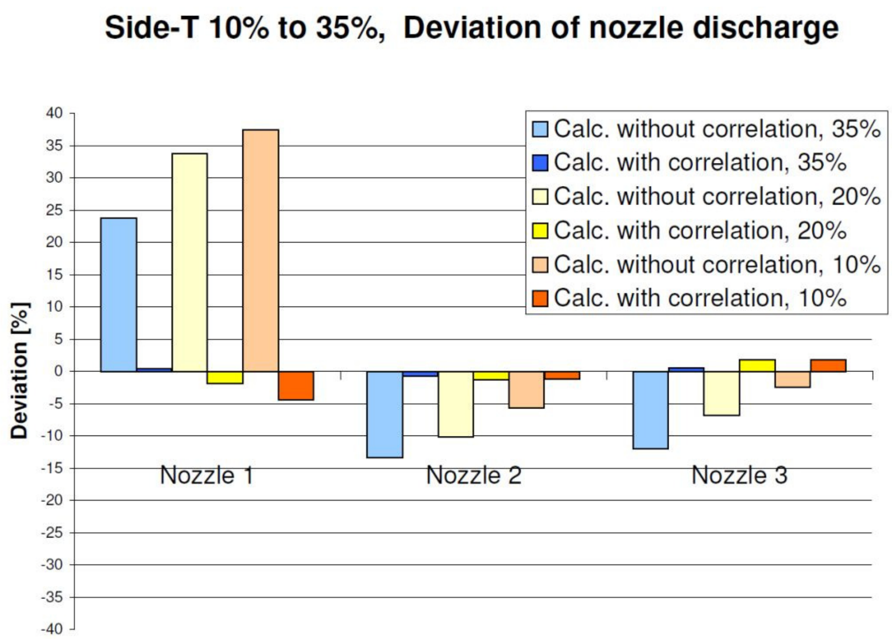


Chart 2: Deviation of nozzle discharge from experimental results for calculation with and without empirical correction

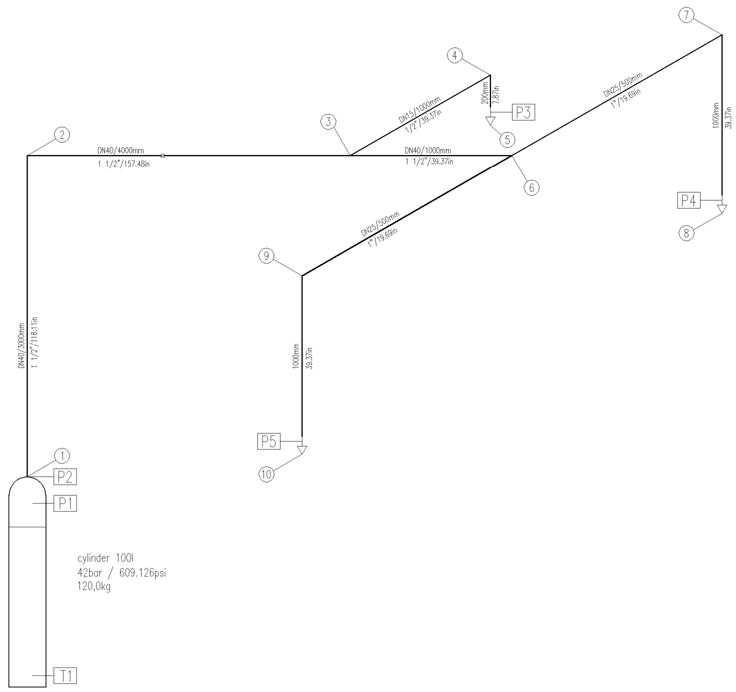
Validation of the correction model

To validate the model several other configurations have been examined. Parameters that have been changed were:

- Filling density of the container
- Container size
- Pipe lengths and diameters.

Inside the pipe systems, the physical values of the fluid at the entrance to the side-T differ regarding velocity, a different gas content and pressure.
Several test systems have been built and measured to validate the model for other situations. Three examples will be presented here.

Validation Test 1
Test 1 is a system with a large container (100 l) and the highest possible filling density (1.2 kg/l). This system has a quick drop of system pressure while discharging. The pressure of the fluid at the entrance of the side-T will change a lot during the discharge time.
The designed portion of extinguishing agent that should discharge at the nozzle behind the side-T was 10%. Using the model, the nozzle orifices have been set to 8.7 mm versus 15.4 mm for the two nozzles that should discharge the 90% amount of agent.
The collected agent from the nozzle behind the side-T was 16.0 kg. That is a deviation of 3.1% from the predicted amount.

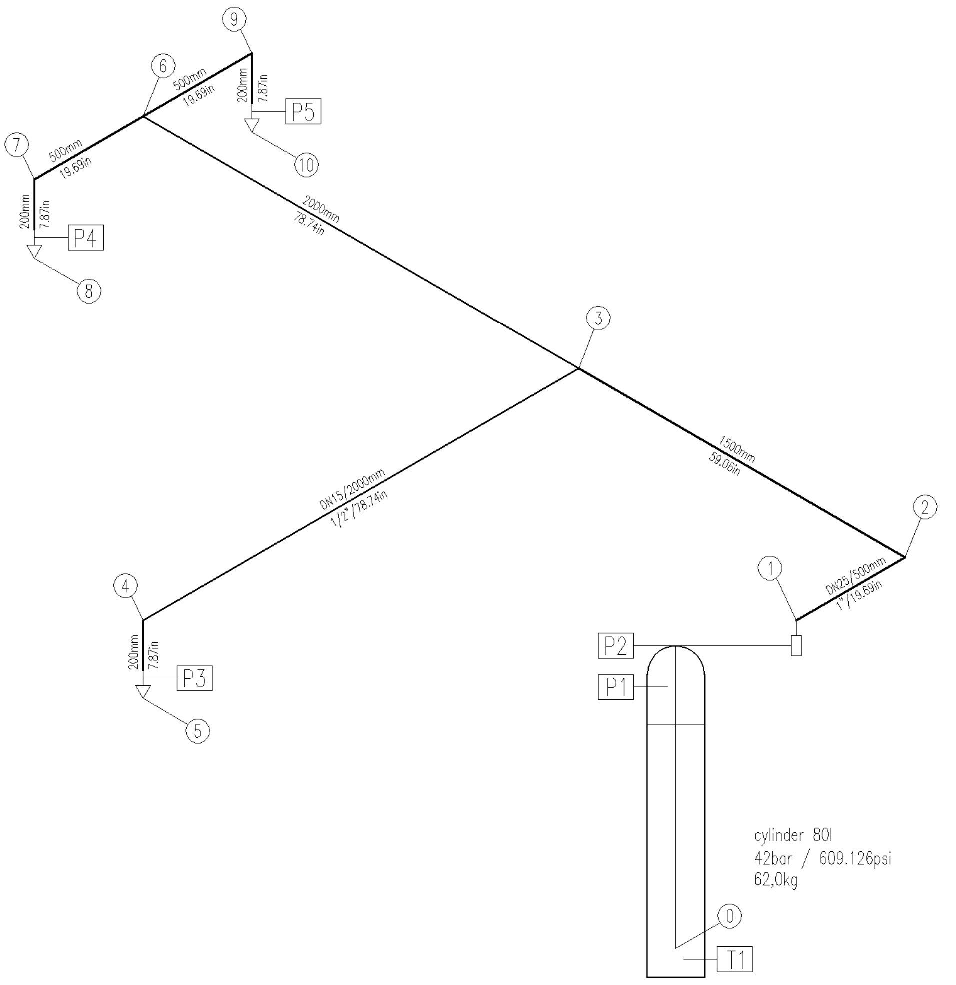


Picture 4: Validation Test 1

Discharge	Exp.	Calc.	Dev.
Nozzle 1	16.0 kg	16.5 kg	3.1 %
Nozzles 2 + 3	101.5 kg	101.3 kg	0.2 %

Validation Test 2
For Test 2 an 80 l-container has been filled with 62 kg extinguishing agent. The resulting fill density is 0.78 kg/l. The pipes have smaller dimensions compared to Validation Test 1. The pipe diameter is reduced by approx. 0.75, so its area is reduced by 0.75^2. The amount of agent is reduced less by approx. factor 0.5. The discharge time remains at 10 s. Therefore fluid velocity is increased and pressure loss in the pipe system increases too.

The minimal mass split to the side of 10% should be achieved. The comparison of predicted values with measured and corrected results show a deviation of 6.6% at the side-T nozzle.



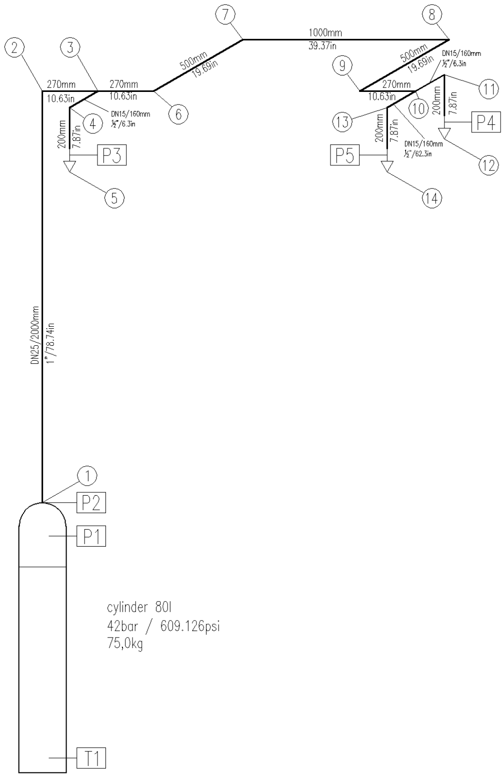
Picture 5: Validation Test 2

Discharge	Exp.	Calc.	Dev.
Nozzle 1	6.5 kg	6.1 kg	6.6 %
Nozzles 2 + 3	53.8 kg	54.5 kg	1.3 %

Validation Test 3

Test 3 was fed by an 80 l-container filled with 75 kg extinguishing agent. Fill density is 0.94 kg/l. The pipe dimensions are similar to dimensions of Validation Test 2. The test is designed to split the fluid into 35% to the side and 65% to the straight direction at the T. With its greater amount of agent Validation Test 3 has an even higher pipe velocity than Validation Test 2. An additional difficulty is the unequal length of the pipe run to the nozzles. The way for the fluid to nozzle at point 5, connected to the pipe at the side-T, is much shorter than the length to the nozzles at points 12 and 14 (see the sketch at Picture 6).

This system is extremely unbalanced. Despite of the imbalance the prediction of 25 kg that should be discharged by the side nozzle differs only by 8% from the measured value of 23 kg.



Picture 6: Validation Test 3

Discharge	Exp.	Calc.	Dev.
Nozzle 1	23.0 kg	25,0 kg	8.0 %
Nozzles 2 + 3	50.2 kg	48.5 kg	3.5 %

All three validation test show the ability of the new correction model to compensate the deviation of gas content from the “normal” conservation law at 90° side-T for two phase flow of a clean extinguishing agent and nitrogen.

At all investigated test cases with variations in mass split, pressure, velocity and pipe size the calculation for discharge reached more than 90% accuracy.

Conclusions

Results in all test showed low deviation < 10% in nozzle discharge. The model can be used within the tested limits from 10% to 35% mass split to the side in unbalanced clean agent systems with two phase flow.

The model does not depend on the parameters of the "feeding" container like size and fill density. It is suitable for typical pipe dimensions of clean agent systems and is generally usable for the design of unbalanced pipe systems.

References

[1] Hwang, S.T., Soliman, H.M., Lahey Jr., R.T., Phase Separation in Dividing Two-Phase Flows, Int. J. Multiphase Flow, Vol. 14, No. 4, pp. 439–458, 1988

[2] Stahl, Peter, Neue Entwicklungen auf dem Gebiet der chemisch wirkenden Loeschgase, Alarm Nr.17, 2005

[3] NFPA 2001, Standard on Clean Agent Fire Extinguishing Systems, 2008 Edition

[4] ISO 14520, Gaseous fire-extinguishing systems —Physical properties and system design, Sec. Edition, 2006

[5] Wysocki, Tom, Single Point Flow Calculations for Liquefied Compressed Gas Fire Extinguishing Agents, http://www.nist.gov/el/fire_research/upload/R0301086.pdf

[6] Chisholm, D., Int. J. Heat and Mass Transfer16, pp. 347 ff., 1973

[7] Zetzman, K., Phasenseparation und Druckabfall in zweiphasig durchstroemten vertikalen Rohrabzweigungen, PHD, University of Hanover (Germany), 1982

[8] Honan, T.J. et. al., The measurement of phase separation in wyes and tees, Nucl. Eng. Design Bd. 64, S. 93/102, 1981

[9] Whalley, P.B. et. al., Two-phase flow in a T-junction, AERE-Report R 9699, 1980